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The AI Techno-Economic Segment Analysis

Selected Indicators

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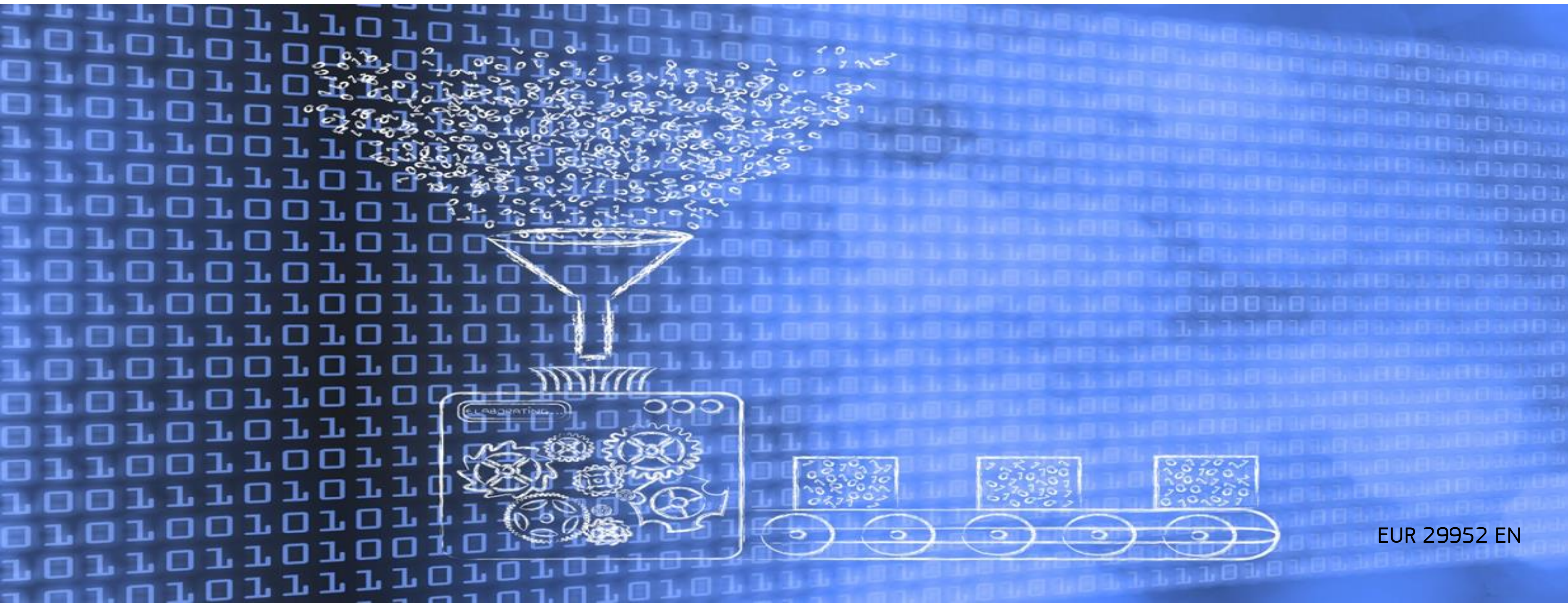

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Foreword

The PREDICT project analyses the supply of Information and Communications Technologies (ICT) and Research and Development (R&D) in ICT in Europe, compared with major competitors worldwide. ICTs are the technologies underpinning the digital transformation of the economy and society. This research aims at supporting policy making by providing evidence to analyse strengths and weaknesses of the European ICT industry and technological take-up compared with its most important trading partners, over a range of several years and to a significant level of detail. The PREDICT project has been producing comparable statistics and analyses on ICT industries and their R&D in Europe since 2006, covering major world competitors including 40 advanced and emerging countries – the EU plus Norway, Russia and Switzerland in Europe; Canada, the United States and Brazil in the Americas; China, India, Japan, South Korea and Taiwan in Asia; and Australia.

Over a decade of research activity PREDICT addressed: the shift of the ICT industry and demand, from manufacturing to services; the rise of the ICT industry in Asia; the international geography of ICT R&D and innovation; the growing problems of the IPR system; the importance of mobile internet, as driving rationale of supply and demand; the deployment of ICT supply-side activities within all sectors of the economy.

Currently, PREDICT is also supporting the initiatives towards the first Digital Europe programme for increasing EU's international competitiveness and developing Europe's strategic digital capacities, by providing evidence about the availability of adequate advanced digital skills in IT and related emerging domains in EU Member States (MSs)

In most recent years, PREDICT expanded by analysing techno-economic segments (TES), describing the dynamics of their ecosystems with factual micro-data from non-official heterogeneous sources, to contribute to measuring the digital transformation of the economy and provide policy recommendations.

Artificial Intelligence (AI) has become an area of strategic importance with potential to be a key driver of economic development. The Commission announced in April 2018 a European strategy on AI in its communication "Artificial Intelligence for Europe", COM(2018)237. The TES methodology is being applied to target AI and map its landscape in the EC AI Watch project, ("the Commission Knowledge Service to monitor the Development, Uptake and Impact of Artificial Intelligence for Europe"), in progress. It will monitor industrial, technological and research capacity, policy initiatives in the Member States, uptake and technical developments of AI and its impact. AI Watch has a European focus and covers all Member States within the global landscape.

PREDICT is a collaboration between the Digital Economy Unit of the European Commission (EC) Joint Research Centre (JRC) and the Digital Economy and Skills Unit of the EC Communications Networks, Content and Technology (CNECT) Directorate General.

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Abstract

The Techno-Economics Segment (TES) analytical approach aims to offer a timely representation of an integrated and very dynamic technological domain not captured by official statistics or standard classifications. Domains of that type, such as photonics and artificial intelligence (AI), are rapidly evolving and expected to play a key role in the digital transformation, enabling further developments. They are therefore policy relevant and it is important to have available a methodology and tools suitable to map their geographic presence, technological development, economic impact, and overall evolution. The TES approach was developed by the JRC. It provides quantitative analyses in a micro-based perspective.

AI has become an area of strategic importance with potential to be a key driver of economic development. The Commission announced in April 2018 a European strategy on AI in its communication "Artificial Intelligence for Europe", COM(2018)237, and in December a Coordinated Action Plan, COM(2018)795. In order to provide quantitative evidences for monitoring AI technologies in the worldwide economies, the TES approach is applied to AI in the present study. The general aim of this work is to provide an analysis of the AI techno-economic complex system, addressing the following three fundamental research questions: (i) Which are the economic players involved in the research and development as well as in the production and commercialisation of AI goods and services? And where are they located? (ii) Which specific technological areas (under the large umbrella of AI) have these players been working at? (iii) How is the network resulting from their collaboration shaped and what collaborations have they been developing?

This report addresses these research questions throughout its different sections, providing both an overview of the AI landscape and a deep understanding of the structure of the socio-economic system, offering useful insights for possible policy initiatives. This is even more relevant and challenging as the considered technologies are consolidating and introducing deep changes in the economy and the society. From this perspective, the goal of this report is to draw a detailed map of the considered ecosystem, and to analyse it in a multidimensional way, while keeping the policy perspective in mind.

The period considered in our analysis covers from 2009 to 2018. We detected close to 58,000 relevant documents and, identified 34,000 players worldwide involved in AI-related economic processes. We collected and processed information regarding these players to set up a basis from which the exploration of the ecosystem can take multiple directions depending on the targeted objective. In this report, we present indicators regarding three dimensions of analysis: (i) the worldwide landscape overview, (ii) the involvement of players in specific AI technological sub-domains, and (iii) the activities and the collaborations in AI R&D processes. These are just some of the dimensions that can be investigated with the TES approach. We are currently including and analysing additional ones.

Executive summary

This report presents an overview of the worldwide AI landscape in the period 2009-2018, as a result of the application of the TES analytical approach to the AI domain. The report focuses on a comparative analysis of the EU and its main competitors. Results of the top worldwide regions and EU NUTS 2 regions are also portrayed.

Results reveal the outstanding role of the US, China and EU in AI, despite different characteristics and performances in specific dimensions. These three areas concentrate 75% of all AI worldwide economic players (firms, research institutions and government bodies). India, South Korea, Canada and Japan also play an important role in the AI landscape. While US leads in overall presence of AI economic agents, and in AI firms, China hosts 57% of all firms filing AI-related patent applications, and Japan has the highest number of patent applications per patenting firm.

The analysis identified six non-mutually exclusive thematic key areas within the AI technological domain, used here to describe the strengths of economic players and geographical areas in AI subdomains. These thematic areas are: Natural Language Processing (NLP), Computer Vision, Machine Learning (ML), Robotics and Automation, Connected and Automated Vehicles (CAVs), and AI Applications and Services. EU players reveal to be mainly involved in Robotics and Automation -conforming to EU's leading presence in the robotics industry, and support by the Public Private partnership for Robotics in Europe- and in AI Applications and Services - explained by the high growth of EU's software industry, and the development of platform services increasingly used by enterprises and governments-. Similarly, US players are mainly specialised in AI Applications and Services and in Robotics & Automation, but with a much larger presence of NLP. China reveals a large involvement in Computer Vision, CAVs and ML methods. At regional level, Chinese regions are the world leaders in four of the six key areas: Beijing in NLP and ML, and Wan Chai for Computer Vision and CAVs. California leads the other two AI areas: Robotics and Automation, and AI Applications and Services. Other regions that appear among the top-5 in at least one area are: Guangdong, Sai Kung, Shanghai, Sichuan, and Zheijang in China, Massachusetts and New York in the US, Soul in South Korea, Tokyo in Japan, Ontario in Canada, and Inner London-West in UK. The French region Île de France is also represented among the top-30 regions.

Regarding R&D processes, that consider patent applications and frontier research activities in AI, China hosts more than 50% of AI R&D players, followed by the US (14%) and the EU (11%). India, which is fourth in the global ranking of AI players, becomes ninth when considering only R&D activities, substituted by South Korea as fourth, while Taiwan enters the top 10 list instead of Israel. The presence of Chinese players is mostly due to patenting activity. In fact, seven out of ten AI R&D players have filed at least one AI-related patent application in the period 2009-2018. Consequently, the AI R&D landscape is led by firms: 64% of all AI R&D players are firms (above 80% in Japan, Us and South Korea), 33% are research institutions and 3% are government bodies or associations.

Among the EU Member States, UK outperforms other countries in number of AI players in general, and AI firms in particular, followed by Germany and France. Germany, however, filed more AI-related patent applications during the studied period, due to the more intense patent activity of its firms (2.7 patent applications per firm in Germany, against 1.7 in UK). This intensity is highest for Finland (6 patent applications per firm). United Kingdom and Germany are the leading countries in all six AI thematic key areas, and only in CAVs Germany comes first. France keeps the third position in all areas but Robotics and Automation, and CAVs. The third position is for Spain in Robotics and Automation, and for Sweden in CAVs.

The EU R&D regional network reveals an intense collaborative structure among German regions. The region of the French capital, Île de France, presents the highest influence potential over the rest of the EU network, followed by Cataluña (Spain). The UK regions of Inner London – West and Berkshire, Buckinghamshire and Oxfordshire are amongst the most active in frontier research in AI. The analysis of the R&D subnetworks individually (co-patenting, co-publications, co-participation in EU funded projects) shows that the co-participation in EU projects creates a much more connected network, with a more uniform distribution of activity among regions than patenting and frontier research, which appear more concentrated in fewer regions. This seems to be the consequence of the key role of EU framework programmes in the promotion of EU wide collaborations and the subsequent development of networks of excellence. In all three subnetworks, the norms seems to be the collaboration with players outside the country. In the patenting subnetwork, there is a higher tendency to collaborate with players from the same region.

1 Introduction

Since 2006, JRC is jointly running with DG CNECT the "Prospective Insights in ICT R&D" project (PREDICT), which analyses the supply of Information and Communications Technologies (ICT) and the investments in Research and Development (R&D) in ICT in Europe, with comparison to major competitors worldwide, supporting digital policies and feeding in the Digital Economy and Society Index (DESI).

In recent years, PREDICT expanded by developing an analytical approach for analysing techno-economic segments (TES), providing a timely representation of their integrated and very dynamic domain, and describing the dynamics of their ecosystems with factual micro-data from non-official heterogeneous sources, to contribute to measuring the digital transformation of the economy. TES refers to emerging and largely integrated technological domains that usually do not correspond to an industrial or a product classification, while are expected to be driving forces for growth and employment and also to enable further innovation and technological development, thus playing a key role in the digital transformation and possibly gate-keeping further developments. The TES analysis is conceived as an analytical framework and replicable methodology to analyse and describe the dynamics of specific ecosystems, by exploiting different types of factual data including non-official heterogeneous sources in order to bridge the needs of mapping, monitoring and benchmarking such segments with suitable scientific evidence. The proposed approach provides quantitative analysis in a micro-based perspective.

The field of AI is experiencing a period of substantial progress, due to the consolidation of several key technological enablers. As past industrial revolutions transferred technological power to the more industrialized nations, AI could be a similar game changer internationally, besides being potentially a key driver of economic development. It has therefore become an area of strategic importance, as confirmed by the European Commission (EC) announcing in April 2018 a European strategy on AI in its communication "Artificial Intelligence for Europe", COM(2018)237. A "Coordinated Plan on Artificial Intelligence", contributing to the implementation of the strategy, was published by the EC in December 2018, COM(2018)795. The coordinated plan provides a strategic framework for national AI strategies in the EU Member States.

An analysis of the AI techno-economic segment offers relevant insights while also monitoring the evolving international industrial and research landscape. The TES approach helps mapping the considered ecosystem, monitoring and benchmarking its main players, their locations and R&D activities. It also sheds light on the dynamics of the worldwide networks of stakeholders and technological subdomains, their gatekeepers and expected future excellences, from a country, regional and local perspective. In this report, some indicators provide a first overview of the ecosystem, to highlight some characteristics of the EU in the worldwide scene. It also contributes to the debate on EU's competitiveness, attractiveness and excellence in AI (and in AI R&D), key aspects targeted by the European strategy on AI. Different types of economic players (firms, research institutions and governmental institutions) and activities (general economic processes, research and innovative processes, firms funding, etc.) are considered.

The structure of this report is as follows. In section 3, an overview the AI worldwide landscape is developed mainly by considering the number of players per geographic area (in absolute terms and in relative terms, using national GDP to develop relative comparisons) and per organisational type. In section 4, we identify technological key areas (or sub-domains) under the large umbrella of AI, and analyse the countries' level of activity in each of them. In section 5, we analyse the AI R&D processes and, more specifically, the involvement of players (grouped by country) in patenting activities and scientific publications, with the additional consideration of EU funded projects when focusing on EU Member States. Additional, and more detailed, analyses will be published in a forthcoming report (Samoili S. et al., in press). Our research is currently moving towards the inclusion and the analysis of further dimensions, among which corporate ownership, firm size, economic sectors in which firms operate, EU projects funding.

2 Methodology overview

Definition of player and activity in the TES approach

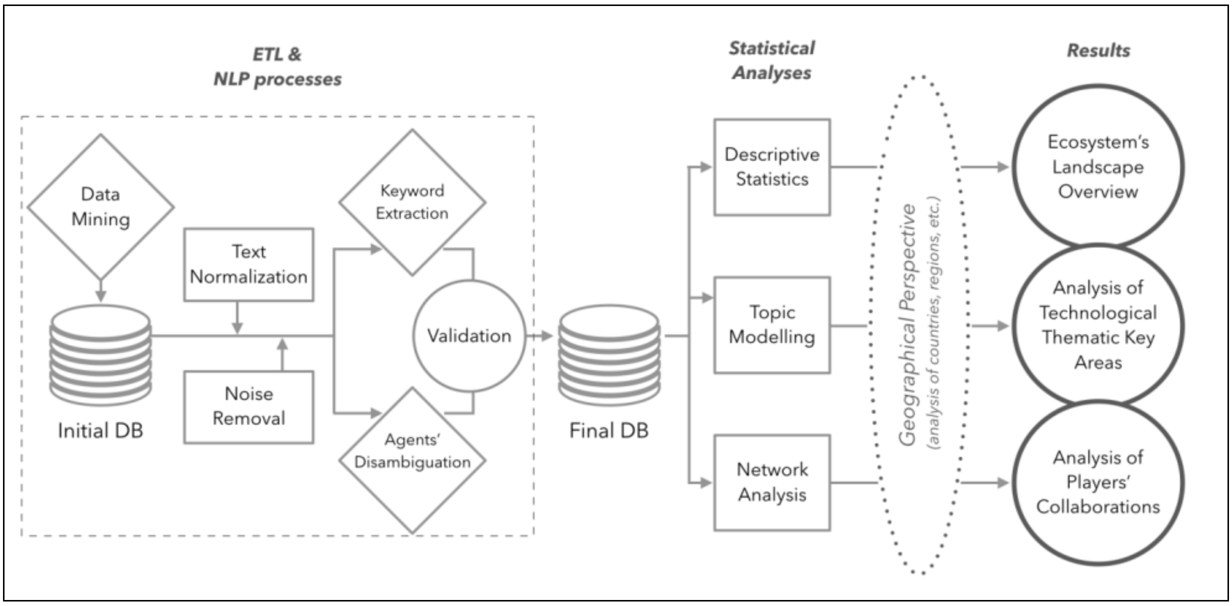
Since the main goal of the methodology is to map a techno-economic segment, the unit of analysis is the economic agent or player, referred henceforth as "player", that can be a company, research institution or governmental authority. Such player is expected to have an active role in the segment, with the capability to influence its economic development and future evolution. In this sense, the focus is put on the organisations, and not on individuals: the applicant organisation owning the invention in the case of patents, authors´ affiliation in conference proceedings, companies, governmental entities, etc.

With the intention to establish a comprehensive landscape, we target both industrial and R&D activities. This helps to capture economic agents 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, marketing and other services-, firms funding –venture capital funds or other types of investment-.

TES analytical approach overview

The workflow depicted in Figure 1 presents the main aspects of the TES analytical approach, from left to right.

Figure 1. TES AI Workflow & Methodology



The methodology first defines the boundaries of the TES, the AI segment, by detecting players with a focus on the selected segment as their primary or secondary activity. In the absence of standard classifications allowing the identification of emerging and evolving techno-economic segments, the involvement of economic players in the TES under scrutiny is captured through the analysis of the player´s activities as expressed in textual data. Players´ activities may have been explicitly stated -e.g. companies' activities descriptions- in general business registers or segment specific firms' repositories, or derived from the analysis of their R&D activities –text from patent applications, conference proceedings, research projects-. In order to discern which players´ activities are to be considered as related to the TES under study, we use a comprehensive dictionary of domain specific keywords covering the technological aspect of the segment. The initial phase of data mining is integrated with a series of procedures defining the data pre-process. The collected sources are: AI startups from AngelList, the Global Artificial Intelligence Landscape by Asgard and Roland Berger 2018, CB Insights, Crunchbase, EPO PATSTAT, CORDIS, BvD Orbis, Venturesource by Dow Jones, VentureRadar. Moreover, scientific articles are collected from the top 10 AI international conferences[1]. Additional sources are: AAI Job Fair, AI & Big Data Expo Global 2018, Allianz Global Artificial Intelligence, AI Breakthrough Awards 2018. Two types of information are extracted for the TES approach: (i) information about the techno-economic activity: description of the activity (e.g. description of companies' activity, abstracts of articles, keywords…), date of the activity (publication date, patent application filing date, firm's founding date…), and (ii) information about the players involved and their location. Several pre-processes (including cleaning and disambiguation) are developed to obtain the final database.

The information used to depict the AI worldwide ecosystem from 2009 to 2018 presented in this report concerns 34,009 players identified by means of 57,722 documents. Information is collected at a micro-level, so the final database consists of detailed information about the participation of each detected player into the AI ecosystem. Once the boundaries of the TES are set, and the players mapped,

With the final database completed, we implement statistical methods to orient the analyses towards specific types of outcome. The geographical perspective, consisting in country[2] or regional level in this report, is always considered. As presented in the right part of Box 1 ("Statistical Analyses" and "Results"), for this report the final database is used to carry out three analyses:

(a) Descriptive statistics for an overview of the ecosystem's landscape: based on the information regarding the location of players, their organisational type (firm, research institution, government) and the activities they participated in.

(b) Topic modelling techniques for the study of thematic and technological key areas: the textual semantic information derived from the collected documents is used to assess the players' key areas of technological and thematic attention or specialisation. Subsequently, the players' association to the corresponding documents allows the computation of the countries' thematic topics profiles.

(c) Network analysis for the investigation of players' collaborations, in this work exclusively referred to R&D activities (e.g. co-patenting, co-authorship in scientific publications): we examine player's interconnections to describe the ecosystem as a network of interdependent economic agents. We also generated geographical networks by considering together all players in the same geographical area. By doing so, thanks to the initial information on players' collaborations, we derive the structure of collaborations among geographical areas.

More detailed information on the TES methodology is available in (Samoili S. *et al.*, in press).

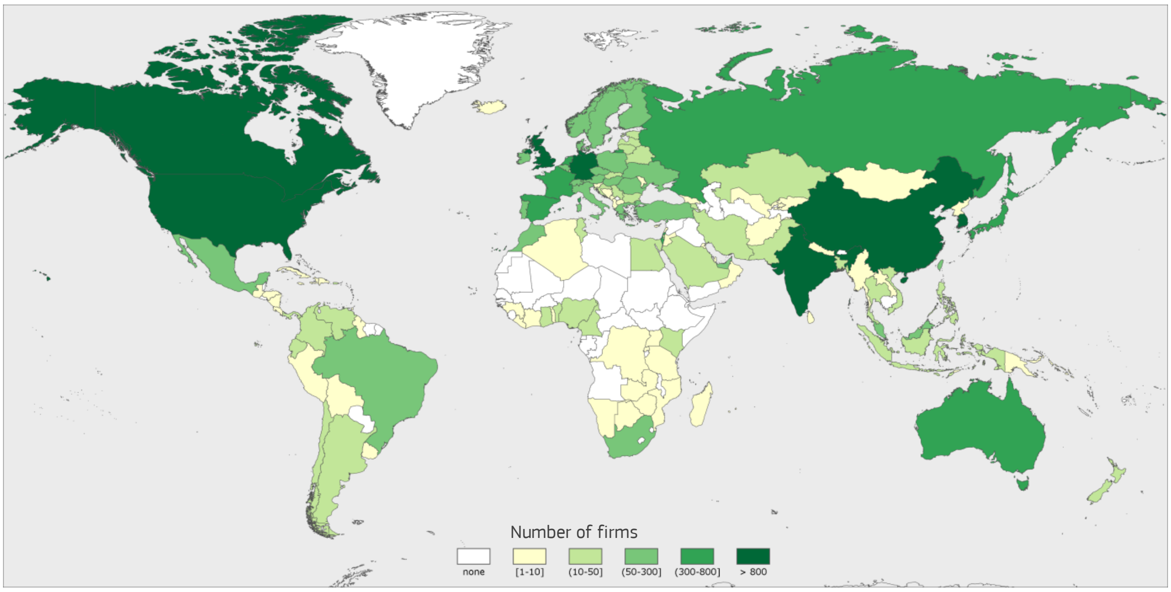
[1] The list of selected conferences is reported in Annex 1.

[2] When results are provided at country level in a worldwide perspective, the EU is presented as an aggregate.

3 Competitive International Landscape Overview

Figure 2 provides an overview of the AI worldwide ecosystem in the period 2009-2018 The collected micro-data are used to assess the relevance and the weight of countries. The aggregation at country level is based on the location of AI players (i.e. firms, research institutes, universities, governmental institutions, laboratories, etc., involved in AI-related activities). Subsequently, the size of the countries' economies (in terms of GDP) is considered for comparative purposes. The types of involved institutions and their patenting performance are also analysed.

Figure 2. Worldwide distribution of players active in Artificial Intelligence, 2009-2018



Source: JRC PREDICT- AI TES Dataset.

3.1 Worldwide overview

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 (Figure 3). 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 (China Institute for Science and Technology Policy at Tsinghua University, 2018; WIPO, 2019). In other to account for the size of the countries' economies, we also obtain the indicator of number of players over GDP -measured in € billion PPS[3] so that price differences between countries are accounted for-. Countries like Israel, Canada or South Korea outperform the three world leaders in number of players over GDP, reflecting a higher relative participation of these countries in the AI landscape.

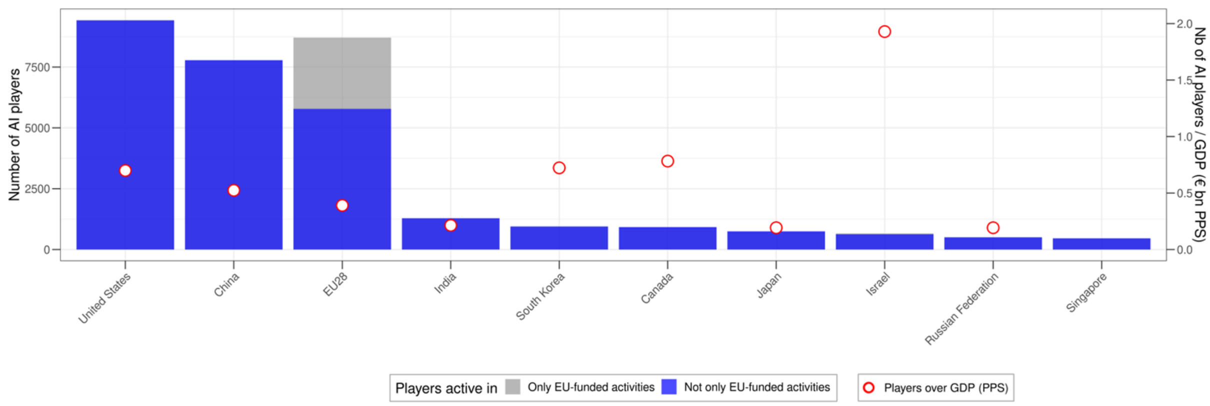
For the sake of comparability, we have not considered, so far, the players whose involvement in AI activities concerns only EU funded projects (grey bar in Figure 3), since comparable national or regional funding programmes in other world regions are neither considered. When EU projects are taken into account, the number of EU players active in AI increases by 51%. This suggests that a big share of the R&D activity addressing to any extent AI in Europe is taking place under the umbrella of the EC Framework Programmes, involving different types of players and possibly facilitating industrial take-up of AI technologies.

The number of AI firms detected in the US is considerably higher than in any other geographical area. US hosts one third of all detected worldwide AI firms, 40% more than in China (Figure 4a). Out of all firms, one third has filed at least one AI-related patent application between 2009 and 2018, of which 57% are located in China (Figure 4b). When considering patent applications, instead of applicants, the share of China rises to 62%: in the considered period, the number of patent applications by Chinese players is 4 times that of

[3] To allow cross-country comparability, national currencies have been converted into euro Purchasing Power Standard (PPS), a unit based on current euros, to account for the effect of differences in price levels across countries and of movements in exchange rates.

applications by US players. However, on average, US and Japanese firms patent considerably more than Chinese (over 4 AI-related patent applications per firm for the former, 2 for EU, 1.9 for China) (Figure 4c). These findings are in line with other relevant work in the field, where the evidences regarding Chinese players' performances in patenting are completed by the information that only 4% of Chinese patents are also filed in another jurisdiction (WIPO, 2019).

Figure 3. Top 10 world geographic areas by number of AI players: Absolute number and Relative to GDP (€ bn PPS), 2009-2018

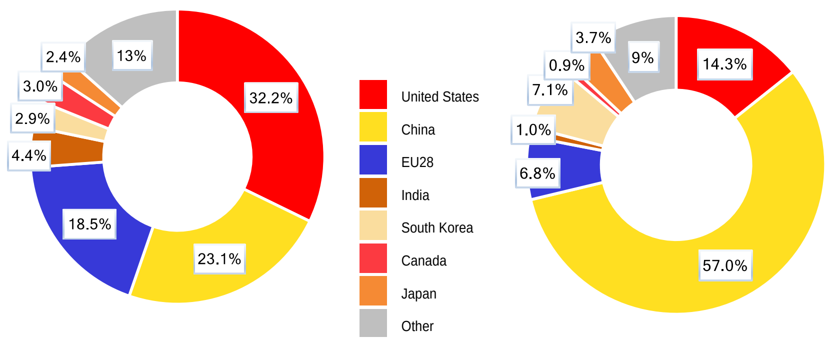


Source: JRC PREDICT- AI TES Dataset (AI players), OECD, IMF and Eurostat (GDP).

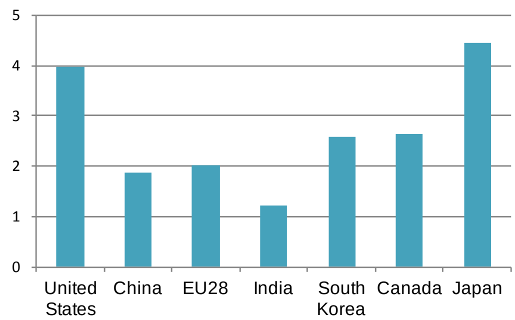
Figure 4. Overview of firms involved in AI related processes, 2009-2018

(a) AI firms by country (%)

(b) AI firms with at least one patent application filed by country (%)



(c) Average number of AI-related patent applications filed per patenting firm, by country

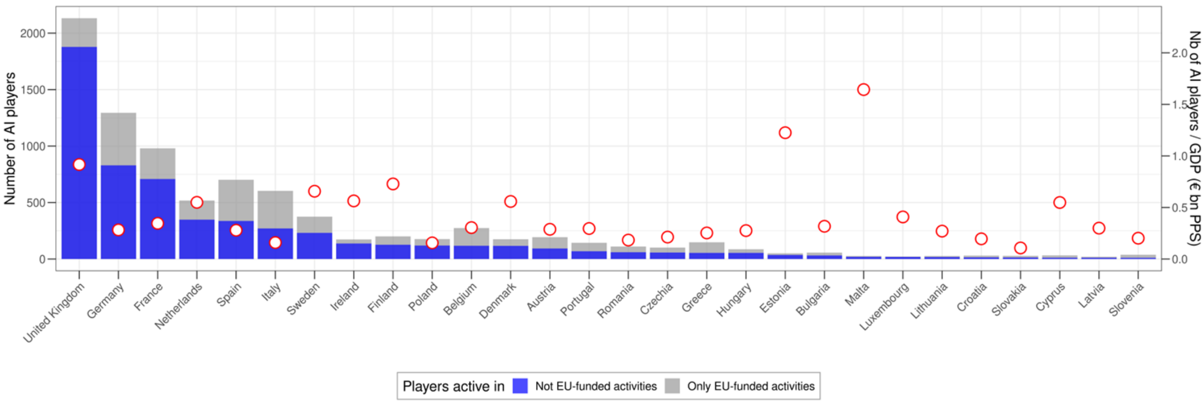


Source: JRC PREDICT- AI TES Dataset.

3.2 Focus in EU Member States

The most noticeable presence of EU AI players is in its Northern and Western Member States. Considering the ratio between number of AI players and GDP, Malta, Estonia, UK, Netherlands, Finland and Sweden are the leading countries. When considering absolute values, the countries with the largest number of players are the UK, Germany and France. In addition, the impact of EU funded projects in the involvement of new players (grey bar in Figure 5) is relatively low in the UK (12% of players are involved in AI only due to their participation in EU funded projects), while more substantial in Germany (36%), France (28%), and even larger in Spain (52%) and Italy (55%).

Figure 5. AI players: Absolute number and Relative to GDP (€ bn PPS), European Union, 2009-2018



Source: JRC PREDICT- AI TES Dataset (AI players), and Eurostat (GDP).

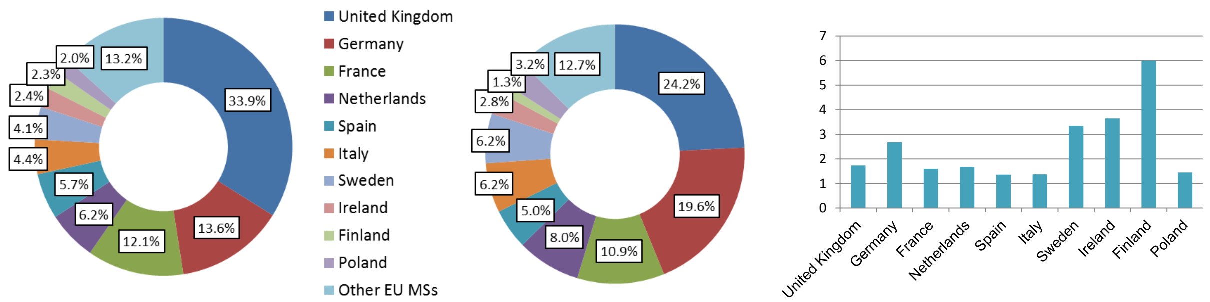
The UK is also the MS with highest number of AI firms, more than twice than in Germany (Figure 6). The highest number of AI-related patent applications is detected in Germany, followed by the UK, Sweden and France, all of them with more than 100 patent applications filed between 2009 and 2018, although the number of patenting players is higher in UK. This is explained by the more intense patent activity per firm (and more generally by all types of players) showed by some countries, as is the case of Finland (6 patent applications per firm), Ireland (3.6), Czechia (3.4), Sweden (3.3), and Germany (2.7).

Figure 6. Overview of firms involved in AI related processes, European Union, 2009-2018

(a) AI firms by EU MS (%)

(b) AI firms with at least one patent application filed by EU MS (%)

(c) Average number of AI-related patent applications filed per patenting firm, by EU MS



Source: JRC PREDICT- AI TES Dataset.

4 AI Thematic Key Areas of Strength

We analysed the textual content of worldwide R&D and industrial activities to identify technological subdomains from the entire AI technological landscape and key areas of strength. By means of a machine learning approach (Latent Dirichlet Allocation) implemented on the collected corpus of documents representing AI R&D and non-R&D activities (see Figure 1), we identified six non-mutually exclusive thematic key areas. These thematic areas are the following:

- Natural Language Processing (NLP)
- Computer Vision
- Machine Learning (ML)
- Robotics and Automation
- Connected and Automated Vehicles (CAVs)
- AI Applications and Services

Description of the six thematic areas:

- **Natural Language Processing**: contains activities related to machine identification and generation of information from and 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**: 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 Applications and 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).

4.1 Thematic key areas in the main Worldwide Countries

EU key areas of strength are Robotics & Automation and AI Applications & Services (Figure 7). EU's substantial role in robotics results from its leading presence in the robotics industry (Figure 7 (a)), producing more than 25% of the world's industrial and professional service robots (International Federation of Robotics, COM(2018) 237;), in research in view of public private partnership (Robotics Public Private Partnership (PPP), SPARC Public Private partnership for Robotics in Europe) and investments (Accenture, 2018; Indian National

Strategy for Artificial Intelligence #AIFORALL, 2018). EU's strong presence in the AI Applications & Services key area is explained by the growth of its software industry, five times the growth of the rest of the European economy, and by the development of platforms providing services contributing to the "intelligent enterprise" and e-government schemes (Atomico, 2018; COM(2018) 237).

The US appear to be active in Robotics & Automation, and in AI Applications & Services, but also significantly in NLP ((Figure 7 (b)). US's and China's thematic profiles indicate that they are not explicitly focused on a specific thematic area, as they are the two colossi in AI, and they have an extensive presence in all areas.

China's main areas of strength are in Computer Vision, and in CAVs (Figure 7 (c)). It is also prevailing in the "know-why", namely in Machine Learning (ML), which is used also in the development of methods implemented in other areas. The country is also substantially present in NLP and Robotics & Automation. The activities are mainly government-led following a national plan on AI and investment on Chinese companies (AIDP), especially in CAVs (China's State Council, 2017; Viereckl et al., 2016). China is among the top three global venture capital investors in unmanned vehicles (CAVs and drones), robotics and virtual reality (Pinho, 2019; Ke and de Diego, 2019). In CAVs, the governmental investments to Chinese companies led them to partner with international vehicle automobile companies as developers or stakeholders, making the country competitive in the relevant thematic key area.

India has a focused participation in activities on AI Applications & Services (Figure 7 (d)), while South Korea (Figure 7 (e)) and Japan (Figure 7 (g)) present similar thematic profiles. Both South Korea and Japan appear focused on the areas of NLP, Computer Vision, and CAVs (Viereckl et al., 2016)); the theoretical aspects of AI follow.

Canada is mainly concentrated in AI Applications & Services and Robotics & Automation areas (Figure 7 (f)). Canada's emerging presence in the AI industrial landscape, as the fourth country in number of AI enterprises after US, China and UK, according to the China Institute for Science and Technology Policy at Tsinghua University (2018), and in the top 20 countries in number of patent applications, explains its leaning on the application side of AI (WIPO, 2019).

Israel is one of the emerging economies in the AI field, holding a key position along with Canada and the United Kingdom (Parliamentary Mission (Villani Mission), 2018). It is more active in the "know-how" side of AI (Figure 7 (h). AI Applications & Services and Robotics & Automation are Israel's core activities in AI.

The Russian Federation's thematic profile suggests that the country's main activities are focused on CAVs (Figure 7 (i)), due to the presence in the country of manufacturing firms developing electric vehicles, unmanned vehicles for taxi services, trams and trucks. The government's regulation allowing the testing of unmanned vehicles is expected to positively affect this area (KPMG, 2019; Regulation 1415, 2018).

4.2 EU Member States' thematic hotspots

Figure 8 shows an overview of the EU MSs' performance on each AI thematic area. It represents the relative position of each country with respect the number of AI activities performed by all players of the country. Within EU, the United Kingdom and Germany are the leading countries in all thematic key areas, and only in CAVs Germany comes first (Figure 8).

France ranks in the top-5 for all thematic areas, reaching the third position in all except Robotics & Automation and CAVs. This result is in line with other studies' outputs showing that France holds 16.5% of the AI experts worldwide, is in the top-10 of the worldwide AI enterprises (also found in our analysis) and in the top-20 research institutions with AI activities (CNRS) (China Institute for Science and Technology Policy at Tsinghua University, 2018; WIPO, 2019).

Germany leads in CAVs, followed by the United Kingdom and Sweden, given their respective automobile companies that dominate in the autonomous automobile worldwide industry, and their number of patents' applicants (by location) for autonomous driving (Bardt, 2017; Statista, 2017). United Kingdom holds a significant role also in the key areas of NLP and AI Applications & Services.

The country distribution of activities by key area reveals that also the Netherlands holds an important position in the top-5 leading countries in every thematic area, apart from Robotics & Automation where it ranks sixth.

4.3 Worldwide regional thematic hotspots

This Section presents results at regional level, the geographical level corresponds to NUTS 2 regions in the EU and equivalent administrative areas in non-EU countries (e.g. state in US, province in China). Chinese regions are the world leaders in four of the six key areas: Beijing in NLP and ML, and Wan Chai for Computer Vision and CAVs, while Guangdong and Shanghai are also among the top-30 in most areas (Figure 9). Many other regions from China are involved in AI, with lower positions. Additionally, although the Sai Kung region presents few AI activities, the indicator reveals a concentrated presence in the area of Robotics & Automation.

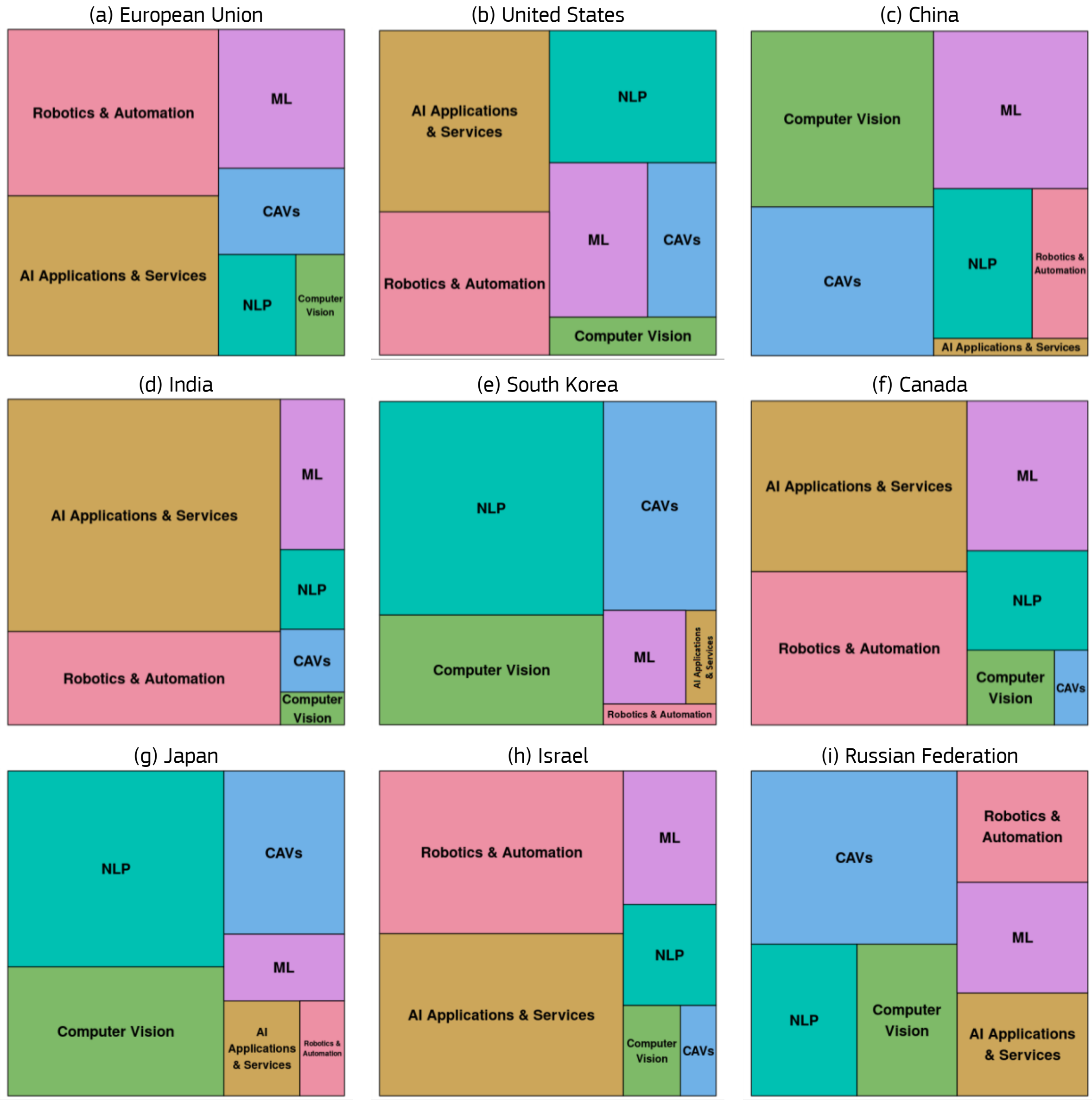
In the US, the states of California and New York are among the top-30 regions in all six key areas. Washington, Massachusetts, Michigan, Texas and Pennsylvania follow, with involvement in multiple key areas. The identification of these hotspots is in line with other studies' results (WIPO, 2019) and are explained given the location of US innovation hubs, universities and research institutes, six of which are included in the top 20 of those having AI activities (University of California, Carnegie Mellon University, IEEE, Massachusetts Institute of Technology (MIT), Stanford University, Georgia Institute of Technology).

The only European countries present in the top-30 regions are United Kingdom, France and Switzerland, being West Inner London, and Île de France the most represented regions. This presence shows a concentration in the areas of Robotics & Automation and ML.

The South Korean region of Seoul shows a strong leadership in all the key areas apart from Robotics & Automation, especially in NLP.

Tokyo is very actively present in NLP and in Computer Vision, and less in the other areas.

Figure 7. Thematic profiles of geographical areas: Distribution of activities by country (%), 2009-2018



Notes:

NLP: Natural Language Processing; ML: Machine Learning; CAVs: Connected & Automated Vehicles; AI Applications & Services.

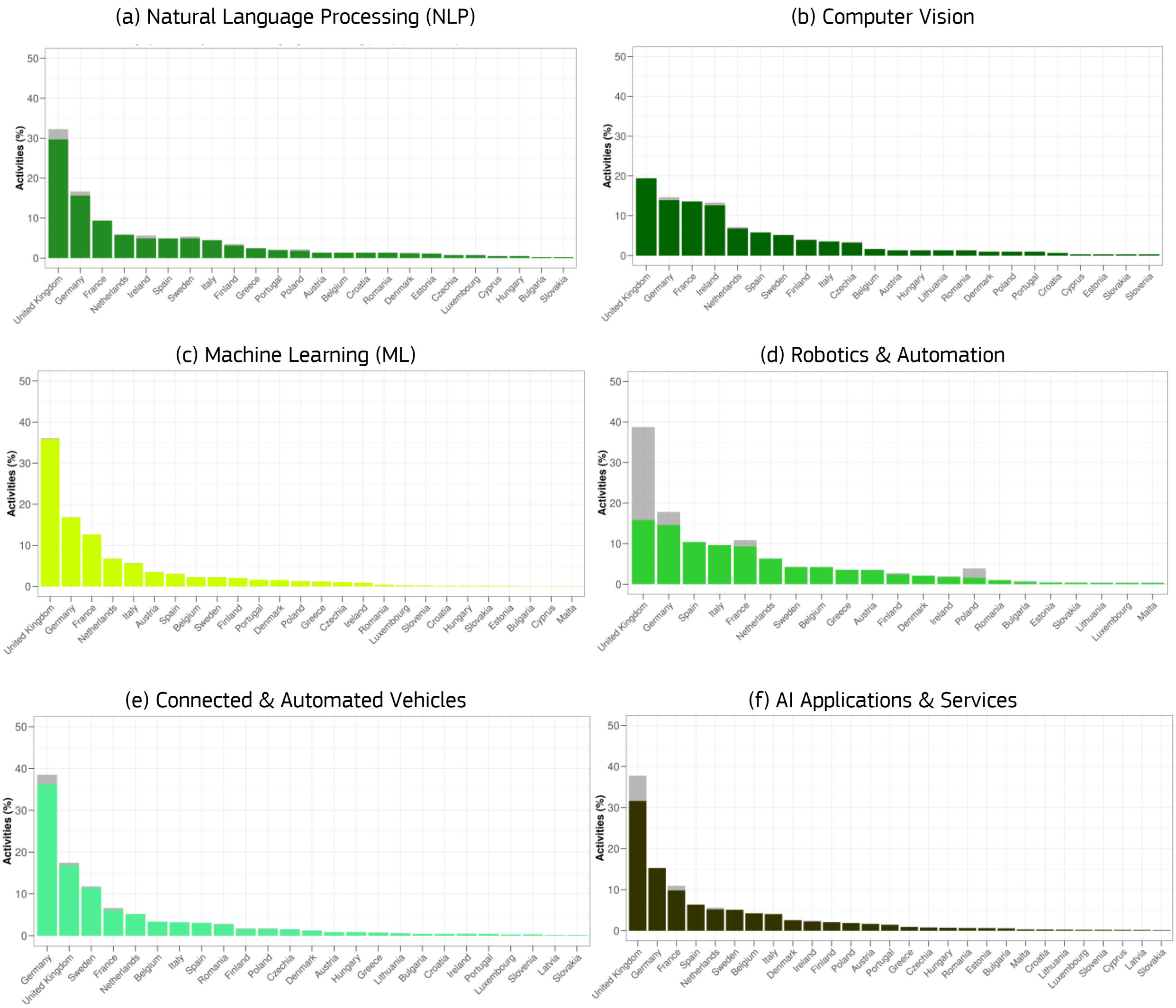
The Thematic profile indicator (TPI) for country C and topic T is defined as:

$$\mathrm{TPI}_{\mathrm{C,T}} = \frac{A_{C,T}}{\sum_T A_{C,T}} = \frac{number\ of\ activities\ of\ country\ C\ in\ a\ topic\ T}{sum\ of\ number\ activities\ of\ country\ C\ in\ all\ topics}\ x\ 100$$

Values 0 to 100%.

Source: JRC PREDICT- AI TES Dataset.

Figure 8. National hotspots of thematic key areas: Number of activities per country (%) in each key area, European Union, 2009-2018.



Notes:

EU-funded activities are illustrated with grey when applicable.

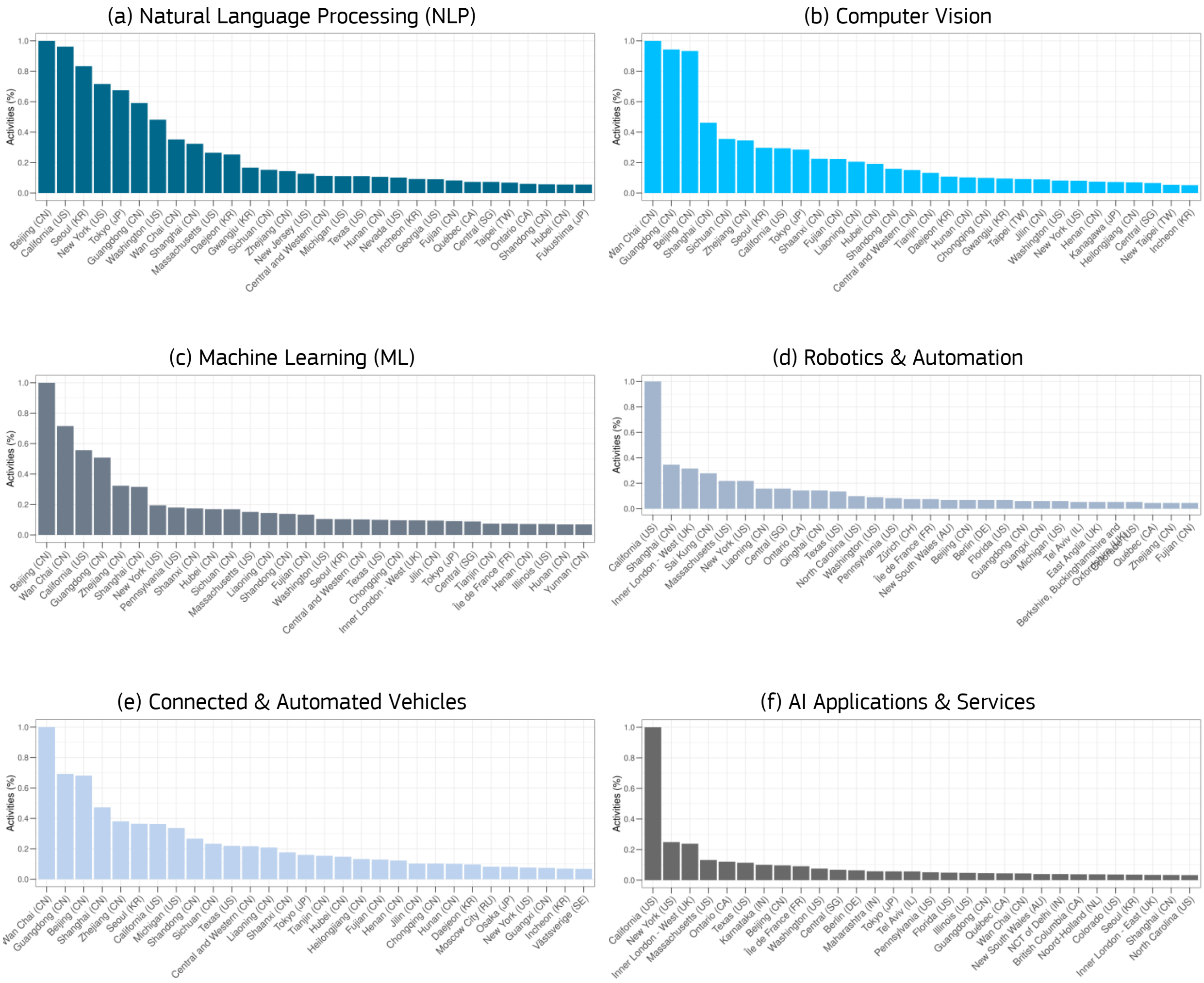
The Country Thematic Hotspot Indicator (CTHI) for country C and topic T is defined as:

$$CTHI_{C,T} = \frac{A_{C,T}}{\sum_C A_{C,T}} = \frac{number\ of\ activities\ of\ country\ C\ in\ topic\ T}{sum\ of\ number\ of\ activities\ of\ EU\ countries\ in\ topic\ T} x100$$

Values 0 to 100%.

Source: JRC PREDICT- AI TES Dataset.

Figure 9. Regional hotspots of thematic key areas: Number of activities per region (normalised to [0-1]) in each key area. Top 30 regions, 2009-2018



Notes:

EU-funded activities are illustrated with grey when applicable.

The Regional Thematic Hotspot Indicator (RTHI) for region R and topic T is defined as:

$$RTHI_{R,T} = \frac{A_{R,T}}{\sum_R A_{R,T}} = \frac{number\ of\ activities\ of\ region\ R\ in\ topic\ T}{sum\ of\ number\ of\ activities\ worldwide\ in\ topic\ T}$$

And the RTHI normalised, as:

$$RTHIN_{R,T} = \frac{RTHI_{R,T} - min_T(RTHI_{R,T})}{max_T(RTHI_{R,T}) - min(RTHI_{R,T})}$$

The values are normalised [0,1] within each Topic with the min-max normalisation.

Source: JRC PREDICT- AI TES Dataset.

5 Attractiveness & Excellence in AI Research

R&D outcomes, in particular patenting and publications, are analysed in this section. With patenting, we aim at capturing innovative industrial developments in the field. With publications, we identify the most important theoretical advancements and other results of academic research. We also refer to this second type of activities as "frontier research". Information regarding EU funded projects is considered when analysing EU countries and the R&D network of EU regions. However, EU funded projects are not used in the worldwide landscape analysis to avoid a biased analysis, as information on comparable national or regional funding programmes in other world regions are not considered.

5.1 Worldwide Players in AI R&D Processes

The top 10 geographical areas by number of AI R&D players are almost the same as the top in global number in AI players. Only Taiwan enters the list instead of Israel. The ranking is also a bit different. China is by far the country with more AI R&D players, followed by the US and the EU. India, which is fourth in the global ranking of AI players, becomes ninth when considering only R&D activities. It is substituted by South Korea, with 6.35% of the worldwide AI R&D players (Figure 10b). Japan (5th), Russia (6th), and Taiwan (7th) also have a higher position in the AI R&D landscape than in the global one, while Canada gets down to the 8th position.

In general terms, firms outnumber research institutions in the R&D landscape, with 64% of all AI R&D players being firms, 33% research institutions and only 3% governmental institutions or associations. This predominance of firms is observed in all top 10 geographical areas. The relative presence of firms participating in AI R&D processes is larger in Japan (84%), the US and South Korea (82%) and China (80%). On the contrary, the EU has the highest share of research institutions active in AI (47%) (Figure 10a).

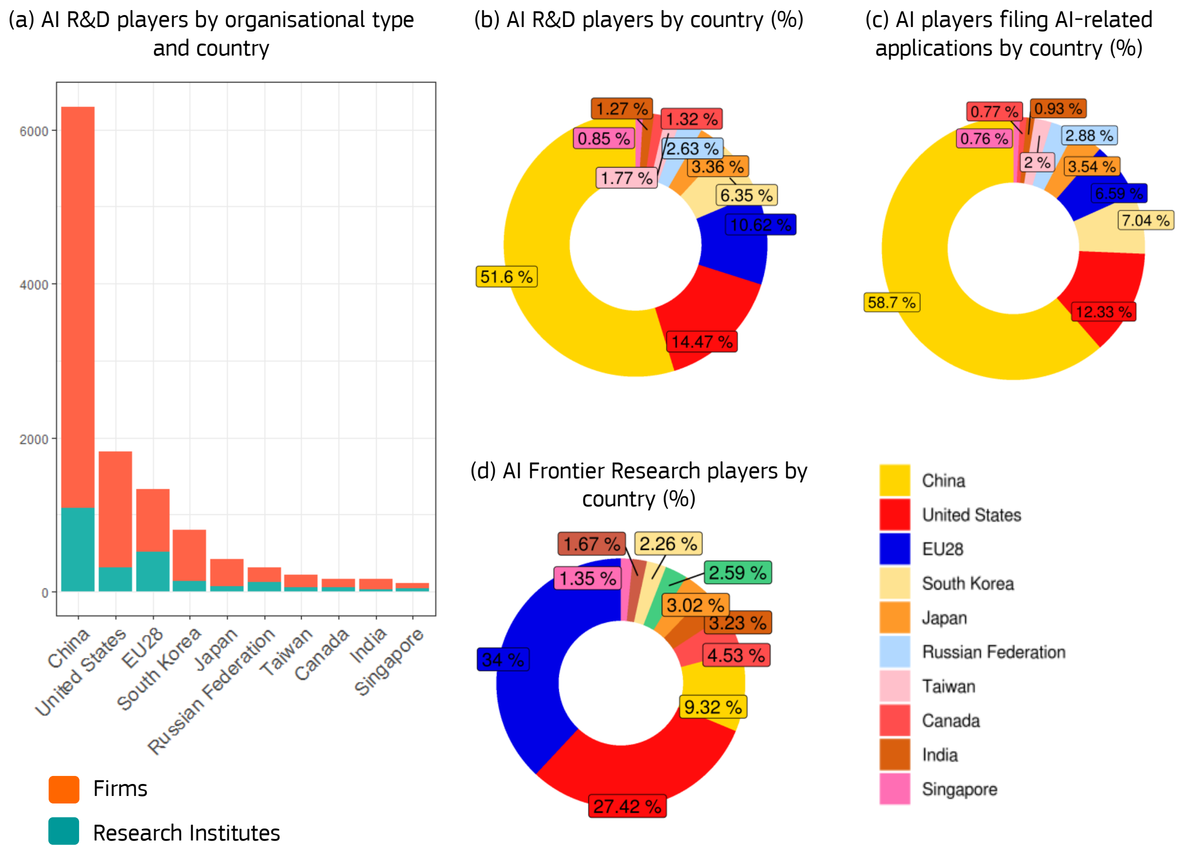
Around 70% of all AI R&D players have filed at least one AI-related patent application in the period 2009-2018. The share of Chinese players among them very is large (Figure 10c), and this confirms China as very active in this activity (WIPO, 2019). The large number of Chinese players patenting explains the prominent position of China in the AI R&D landscape (Figure 10a-b). The presence of South Korea is moderate (7.0% of AI patenting players, in Figure 10c) while that of the US is modest (12.3% of AI patenting players, in Figure 10c.). However, even if the number of US patenting players is not as high as China's, their productivity is larger than the one presented by players of any other country (4 patents per patenting firm, as seen in Figure 4c). From the point of view of frontier research, considering exclusively players with at least one publication in top AI conferences, the landscape is different. EU is the first area with 34% of the total AI players (Figure 10d). US follows closely (27.4%), whereas China hosts only 9.3% of them.

5.2 The EU R&D regional network

Considering players involved in the most relevant AI R&D processes (patents, frontier research and EU funded projects), in the majority of EU regions we find a large presence of research institutions. A higher presence of firms is found in north/western Europe: *Inner London – West* (49% of firms), *Västsverige* (42% of firms), *Zuid-Holland* (35% of firms), *Stuttgart* (35% of firms), *Noord-Holland* (35% of firms), *Darmstadt* (34% of firms), *Oberbayern* (34% of firms), *Île de France* (32% of firms), *Hovedstaden* (32% of firms), *Région de Bruxelles-Capitale / Brussels Hoofdstedelijk Gewest* (31% of firms). As R&D activities are often characterised by collaborations among players (i.e. co-patenting, co-publications, co-participation in EU funded projects), we investigate the structure of connections that they develop through these activities. In order to assess the relevance of each region (by means of its players) in the whole network of collaborations, we calculate the weighted betweenness centrality (WBC) of EU regions[4]. The most influential region (measured in terms of WBC), is *Île de France, followed by Cataluña*. Other relevant regions are also *Oberbayern, Köln, Toscana* and *Lazio*.

[4] Weighted betweenness centrality allows the estimation of the level of power or influence that, thanks to the set of developed connections, the considered region can exert over the rest of the network. This statistic is computed for the whole R&D network (all collaborations simultaneously considered) and for its subnetworks (one type of collaboration at a time). WBC considers in how many shortest paths (between all possible couples of regions) the region is detected. Therefore, the larger the number of shortest paths on which the region is detected, the larger its influence over the network is, and the higher its WBC. The number of collaborations between regions is used to weight the connections between regions, and this affects the computation of the shortest paths (Brandes, 2001).

Figure 10. Indicators on AI players in R&D activities, 2009-2018



Note: In (a), governmental institutions are excluded.
Source: JRC PREDICT- AI TES Dataset.

In addition, in this part of the report we separately analyse the types of R&D collaborations. By considering only one subnetwork at a time we better disentangle the role of different types of collaborations.

Subnetwork of participations in EU funded projects (Figure 11 and Table A 1(b) in Annex 2)

— As expected, this R&D subnetwork is dominated by the presence of research institutes. Two noticeable exceptions are the *Région de Bruxelles-Capitale / Brussels Hoofdstedelijk Gewest* and *Île de France*, where we observe a higher involvement of firms, 33% and 14% of the players, respectively.

— In terms of potential to influence the activity of other regions, three regions outperform: *Île de France*, *Zuid-Holland* and *Helsinki-Uusimaa*.

— Regarding the involvement of players in EU funded projects, the regions with the most active players on average (number of EU projects divided by number of players in the region) are *Oberbayern* and *Inner London – West*.

Subnetwork of patenting collaborations (Figure 11 and Table A 1(c) in Annex 2)

— As expected, this is the only subnetwork in which the presence of firms is more substantial than that of research institutions.

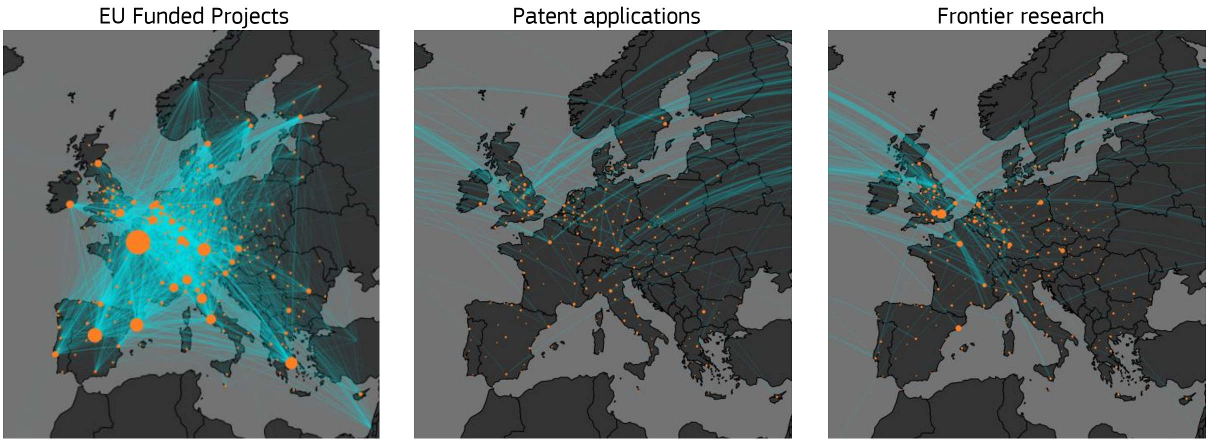
— The area with the highest potential to influence other regions is *Inner London – West*, with a high WBC at worldwide level.

— The most productive regions, in terms of number of patent applications per player, are located in the north-west of Europe. These are *Helsinki-Uusimaa* (4.5 patents per player), *Stuttgart* (4.3), *Southern and Eastern Ireland* (4.0), *Stockholm* (3.7), *Berkshire, Buckinghamshire and Oxfordshire* (3.5), *Noord-Brabant* (3.2), and *Västsverige* (3.0).

Subnetwork of collaborations in frontier research (Figure 11 and Table A 1 (d) in Annex 2)

- The subnetwork of players with publications in top AI conferences presents several regions with a balanced number of firms and research institutes developing research publications. These are *Stuttgart* (57% of firms), *Zuid-Holland* (57%), *Comunidad de Madrid* (56%), *Lazio* (50%) and *Emilia-Romagna* (50%).
- In terms of the potential to influence other regions, France has two regions with a high WBC value. These are *Île de France* (WBC equals 0.71, which means that it has the 71% of the centrality of the most influent region in the world) and *Rhône-Alpes* (WBC equals 0.33).
- The region presenting the largest academic productivity is *Berkshire, Buckinghamshire and Oxfordshire* (15.5 publications per player), with 25% of its players being firms. Other productive regions follow in decreasing order: *Noord-Holland* (5.2 publications per player and 31% of firms), *Stuttgart* (4.7 publications per player and 57% of firms), *Inner London – West* (4.2 publications per player and 46% of firms), *Emilia-Romagna* (3.7 publications per player and 50% of firms), and *Rhône-Alpes* (3.1 publications per player and 43% of firms).

Figure 11. AI R&D Subnetworks of EU regions, 2009-2018.



Note: The maps show the subnetworks of the entire AI R&D regional networks based on collaborations between players from different regions. In the images, each node represents a different region. The width of the connections is proportional to the number of collaborations developed by the players of the corresponding regions. The size of the nodes is proportional to the potential of the region to influence the subnetwork, measured as WBC.

Source: JRC PREDICT- AI TES Dataset.

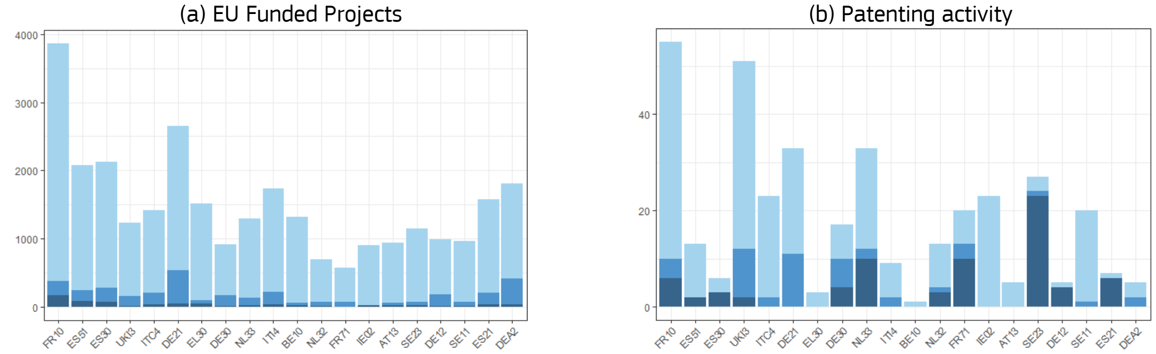
5.3 R&D Openness in Patenting, Frontier Research and EU Projects

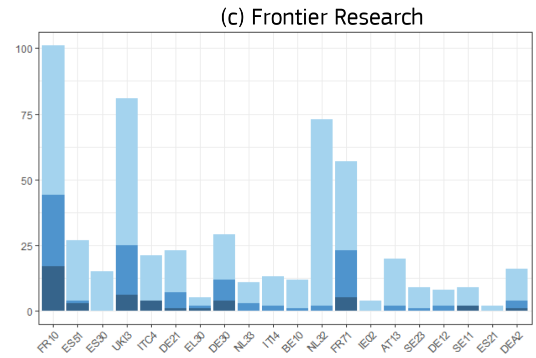
Of the three types of activities analysed, the one capturing a higher level of collaboration is, by far, the co-participation in EU funded projects. In the top 30 regions presented in Table A 1 (Annex 2) (top 30 by number of players involved in AI R&D processes), the number of project collaborations per region is one order of magnitude higher than the number of activities (subtable (b)). However, in co-patenting and co-authoring of frontier research, number of collaborations and number of activities are of the same order of magnitude (subtables (c) and (d). One of the key roles of EU funded projects is that of promoting and activating EU wide collaborations, and the subsequent development of networks of excellence. We observe that the distribution of collaborations over the different regions is more uniform than the respective distributions for patenting and frontier research, which appear more concentrated in fewer regions. Figure 12 shows that, apart from *Île de France* (FR10), presenting a higher number of collaborations in EU funded projects, the other regions do not show large differences. This is not the case of the distribution of the number of collaborations in patent applications and in frontier research publications, where we can observe larger discrepancies among regions. This suggests that the EU funded projects are able to foster a more homogeneous and balanced involvement in AI at regional level.

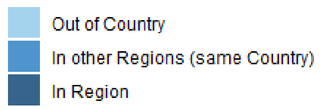
Regarding the co-patenting activities, the regions with higher number of R&D players present a high tendency to develop collaborations within the same region. This is especially pronounced in *Västsverige* (85% of collaborations are developed internally), *Karlsruhe* (80%), *Comunidad de Madrid* (50%), and *Rhône-Alpes* (50%). Regarding collaborations with other regions in the same country, the regions more prone to develop this kind of collaborations are located in Germany: this confirms the detection of an intense collaborative structure among German players.

In the academic research network of the top 30 European regions, five regions present more than 25% of their collaborations with players belonging to the same country but not to the same region. These are *Île de France* (27%), *Oberbayern* (26%), *Berlin* (28%), *Zuid-Holland* (27%), and *Rhône-Alpes* (32%). Given also the overall amount of activities developed by the involved players, these regions appear to have a leading role within their country in terms of frontier research in AI.

Figure 12. Number of collaborations by location of the peers, in EU funded projects, Patenting and Frontier Research. Top 20 EU Regions by number of players in AI-related R&D activities, 2009-2018







The listed NUTS2 regions, from left to right in decreasing order by number of AI players in R&D process, are: FR10 - *Île de France*; ES51 – *Cataluña*; ES30 – *Comunidad de Madrid*; UKI3 – *Inner London – West*; DE21 – *Oberbayern*; ITC4 – *Lombardia*; EL30 – *Attica*; DE30 – *Berlin*; NL33 – *Zuid-Holland*; ITI4 – *Lazio*; BE10 – *Région de Bruxelles-Capitale / Brussels Hoofdstedelijk Gewest*; NL32 – *Noord-Holland*; FR71 – *Rhône-Alpes*; AT13 – *Wien*; IE02 – *Southern and Eastern*; SE23 – *Västsverige*; DE12 – *Karlsruhe*; ES21 – *País Vasco*; SE11 – *Stockholm*; DEA2 – *Köln*..

Notes:
See Table A 1(a) in Annex 2.
Types of collaboration (of region X) are defined as:

- Out of Country: Number of collaborations of players in region X that happen with players belonging to a different country
- In other Regions (same Country): Number of collaborations of players in region X that happen with players belonging to the same country but not to the same region
- In Region: Number of collaborations of players in region X that happen with other players in region X.

Collaborations in the three subnetworks are taken into account separately. Collaborations are classed depending on where the peers are located, with respect to the considered region. For example, when considering region AT13, i.e. *Wien*, the "In Region" collaborations refer to collaborations between players located in *Wien*. The "In other Regions (same Country)" collaborations refer to collaborations in which one player is located in *Wien* and another one in an Austrian region different from *Wien*. The "Out of Country" collaborations refer to collaborations in which one player is located in *Wien* and another one is in a country different from Austria.

Source: JRC PREDICT- AI TES Dataset.

5.4 Thematic areas of main R&D regions in EU

Figure 13. Regional thematic hotspots of key areas. Number of activities per region (normalised to [0-1]) in each key area. Top 20 EU regions, 2009-2018

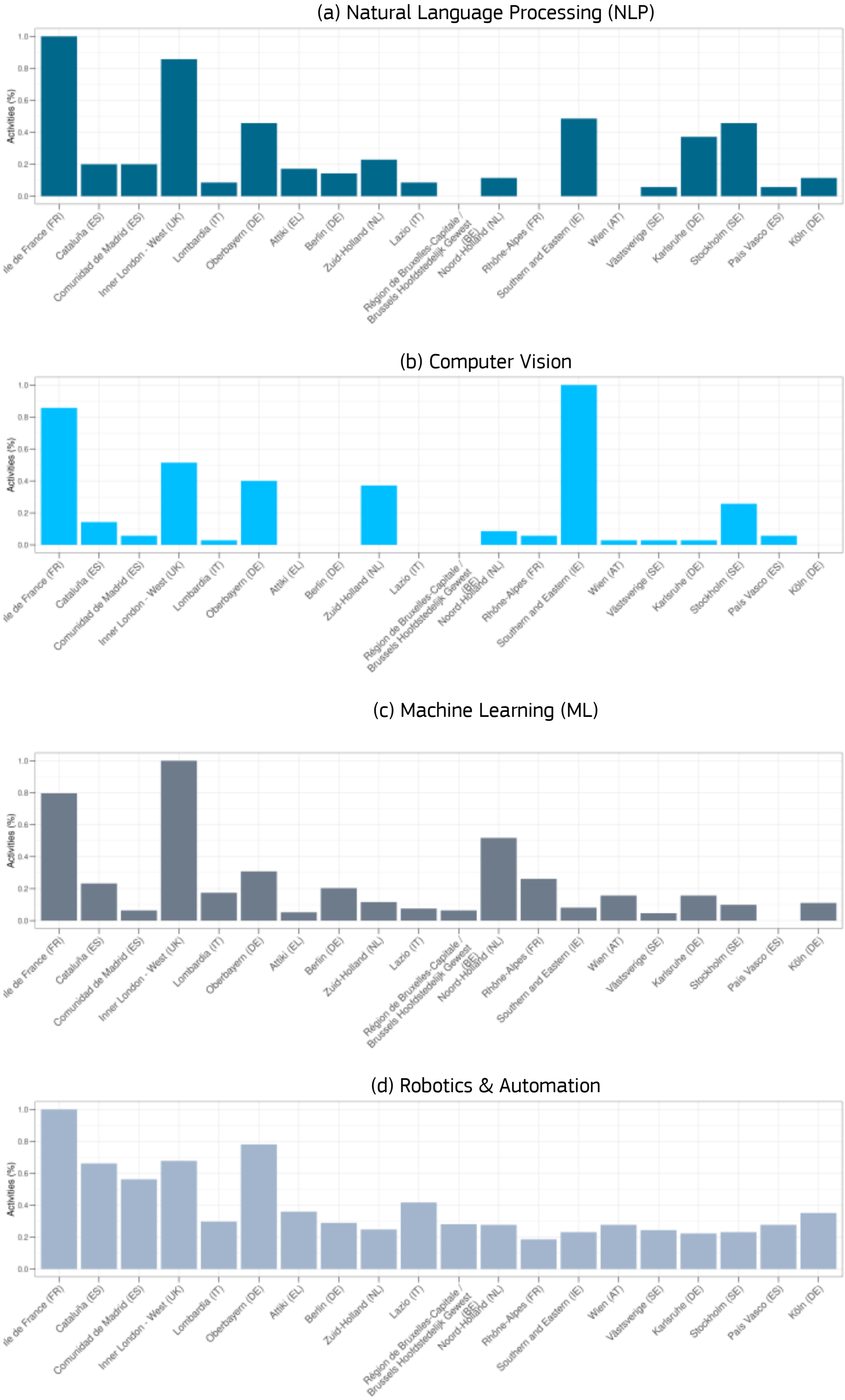
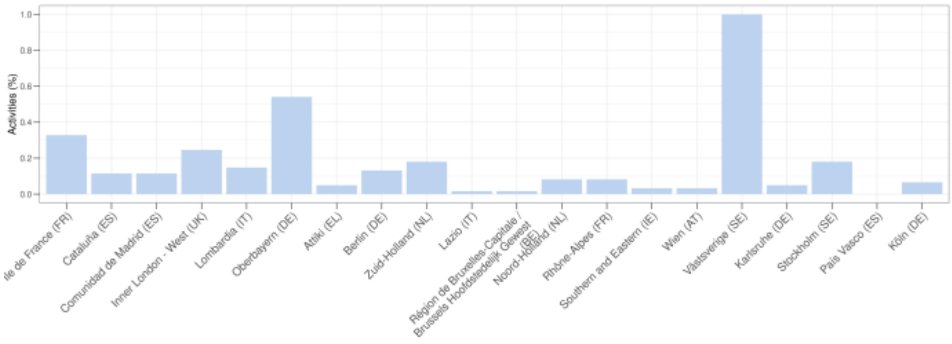
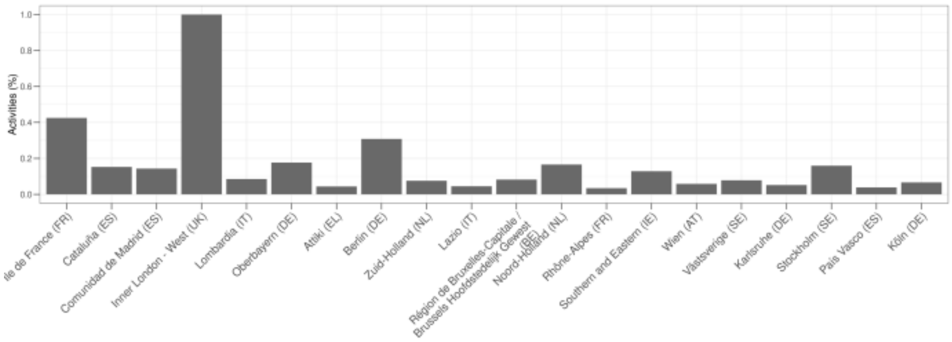


Figure 13 (continuation). Regional thematic hotspots of key areas.

(e) Connected & Automated Vehicles



(f) AI Applications & Services



Note: Regions of EU countries are selected and presented according to the number of players involved in AI R&D related processes (top 20), as in subsections 5.2 and 5.3, and in the same order as in Figure 12.

EU-funded activities are included. The Regional Thematic Hotspots Indicator (RTHI) and the normalised one (RTHIN) are defined in Figure 9.

Source: JRC PREDICT- AI TES Dataset.

This Section presents the EU regional hotspots. Île de France leads in all key areas in France. Rhône-Alpes contributes more in Machine learning, and is marginally present in Computer vision, Robotics & Automation and Connected & Automated Vehicles.

In Germany, multiple regions (Oberbayern, Berlin, Köln, Stuttgart, Karlsruhe, Münster) are strongly present showing the leadership of the country in multiple key areas, but in particular in Connected and Automated Vehicles and in Robotics & Automation.

United Kingdom leads in multiple key areas and with multiple regions. A strong leadership among all EU is shown by the West Inner London region in the ML area and in AI Applications and Services. The same region is ranked second, behind Île de France, in NLP. The region of Berkshire, Buckinghamshire and Oxfordshire follows with a moderate presence in NLP and a strong presence in ML, along with North Yorkshire.

Netherlands appears active in all the thematic key areas, and more concentrated activities are shown in AI “know-why”, ML methods, in the Noord-Holland region. Another two thematic areas that appear as strong in the Zuid-Holland area are, Computer Vision and NLP.

In CAVs, the Swedish and German regions of Västsverige and Oberbayern lead, as expected due to their leadership in the automotive sector.

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List of abbreviations and definitions

GDP — Gross Domestic Product. Measures the total final market value of all goods and services produced within a country during a given period. GDP is the most frequently used indicator of economic activity and is most often measured on an annual or quarterly basis to gauge the growth of a country's economy between one period and another.

PPS — Purchasing Power Standard. National currencies are converted into Purchasing Power Standards (PPS), an accounting unit based on current euros, to net for the effect of differences in price levels across countries and of movements in exchange rates. Using PPS it is possible to produce meaningful indicators (based on either price or volume) required for cross-country comparisons.

TES — Techo-Economic Segment. The ecosystem where interactions happens among all the economic players (e.g. firms, universities, research centres, governmental institutions) active or involved in (i) the commercialization and/or (ii) development of goods/services and/or (iii) development of R&D or innovation activities related to a specific technology (in the case of this report, AI). The TES can also be intended as a complex system in which multiple dimensions are present (e.g. geographic locations, thematic profiles, network of collaborations) and therefore explored. The project is currently moving towards the inclusion of new dimensions.

WBC — Weighted Betweenness Centrality. Statistics regarding nodes' centrality in a given network. As it is "weighted", in order to computed the shortest paths between couple of nodes in the network it also consider that connections can have different weights (Brandes, 2001).

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Annex 1. List of top AI conferences

The list of top 10 AI conferences is populated based on google.scholar.com top conferences on AI, and AI experts suggestions. The considered conferences and short description of their aim follows.

- International Conference on Learning Representations (ICLR, iclr.cc): ICLR is focused on learning representations, more commonly known as deep learning, as its aim is to learn higher-level features, or else representations.
- International Conference on Machine Learning (ICML, icml.cc): ICML is focused on the machine learning branch of AI.
- Conference on Neural Information Processing Systems (NeurIPS, nips.cc): NeurIPS is focused, but not exclusively, on neural information systems in multiple aspects.
- AAAI Conference on Artificial Intelligence (AAAI, aaai.org/Conferences/AAAI): AAAI is supported by the Association for the Advancement of Artificial Intelligence (AAAI), and focuses on theoretical and applied AI research.
- Artificial Intelligence for Interactive Digital Entertainment Conference (AIIDE, aaai.org/Conferences/AIIDE): AIIDE is supported by the Association for the Advancement of Artificial Intelligence (AAAI), and is applications-oriented to allow the fruitful interactions between AI entertainment software developers, academic and industrial AI researchers.
- Innovative Applications of Artificial Intelligence Conferences (IAAI, aaai.org/Conferences/IAAI): IAAI is sponsored by the Association for the Advancement of Artificial Intelligence (AAAI), focusing on AI-based applications.
- Computer Vision and Pattern Recognition (CVPR, cvprYEAR.thecvf.com): CVPR is supported by the IEEE Computer Society and intends to provide the latest insights for students, academics and industry researchers.
- European Conference on Machine Learning and Principles and Practice of Knowledge Discovery in Databases (ECML PKDD, ecmlpkdd2019.org): ECML PKDD is considered among the leading conferences on machine learning and knowledge discovery.
- International Conference on Computer Vision (ICCV, iccvYEAR.thecvf.com): ICCV focuses on computer vision and applications in all its subdomains.
- International Joint Conference on Artificial Intelligence (IJCAI, ijcai.org): IJCAI intends to assist in the dissemination of information on AI by including cutting.

Annex 2. Statistics regarding EU Regional Network of AI R&D collaborations

Table A 1. Network indicators of the top 30 EU regions, by number of AI R&D players, 2009-2018

The entire AI R&D network is considered in (a), while subsequently its subnetworks are considered separately. In (b) the subnetwork of EU Funded Projects, in (c) the subnetwork of patenting collaborations, and in (d) the subnetwork of frontier research collaborations. The provided statistics are (column names in parenthesis):

- Number of players in a region over total number of AI R&D players detected in EU, in percentage (*% of Players (over EU28)*)
- Percentage of research institutions over AI R&D players in the region (*% of Res. Institute (in the area)*)
- Percentage of firms over AI R&D players in the region (*% of Firms (in the area)*)
- Number of corresponding activities in which regional players participated (*N. of Activities*)
- Number of other regions with which at least one collaboration between players is present (*N. of Collaborating Areas*)
- Total number of collaborations in which players from the corresponding region are involved (*N. of Collaborations*)
- Potential to influence the network, measured in terms of Weighted Betweenness Centrality (*WBC*) (Brandes, 2001), normalized in interval [0-1]
- Propensity to establish collaborations with other areas, computed as the number of collaborations involving players of the region divided by the number of activities developed by the players in the region (*Coll. Areas / N. of Activities*)
- Average number of R&D activities in which regional players are involved (*N. of Activities / N. of Players*).

(a) All R&D Network

NUTS2 code	Region	Country	% of Players (over EU28)	% of Res. Institute (in the area)	% of Firms (in the area)	N. of Activities	N. of Collaborating Areas	N. of Collaborations	WBC	Coll. Areas / N. of Activities	N. of Activities / N. of Players
FR10	Île de France	FR	3.79%	62%	32%	469	278	4015	1.00	0.59	2.14
ES51	Cataluña	ES	2.53%	83%	12%	250	227	2122	0.69	0.91	1.71
ES30	Comunidad de Madrid	ES	1.99%	77%	17%	191	236	2152	0.27	1.24	1.66
UKI3	Inner London - West	UK	1.85%	49%	49%	343	223	1364	0.08	0.65	3.21
DE21	Oberbayern	DE	1.49%	65%	34%	326	227	2708	0.67	0.70	3.79
ITC4	Lombardia	IT	1.49%	76%	22%	127	213	1459	0.35	1.68	1.48
EL30	Attiki	EL	1.33%	86%	9%	120	209	1520	0.21	1.74	1.56
DE30	Berlin	DE	1.28%	69%	28%	116	188	962	0.07	1.62	1.57
NL33	Zuid-Holland	NL	1.23%	56%	35%	128	188	1339	0.26	1.47	1.80
ITI4	Lazio	IT	1.19%	80%	14%	134	211	1760	0.43	1.57	1.94
BE10	Région de Bruxelles-Capitale / Brussels Hoofdstedelijk Gewest	BE	1.06%	54%	31%	95	201	1336	0.09	2.12	1.56
NL32	Noord-Holland	NL	1.04%	65%	35%	173	178	784	0.33	1.03	2.88
FR71	Rhône-Alpes	FR	1.02%	66%	29%	100	157	649	0.05	1.57	1.69
AT13	Wien	AT	0.99%	81%	14%	108	178	971	0.04	1.65	1.89
IE02	Southern and Eastern	IE	0.99%	74%	25%	133	177	937	0.00	1.33	2.33
SE23	Västsverige	SE	0.95%	56%	42%	138	174	1184	0.18	1.26	2.51
DE12	Karlsruhe	DE	0.88%	78%	22%	109	182	1005	0.01	1.67	2.14
ES21	País Vasco	ES	0.86%	88%	12%	91	184	1583	0.24	2.02	1.82
SE11	Stockholm	SE	0.86%	70%	24%	113	173	995	0.03	1.53	2.26
DEA2	Köln	DE	0.85%	76%	16%	125	193	1831	0.46	1.54	2.55
ITH5	Emilia-Romagna	IT	0.78%	80%	20%	62	151	879	0.05	2.44	1.38
ITI1	Toscana	IT	0.76%	82%	11%	77	186	1309	0.49	2.42	1.75
NL41	Noord-Brabant	NL	0.76%	80%	16%	70	149	1176	0.02	2.13	1.59
ITC1	Piemonte	IT	0.74%	86%	12%	87	189	1621	0.02	2.17	2.02
DE71	Darmstadt	DE	0.71%	66%	34%	66	141	630	0.00	2.14	1.61
UKJ1	Berkshire, Buckinghamshire and Oxfordshire	UK	0.71%	73%	24%	221	161	546	0.04	0.73	5.39
FI1B	Helsinki-Uusimaa	FI	0.69%	70%	20%	93	174	1104	0.04	1.87	2.33
DK01	Hovedstaden	DK	0.66%	53%	32%	74	155	531	0.05	2.09	1.95
DE11	Stuttgart	DE	0.64%	62%	35%	127	158	940	0.01	1.24	3.43
HU10	Közép-Magyarország	HU	0.64%	70%	27%	36	102	301	0.03	2.83	0.97

(b) EU Project Network

NUTS2 code	Region	Country	% of Players (over EU28)	% of Res. Institute (in the area)	% of Firms (in the area)	N. of Activities	N. of Collaborating Areas	N. of Collaborations	WBC	Coll. Areas / N. of Activities	N. of Activities / N. of Players
FR10	Île de France	FR	2.56%	78%	14%	284	253	3859	1.00	0.89	1.92
ES51	Cataluña	ES	2.16%	90%	5%	194	216	2082	0.19	1.11	1.55
ES30	Comunidad de Madrid	ES	1.68%	89%	3%	164	229	2131	0.13	1.40	1.69
UKI3	Inner London - West	UK	0.64%	84%	8%	143	193	1232	0.03	1.35	3.86
DE21	Oberbayern	DE	0.83%	92%	6%	217	219	2652	0.14	1.01	4.52
ITC4	Lombardia	IT	1.11%	92%	5%	88	198	1415	0.15	2.25	1.38
EL30	Attiki	EL	1.19%	88%	6%	111	207	1512	0.32	1.86	1.61
DE30	Berlin	DE	0.67%	95%	0%	70	179	916	0.00	2.56	1.79
NL33	Zuid-Holland	NL	0.76%	84%	2%	79	177	1295	0.79	2.24	1.80
ITI4	Lazio	IT	1.00%	90%	3%	118	199	1738	0.20	1.69	2.03
BE10	Région de Bruxelles-Capitale / Brussels Hoofdstedelijk Gewest	BE	0.95%	51%	33%	83	197	1323	0.09	2.37	1.51
NL32	Noord-Holland	NL	0.52%	97%	3%	75	147	698	0.29	1.96	2.50
FR71	Rhône-Alpes	FR	0.64%	89%	3%	47	143	572	0.01	3.04	1.27
AT13	Wien	AT	0.78%	87%	7%	78	173	946	0.01	2.22	1.73
IE02	Southern and Eastern	IE	0.66%	95%	3%	67	168	910	0.11	2.51	1.76
SE23	Västsverige	SE	0.55%	91%	6%	67	168	1148	0.01	2.51	2.09
DE12	Karlsruhe	DE	0.55%	97%	3%	66	178	992	0.04	2.70	2.06
ES21	País Vasco	ES	0.76%	98%	2%	83	182	1574	0.24	2.19	1.89
SE11	Stockholm	SE	0.55%	88%	3%	63	161	966	0.03	2.56	1.97
DEA2	Köln	DE	0.62%	83%	6%	99	185	1810	0.00	1.87	2.75
ITH5	Emilia-Romagna	IT	0.59%	100%	0%	38	145	849	0.12	3.82	1.12
ITI1	Toscana	IT	0.64%	89%	3%	67	178	1293	0.02	2.66	1.81
NL41	Noord-Brabant	NL	0.62%	89%	6%	45	143	1163	0.28	3.18	1.25
ITC1	Piemonte	IT	0.66%	95%	3%	73	183	1604	0.06	2.51	1.92
DE71	Darmstadt	DE	0.52%	83%	17%	46	136	612	0.16	2.96	1.53
UKJ1	Berkshire, Buckinghamshire and Oxfordshire	UK	0.47%	89%	7%	69	133	445	0.01	1.93	2.56
FI1B	Helsinki-Uusimaa	FI	0.54%	77%	10%	57	162	1083	0.47	2.84	1.84
DK01	Hovedstaden	DK	0.31%	67%	0%	41	149	514	0.01	3.63	2.28
DE11	Stuttgart	DE	0.45%	85%	12%	51	144	900	0.00	2.82	1.96
HU10	Közép-Magyarország	HU	0.40%	96%	0%	28	101	277	0.08	3.61	1.22

Source: JRC PREDICT- TES Dataset.

Table A 1 (continuation)

NUTS2 code	Region	Country	(c) Patent Applications Network: % of Players (over EU28)	% of Res. Institute (in the area)	% of Firms (in the area)	N. of Activities	N. of Collaborating Areas	N. of Collaborations	WBC	Coll. Areas / N. of Activities	N. of Activities / N. of Players	(d) Frontier Research Network: % of Players (over EU28)	% of Res. Institute (in the area)	% of Firms (in the area)	N. of Activities	N. of Collaborating Areas	N. of Collaborations	WBC	Coll. Areas / N. of Activities	N. of Activities / N. of Players
FR10	Île de France	FR	0.67%	13%	87%	73	23	55	0.08	0.32	1.87	0.76%	57%	43%	112	42	101	0.71	0.38	2.55
ES51	Cataluña	ES	0.21%	25%	75%	16	7	13	0.02	0.44	1.33	0.31%	72%	28%	40	22	27	0.23	0.55	2.22
ES30	Comunidad de Madrid	ES	0.24%	21%	79%	17	3	6	-	0.18	1.21	0.16%	44%	56%	10	12	15	0.09	1.20	1.11
UKI3	Inner London - West	UK	0.61%	6%	94%	44	29	51	0.16	0.66	1.26	0.64%	54%	46%	156	46	81	0.29	0.29	4.22
DE21	Oberbayern	DE	0.50%	10%	90%	78	15	33	0.02	0.19	2.69	0.26%	87%	13%	31	16	23	0.13	0.52	2.07
ITC4	Lombardia	IT	0.24%	7%	93%	24	15	23	0.03	0.63	1.71	0.17%	70%	30%	15	12	21	0.12	0.80	1.50
EL30	Attiki	EL	0.05%	33%	67%	3	3	3	-	1.00	1.00	0.12%	71%	29%	6	4	5	0.01	0.67	0.86
DE30	Berlin	DE	0.21%	17%	83%	15	4	17	-	0.27	1.25	0.45%	58%	42%	31	20	29	0.30	0.65	1.19
NL33	Zuid-Holland	NL	0.36%	5%	95%	34	13	33	0.02	0.38	1.62	0.12%	43%	57%	15	7	11	-	0.47	2.14
ITI4	Lazio	IT	0.07%	0%	100%	4	9	9	0.03	2.25	1.00	0.14%	50%	50%	12	12	13	0.01	1.00	1.50
BE10	Région de Bruxelles-Capitale / Brussels Hoofdstedelijk Gewest	BE	0.03%	100%	0%	2	1	1	-	0.50	1.00	0.12%	86%	14%	10	11	12	0.13	1.10	1.43
NL32	Noord-Holland	NL	0.26%	0%	100%	15	9	13	0.01	0.60	1.00	0.28%	69%	31%	83	37	73	0.46	0.45	5.19
FR71	Rhône-Alpes	FR	0.21%	17%	83%	9	7	20	0.00	0.78	0.75	0.24%	57%	43%	44	25	57	0.33	0.57	3.14
AT13	Wien	AT	0.07%	25%	75%	4	3	5	-	0.75	1.00	0.16%	78%	22%	26	17	20	0.16	0.65	2.89
IE02	Southern and Eastern	IE	0.24%	14%	86%	56	14	23	0.07	0.25	4.00	0.12%	86%	14%	10	4	4	-	0.40	1.43
SE23	Västsverige	SE	0.36%	5%	95%	63	4	27	-	0.06	3.00	0.05%	67%	33%	8	9	9	0.08	1.13	2.67
DE12	Karlsruhe	DE	0.17%	30%	70%	19	1	5	-	0.05	1.90	0.21%	75%	25%	24	8	8	0.03	0.33	2.00
ES21	País Vasco	ES	0.16%	44%	56%	7	1	7	-	0.14	0.78	0.02%	100%	0%	1	1	2	-	1.00	1.00
SE11	Stockholm	SE	0.19%	18%	82%	41	11	20	0.04	0.27	3.73	0.12%	71%	29%	9	6	9	0.10	0.67	1.29
DEA2	Köln	DE	0.14%	25%	75%	8	4	5	0.00	0.50	1.00	0.12%	86%	14%	18	14	16	0.04	0.78	2.57
ITH5	Emilia-Romagna	IT	0.14%	13%	88%	9	8	11	0.01	0.89	1.13	0.07%	50%	50%	15	11	19	0.18	0.73	3.75
ITI1	Toscana	IT	0.07%	0%	100%	5	5	5	-	1.00	1.25	0.07%	100%	0%	5	10	11	0.06	2.00	1.25
NL41	Noord-Brabant	NL	0.10%	17%	83%	19	4	5	-	0.21	3.17	0.05%	67%	33%	6	5	8	-	0.83	2.00
ITC1	Piemonte	IT	0.09%	40%	60%	9	8	10	0.06	0.89	1.80	0.07%	75%	25%	5	7	7	0.01	1.40	1.25
DE71	Darmstadt	DE	0.19%	18%	82%	15	6	13	0.03	0.40	1.36	0.09%	80%	20%	5	4	5	0.00	0.80	1.00
UKJ1	Berkshire, Buckinghamshire and Oxfordshire	UK	0.14%	13%	88%	28	15	39	0.01	0.54	3.50	0.14%	75%	25%	124	41	62	0.37	0.33	15.50
FI1B	Helsinki-Uusimaa	FI	0.07%	25%	75%	18	2	2	-	0.11	4.50	0.12%	71%	29%	18	15	19	0.10	0.83	2.57
DK01	Hovedstaden	DK	0.14%	0%	100%	11	5	7	-	0.45	1.38	0.22%	69%	31%	22	7	10	0.01	0.32	1.69
DE11	Stuttgart	DE	0.17%	20%	80%	43	4	7	0.00	0.09	4.30	0.12%	43%	57%	33	22	33	0.07	0.67	4.71
HU10	Közép-Magyarország	HU	0.16%	0%	100%	5	4	20	0.01	0.80	0.56	0.09%	80%	20%	3	1	4	-	0.33	0.60

Source: JRC PREDICT- TES Dataset.

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