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The techno-economic segment analysis of the Earth observation ecosystem

The TES approach applied to the EO worldwide ecosystem

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Foreword

This report has been prepared as a contribution to the EOValue project (2018-2021) implemented by the European Commission (EC) Joint Research Centre (JRC) in partnership with the Directorate-General for Research and Innovation (DG RTD), and the Space Data Economy activity of the Copernicus II Administrative Arrangement between EC JRC and the Directorate General for Internal Market, Industry, Entrepreneurship, and SMEs (DG GROW).

The report analyses the worldwide landscape of the Earth observation (EO) ecosystem to identify opportunities, synergies, and obstacles that need to be addressed to foster the development of a vibrant space data economy in Europe.

The report applies the Techno-Economic Segments (TES) analytical approach. The approach was originally developed by EC JRC in the framework of the "Prospective Insights on ICT R&D" (PREDICT) project to contribute to measuring the digital transformation of the economy and to offer new metrics and quantitative indicators to back policy recommendations. The TES analytical approach targets technology-based dynamic segments that play an important role in the digital transformation but elude available official statistics or classifications. This methodological approach allows describing the technology-driven ecosystems with factual data from non-official heterogeneous sources. The approach has so far been applied to other techno-economic segments, including Photonics and Artificial Intelligence (AI).

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Abstract

This report analyses the worldwide landscape of the Earth observation ecosystem to identify opportunities, synergies, and obstacles that need to be addressed to foster the development of a vibrant space data economy in Europe. The report uses the Techno-Economic Segment (TES) analytical approach to provide a holistic view of the EO and geospatial ecosystem in Europe and worldwide through the identification of players and key clusters of activities. It also takes into consideration the potential flows of knowledge resulting from shared activities, locations and technological fields. The approach adopts a micro-based perspective considering a wide range of both horizontal and segment specific data sources. The outcome is a compelling characterisation of the key features of this very dynamic ecosystem.

The TES EO ecosystem shows a very diverse global landscape with three distinguished global hubs, namely EU28, China and the US, as possible incubators for EO-linked innovation. Those hubs have the largest number of players in case of R&D and well as in case of industry. Nevertheless, the distribution of EO activities and concentration of those activities look quite different in the three leading macro areas.

As far as the R&D activities are considered, the EU28 has the highest overall number of players involved in the all types of R&D activities, but scores quite low if only the patents are taken into account.

Out of the three big players, the US has the smallest number of players involved in the overall EO R&D and stable position in number of patenting. In case of China, the largest number of R&D activities is concentrated in hands of relatively few players.

In conclusion, the findings of this report confirm a general expectation about the growth in the EO downstream segment. However, up to 2017 the growth has not been staggering. Since 2017, there have been continuous policy efforts to increase the uptake of EO data in order to enable market growth.

1 Introduction

The objective of this report is twofold. First, it contributes to the body of studies on the value of EO by providing a common quantitative context for the typically fragmentary picture of the value propositions provided by other methodologies.

Second, it contributes to the better comprehension of a vibrant EO ecosystem and data economy in general. The report links the value of Earth observation to the EO activities performed by different users (public and private) and for different purposes. It defines EO activities as activities linked to EO data, hence activities not only concerned with the use of data output but also those linked to the collection of EO data. The analysis focuses on detecting a wide range of different types of economic and research activities in order to capture the ecosystem of EO users (players). The analysis results in heterogeneous landscape of data and technology users (players) in the EO domain. To this end, the EO-adapted TES approach (EO TES) is applied.

The Techno-Economic Segment approach is justified because the EO domain is enabled and constantly reshaped by technological developments. EO is an area where data, technology and economy are locked in a dynamic relation. The technological infrastructures located in outer space, flown in the air, or ground-based, enable the collection of terabytes of EO data on a daily basis. For example, currently, there are 169 earth observation missions in orbit and 140 approved future missions, as recorded by the Committee on Earth Observation Satellites (CEOS) (CEOS, 2019). The growing number of satellites, the improved performance of the sensing instruments, and higher resolution of the images have led to a fast-growing volume of data. A single Sentinel-1 satellite (Copernicus constellation) maps the whole world once every 12 days (ESA, 2017) and produces an estimated 1.5 petabytes of raw data per year (OECD, 2016). The EO data constitutes a significant portion of big data and its contribution to data economy is potentially enormous (EC 2017). EO data is a source of wealth of valuable information. However, finding and understanding information in the ever-growing volume of heterogeneous EO data proved the traditional way of analysis obsolete. The last decade's advances in data processing and computing capacity, in particular in AI and cloud computing have enabled advanced data analytics potentially contributing to the increased use of data.[1] EO data, often combined with other types of data, is used to create data-based solutions, products and services creating value for the economy and society at large. In order to maximise the value of data for a society the EU, as well as other governments worldwide, work to enhance access to publicly funded data, including EO data. This is expected to lead to a boost in data economy in general and to the creation of the functioning EO market in particular (for the scenarios of possible EO market evolution see for example Denis et al (2017)). This dynamic interconnection between technology and economy within the EO domain validates the recognition of EO as a techno-economic segment.

As a technology-entwined segment, EO does not correspond to any classification suitable to connect to official statistics nor to any quantitative analysis of its agents, activities and technological subdomains. The present study applies the TES approach that allows mapping the EO domain. While TES does not intend to provide a single number for the value of EO data or value of data economy, it helps to reveal and understand the EO ecosystem by providing a set of different indicators that serve as a quantitative canvas for the current economic and research endeavours in the related fields.

Section 2 of the report sets up the scene for the EO TES by providing general characteristics of the EO domain and describing the gap in the existing methodologies in capturing and measuring the value of EO. It presents the general motivation for choosing the TES methodology, the scope of TES as applied to the EO domain, and subsequently it discusses in more detail the data and methodology used in the EO TES. Sections 3, 4 and 5 discuss the main results and findings of the EO TES. First, an overall picture of the

[1] For the summary of the recent trends in handling EO data see for example: Sudmanns (2018); for an example of specific concepts facilitating use of EO data see for example: Nativi, Mazzetti, and Craglia (2017).

whole EO TES ecosystem is provided. The picture highlights the overlapping in time and space of market-oriented firms with players focused on R&D activities. Then the focus goes to R&D processes, and to the interactions of players whose collaborative activity has been tracked, and allows further investigation of the dynamics of R&D. Lastly, insights to the EO industry are shown by analysing the firm players within the EO segment. All parts compare (i) the most important regions worldwide and separately (ii) the EU28 member countries. Selectively more granular geographic information on the EO domain is provided.

This report is a first step in the process of the mapping the EO domain. Further work on the EO TES will take into account the results of the validation process, in particular relating to the data sources and keywords.

2 The EO techno-economic segment: motivation and methodology

2.1 Key definitions

For the purposes of the present report the definitions of "Earth observation", "EO data", "EO activity", "EO sector", "EO domain" and "EO ecosystem" are of key importance.

The most cited definition of "**Earth observation**" is the one developed by the Group on Earth Observations (GEO) that describes it as "gathering of information about planet Earth's physical, chemical and biological systems." This definition was adapted for the purposes of the present report. In the understanding of the report "Earth observation" refers to *collecting data about planet's Earth natural and man-made environment*.

The report also uses "Earth observation" in the meaning of the "EO domain".

"**EO data**" is *data on planet's Earth natural and man-made environment*.

"**EO activity**" means *an activity that links to EO data*. It encompasses collection of EO data and use of EO data output, i.e. any manipulation of data, extraction of information as well as creation of solutions, products and services. The activities in the area of R&D relating to EO have also been included (see Table 1).

"**EO sector**" refers to the upstream, midstream and downstream economic sector relating to EO data use, as explained in Table 1.

"**EO domain**" is a field of economic, social and scientific activities linked to Earth observation or EO data.

"**EO ecosystem**" refers to the ecosystem of players and activities as a result of the EO TES analysis.

2.2 The scope of the EO TES analysis

The scope of the "EO activity" term marks the scope of the EO TES analysis and draws the boundaries of the resulting image of the EO ecosystem. The EO ecosystem includes both private and public sector entities (players) whose activities are linked to EO data. End users were not explicitly targeted by the analysis. They are captured if they also engage in the activities specified in the Table 1 below.

In order to capture players in the EO ecosystem the EO TES targets specific technologies used for data collection (technology design, manufacture and operation) and solutions used for handling data output in the scope of activities as listed in the Table 1.

Table 1. EO activities targeted by the EO TES

Upstream segment	Midstream segment	Downstream segment	R&D activities (across all the segments)
EO data collection based on: - remote sensing (satellite, aeroplane, UAV, other), - seaborne, ground-based, underwater, subsurface/underground sensors, -geodetic instruments; Activities linked to EO data collection include: technology design, manufacture and operation.	EO data storage, host and distribution; Sales of EO data products.	EO data processing: - pre-processing: e.g. discretisation, (data)calibration, georeferencing, triangulation, orthorectification, resampling, reprojection, interpolation, etc. - analysis: e.g. image segmentation, photogrammetry, NDVI, - data representation; Use of EO data for the purpose of: - information products, - development of value-added solutions, applications, services and products to be applied across public and private sectors as well as used by the individuals in the following areas: weather forecast, climatology, geography (land use, land cover), geology, hydrology, forestry, agriculture, insurance, smart cities, digital maps, and many more.	EO-related R&D activities: - taking part in R&D programs, - publishing, - patenting.

Note: The current version of the EO TES focuses on the upstream and downstream segments and does not specifically target the midstream sector.

Source: JRC EO TES, 2019.

2.3 The EO economic sector: general characteristics from the literature

EO sector is largely claimed to undergo the fundamental change (Denis 2017, OECD 2019, PwC 2019). This subsection provides a general characterisation of the EO sector based on the literature review. The later stages of the reportwill focus on how this characterisation is reflected in the EO TES.

EO domain has traditionally been dominated by the public sector that was collecting and using EO data in order to perform its institutional role, in particular in order to meet policy objectives relating to defence, security and natural resources management. When described from the economic perspective, this translates to the dominance of public institutions, public companies and companies dependent on public financial support in both the upstream and downstream segments of the EO sector (OECD 2014). Not even a decade ago the EO market was mostly driven by the demand from the public sector, in particular from the defence and security segments (ca. 60%, see: Keith 2016). As a result, in 2014 there was still no *functioning* EO market (Smart 2014).

The EO upstream segment is concerned with the collection of EO data via satellite, aerial and Unmanned Aerial Vehicles (UAV) remote sensing as well as via ground-based technology. Despite of including various methods and technology for data collection, the EO upstream segment has been to large extent driven by the developments in the space sector. Satellite-based timely and systematic data accounts for the biggest part of EO big data. The historical reason for the domination of the space sector is that EO was born in the context of satellite-based data collection.[3] The space sector enjoys continuous public investment that secures its strategic importance for defence and security as well as in the context of the natural resources management.

The relatively recent technological developments have been having impact on the EO sector. The advances in the areas of AI and cloud computing as well as growing possibilities coming from the direction of IoT result in surge in EO data demand coming in particular from the private sector. Furthermore, the miniaturisation of satellites leading to decrease in production cost as well as the knowledge and technology transfers from the public to the private sector have reshaped the sector from the other side. These developments led to the changes in both the upstream and downstream segments, yet to a different degree.

There is an increasing number of EO players in EO upstream across all the specific areas. One notices the increase in the UAV data collection. Moreover, the access to the space sector has been democratised resulting in increasing diversity and number of actors, especially those coming from the private sector.

The changes in the upstream EO sector have not been as pronounced as in the downstream. The bigger inertia of the upstream is linked to the space sector, namely still relatively high threshold of the initial investment,[4] hazardous environment of outer space, and legal regulations on liability for activities in outer space that is linked to international state liability.[5]

The downstream EO market, on the other hand, knows a significant growth today (EC 2017, Big data in EO…). While in the past the stable financing in the upstream space sector has been crucial for the whole downstream segment, its current growth is fuelled by more horizontal technology advancements in the ICT sector. Those technology developments enabled adding value to EO data in the form of services, solutions, and products. The EO downstream segment offers very interesting possibilities for European companies, especially for the SMES and start-ups across various industry sectors.

Apart from the impact on the upstream and downstream, the technology developments led to one more noticeable change in the traditional structure of the EO sector. It facilitated the prominence of a midstream segment. The midstream segment encompasses companies and departments within large organisations that are predominantly concerned with data acquisition, archiving, organising, maintenance, storage, data analysis and delivery of services and data products that facilitate or enable creation of a final solution (EC 2017).They became an integral part of the EO value chain and often indispensable nexus between the upstream and downstream EO sector.[6]

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3 EO portal, 'Earth Observation History on Technology Introduction': https://directory.eoportal.org/documents/163813/238965/History.pdf.

4 While the access to space has democratised allowing for launch of miniature satellites for the research purposes, the space players with economic objectives are dominated by big companies often supported by venture capital. According to Seraphim Capital, a venture capital fund, the amount of VC in the space sector in general was $3.25 billion in 2018, up 30% from 2017 (http://seraphimcapital.passle.net/post/102f50i/seraphim-q3-global-space-index-investment-remains-concentrated-in-launch-and-co)

5 UN, Convention on International Liability for Damage Caused by Space Objects (Liability Convention) 1972, 961 UNTS 187.

6 For more information on the midstream sector in case of the Copernicus Programme see: Specific Contract under the Framework Service Contract 89/PP/ENT/2011–LOT 3, 'European Earth Observation and Copernicus. Midstream Market Study', available at: https://www.copernicus.eu/sites/default/files/2018-10/Copernicus_Impact_on_Midstream_Sector.pdf [accessed 13/06/2019].

All the characteristics above assure that the Earth observation is a lively and changing domain. Nevertheless, quantitative description of the EO ecosystem as well as capturing its technology-fuelled transformation escapes the traditional statistics, and proves to be challenging.

2.4 Why TES methodology?

2.4.1 Gap in the measuring of the value of EO

The analysis conducted in the framework of the EOValue project (Pogorzelska 2018) provided an overview of the most prominent existing methodologies and approaches used to measure the value of EO.

The value of EO varies according to who values it and for what purpose; therefore there is no conclusive methodology that fits all the users and all the purposes. The analysis revealed a pool of various methodologies and approaches used by different actors at different levels of the EO value. Those methodologies were aggregated into three main clusters. The first cluster focused on capturing economic value of EO and gathers micro- and macroeconomic methodologies. The second one entered the discussion on EO value through the more interdisciplinary conceptual framework of the Value of Information (VOI). Since EO exhibits characteristics of an all-purpose infrastructure good, many admit that measuring EO value in a comprehensive and exhaustive way is impossible; therefore, the third cluster gathered methodologies concerned with maximisation of EO value through the enhancement of data infrastructure and through the open access to EO data. These three clusters are by no means exhaustive of exclusive and rather represent different perspectives or entry points to the ongoing discussion.

Thus, there is a variety of conceptual approaches targeting the issues of measuring in a qualitative and quantitative way the value of EO. The diversity in the pool of these methodologies is linked to the inherent heterogeneity and relativity of the notion of "value" at first place. While it is necessary to have different and fragmentary value propositions the need for a more comprehensive or cross-cutting approach has been voiced for a long time. The TES approach offers a rather unique opportunity for a micro-based landscape description allowing for a quantification of EO ecosystem-related metrics.

2.4.2 Filling the gap

Finding a more generic approach that provides a common reference for the fragmentary and diverse methodologies to measure the value of EO was a main motivation for the deployment of the EO TES. With EO TES we introduce the ecosystem mapping methodology in order to obtain a more comprehensive description of the EO domain.

The TES methodology allows identifying the key players in the EO ecosystem in Europe and worldwide, locating key clusters of activity, and identifying major linkages across the players. A collection of companies, inventors, research institutions, technologies, locations and other stakeholders enable to reflect to some extent the complexity of a mapped domain. This, in turn, allows for capturing interesting trends, relations and collaborations in a quantitative way. The outcome is a compelling characterisation of the key features of the very dynamic and complex ecosystem.

The EO TES is an analytical framework that provides for a common contextual layer that contributes to the better understanding of the EO value as calculated in the framework of different methodologies.

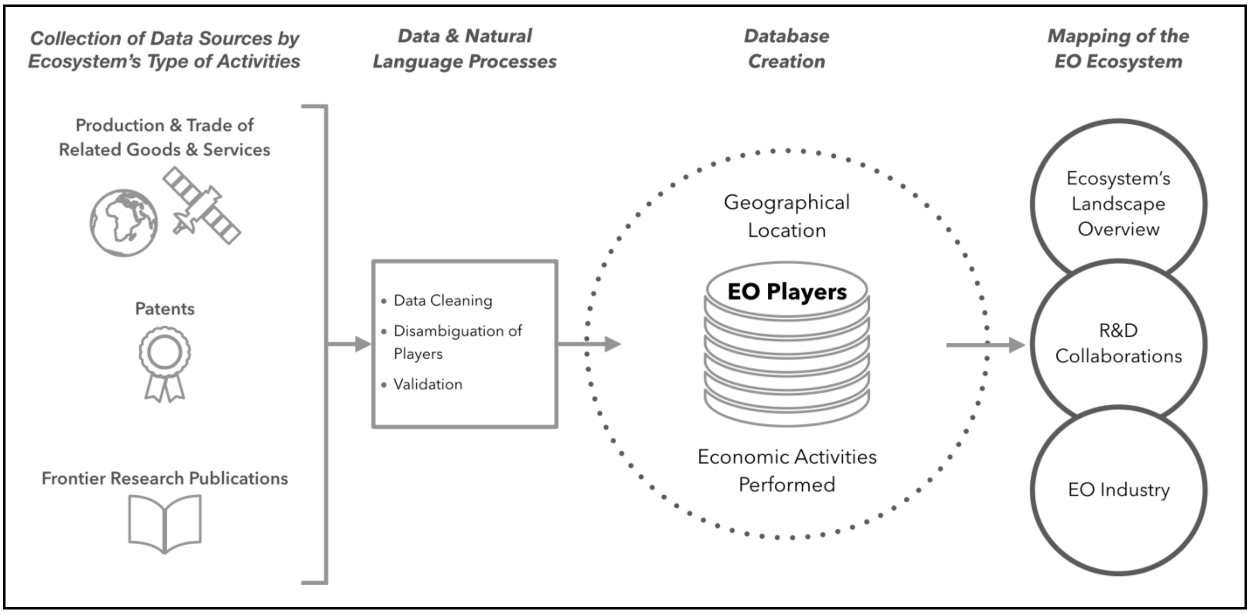
2.5 Description of the TES methodology as applied to EO

This subsection gives an overview of the EO TES workflow, including the data collection and treatment process employed in the analytical part of the report. The first part explains the generation of the database of players in the EO landscape; the second part describes how the data for the industry analysis is added.

2.5.1 EO TES methodology overview

Figure 1 presents the general workflow of TES analysis, which in this case has been adapted for the mapping of EO domain. Initially, data sources are identified in order to cover different activities: (i) the supply of EO goods and services indicates the main economic processes associated to market activities, (ii) the filing of patent applications is considered to capture technological inventions, and (iii) publications of frontier research address empirical and theoretical advancements, usually not yet in the stage of consolidated implementations.

Figure 1. EO TES workflow



Source: JRC EO TES, 2019.

The methodology first defines the boundaries of the EO TES, by detecting players active in the EO ecosystem. The participation in the EO ecosystem is captured through the analysis of the text describing the player's activities. Horizontal data sources, targeting all types of activities, are queried using a comprehensive dictionary of keywords covering the EO and geospatial domains in order to discern which players' activities are EO-specific.

The current version of the EO TES includes 32 data sources. The sources include the horizontal data sources that were queried with the EO keywords as well as EO-specific (vertical) sources. The coverage and scope of sources is detailed in . In this version of the report, the global analysis is based on the data sources presented in the excluding "EU Funded projects (FP7 + H2020)" and the analysis of EU28 is based on all data sources.

Table 2. EO TES data source list

Geographic coverage	*Source scope*	*Source type*	*Source name*
Global	EO specific	Frontier Research	14 Top EO journals + Conferences
Global	EO specific	Governing Bodies & Associations	GEO Group on Earth Observations
Global	EO specific	Market (Production & Trade)	Geospatial World Forum (Partners, Companies, Start-ups)
Global	EO specific	Market (Production & Trade)	Medium Corporation
Global	EO specific	Market (Production & Trade)	UN SPIDER (UN-OOSA) - Disaster Management and Emergency Response Network
Global	EO specific	Market (Production & Trade)	Voices Earth
Global	Horizontal	Market (Production & Trade)	Crunchbase
Global	Horizontal	Market (Production & Trade)	BvD Orbis
Global	Horizontal	Market (Venture Capital)	Venturesource by Dow Jones
Global	Horizontal	Patent	EPO PATSTAT
India	EO specific	Market (Production & Trade)	Analytics India Magazine
India	EO specific	Market (Production & Trade)	GIS in India
EU+	EO specific	Governing Bodies & Associations	European Association of Remote Sensing Laboratories - EARSEL (Members)
EU+	EO specific	Governing Bodies & Associations	Eurisy - Acting collectively to bridge space and society (Members and Partners)
EU+	EO specific	Market (Production & Trade)	European Association of Remote Sensing Companies (EARSC)
EU+	EO specific	Market (Production & Trade)	Geospatial Industry Ecosystem Survey (JRC) (Respondents and Partners)
EU+	Horizontal	EU funded	EU Funded projects (FP7 + H2020)
UK	EO specific	Market (Production & Trade)	British Association of Remote Sensing Companies (BARSC)

Source: JRC EO TES, 2019.

After the collection of data sources, a process of data cleaning is implemented before the data is ready for the analysis. The phases are multiple. First of all, all the documents in which there is no text information regarding activities associated to players are discarded. Players can be firms, government bodies, associations or research institutions. Hence, the set of collected documents (from all data sources), initially made of 39 874 units, is reduced to a set of 39 069 documents.

Then the process of disambiguation of players is performed, so as to identify if the same player is involved in multiple activities and to avoid duplications. Disambiguation is based on (i) the geographical location of players (players are geolocalised at city level by means of available information and, when this is missing, by collecting complementary information from the web or other sources) and (ii) algorithms measuring similarity of names (for example Jaccard algorithm of distance of standardised names) to target misspelled names and variations, finally groups of potential duplicated agents are identified by an algorithm working on network of similarities. 3 455 groups of agents are so detected in this first phase of disambiguation. A final manual overview to check against duplication cases allows the consolidation of the dataset. This phase leads to a reduction from 22 026 players initially detected to 18 367.

After this stage, documents are filtered based on the year to which they refer. As the scope of the analysis is to capture recent evolution of the EO techno-economic segment, we select the last 11 years as period of reference, i.e. from 2009 to 2019. This implies a reduction in the number of considered documents, from 39 069 to 36 648. It is important to mention that for many documents (in particular those addressing firms' descriptions) no date is available. When data sources provide information about economic activities currently existing, the year of reference is taken as the year in which the information is collected, assuming that the information was valid at least for that moment in time.

Finally, an additional step of manual disambiguation is implemented in order to control the most relevant players. This phase, combined with the previously described phase of time selection, causes the reduction of other 2 092 players. With this last stage the cleaning process is considered finished and the final data identified. Therefore, the EO TES 2009-2019 data is constituted of 16 275 players and 36 648 documents.

The information collected for each detected player is of two types: the geographic location at city level and the organisational type. Regarding the location, this information is collected through structured variables present in the documents, or via web scraping and integration from other sources. It is important to mention that the location is a determinant in defining the players. In fact, each player results from the combination of the detected economic institution and the city in which it is located. This implies that if the same economic institution is detected in multiple locations, it generates what are considered as multiple players. In this first overview of the EO landscape, such players are considered individually. In the next analytical phases of the project, the analysis will address also the connections between subsidiaries as well as business structures, ownership and control aspects.

The final distribution of players by macro area and organisational typology is presented in Table 3. It represents the final database for the analyses mainly addressing the ecosystem overview, the R&D collaborations and the EO industry.

Table 3. Distribution of EO players (2009-2019), by macroArea and organisational type

macroArea	F in the macroArea (% over Players in the macroArea)	G in the macroArea (% over Players in the macroArea)	O in the macroArea (% over Players in the macroArea)	R in the macroArea (% over Players in the macroArea)	N. of Players in the macroArea (% over TOTAL N. of Players)
Africa	32.2%	20.7%	3.8%	43.3%	3.5%
Canada	60.7%	4.5%	0.5%	34.4%	2.6%
China	56.3%	5.3%	0.0%	38.3%	19.9%
EU28	56.4%	3.7%	0.5%	39.4%	31.9%
India	69.0%	2.1%	0.0%	28.9%	6.0%
Japan	50.3%	5.4%	0.6%	43.8%	2.2%
Middle East	36.1%	2.6%	0.5%	60.8%	2.3%
Oceania	57.2%	7.3%	0.5%	35.0%	2.3%
Other American countries	31.3%	7.8%	1.1%	59.8%	4.1%
Other Asian countries	40.7%	12.0%	0.7%	46.7%	3.7%
Other European countries	52.9%	4.2%	0.4%	42.5%	4.3%
South Korea	61.3%	1.9%	0.0%	36.8%	2.2%
US	62.5%	3.7%	0.6%	33.2%	15.0%
TOTAL	***55.1%***	***5.1%***	***0.5%***	***39.3%***	***100.0%***

F = Firms, G = Government, O = Other, R = Research

Source: JRC EO TES, 2019.

2.5.2 Methodology used in the EO industry analysis

The analysis addressing the industrial side of EO requires another step in the data preparation process: firm players detected in EO TES are matched with the Bureau van Dijk Orbis database in order to access company level information. Bureau van Dijk compiles this Orbis firm level data from administrative data. An advantage of this database compared to its competitors is the inclusion of data of non-listed companies and therefore a better representation of smaller companies. For Europe the database covers around 75-80% of the economy compared to Eurostat figures and matches the official firm size distribution (Kalemli-Ozcan et al., 2015). A drawback is that for countries with fewer regulatory requirements the data is less representative. Nevertheless, the database is widely applied in academic literature and regarded as the most reliable source to study questions from productivity, innovation to knowledge spillovers worldwide.

After the process of data collection (in which Orbis is also considered) and players' disambiguation, the players resulting to be active in the EO TES 2009-2019 are then searched in Orbis.

The distribution of firms, by patenting class and macro area is presented in Table 4 for all firms originally detected in the data collection. The patenting classes are the following: 0 indicates all the firms for which no patent has been detected; 1 for the firms that filed 1 patent; 2-5 for the firms filing from 2 to 5 patents; 6+ for the firms filing 6 or more patents. The left side of the table shows the distribution of firms, for which firm level data from Orbis was added to the dataset. While the right sight shows the distribution of firms, which were not found in the Orbis database.

Table 4. Number of Firms, per macro area and patenting class (categories)

	Firms Detected in Orbis					**Firms NOT Detected in Orbis**				
	0	*1*	*2-5*	*6+*	***Sub Total***	*0*	*1*	*2-5*	*6+*	***Sub Total***
Africa	*92.59%*	*7.41%*	*0.00%*	*0.00%*	***1.99%***	*88.35%*	*8.74%*	*2.91%*	*0.00%*	***2.15%***
Canada	*92.62%*	*5.37%*	*2.01%*	*0.00%*	***3.66%***	*96.08%*	*3.92%*	*0.00%*	*0.00%*	***2.13%***
China	*28.31%*	*49.74%*	*17.99%*	*3.97%*	***9.28%***	*17.30%*	*66.71%*	*14.81%*	*1.18%*	***30.17%***
EU28	*93.84%*	*4.33%*	*1.70%*	*0.13%*	***39.07%***	*96.14%*	*3.40%*	*0.46%*	*0.00%*	***27.06%***
India	*96.77%*	*2.58%*	*0.65%*	*0.00%*	***3.80%***	*96.88%*	*2.93%*	*0.20%*	*0.00%*	***10.69%***
Japan	*53.91%*	*27.83%*	*10.43%*	*7.83%*	***2.82%***	*43.33%*	*35.00%*	*21.67%*	*0.00%*	***1.25%***
Middle East	*90.14%*	*8.45%*	*1.41%*	*0.00%*	***1.74%***	*95.45%*	*3.03%*	*1.52%*	*0.00%*	***1.38%***
Oceania	*92.86%*	*2.68%*	*4.46%*	*0.00%*	***2.75%***	*96.91%*	*3.09%*	*0.00%*	*0.00%*	***2.03%***
Other American countries	*83.53%*	*11.76%*	*4.71%*	*0.00%*	***2.09%***	*94.21%*	*4.96%*	*0.83%*	*0.00%*	***2.53%***
Other Asian countries	*63.13%*	*25.00%*	*10.63%*	*1.25%*	***3.93%***	*81.61%*	*17.24%*	*1.15%*	*0.00%*	***1.82%***
Other European countries	*92.77%*	*6.02%*	*1.20%*	*0.00%*	***6.11%***	*74.79%*	*21.85%*	*3.36%*	*0.00%*	***2.48%***
South Korea	*14.81%*	*61.73%*	*19.14%*	*4.32%*	***3.98%***	*22.41%*	*63.79%*	*12.07%*	*1.72%*	***1.21%***
US	*81.98%*	*13.05%*	*3.79%*	*1.17%*	***18.80%***	*81.19%*	*15.63%*	*2.63%*	*0.55%*	***15.10%***
Total					***100%***					***100%***

Source: JRC EO TES, 2019.

In each cell, the percentage of firms belonging to the corresponding patenting class over the number of firms in the macro area is computed. The *Subtotal* indicates the percentage of firms detected in that macro area over the total number of firms detected in EO TES. It can be seen that Indian and Chinese EO firms are the most underrepresented in the Orbis dataset, while South Korean and Japanese firms have disproportionately often been found in the Orbis database. Even if the subset of firms with an Orbis ID is not a random sample from the target population of companies, nearly 50% of the firms from the EO TES database were detected.

In order to analyse the information contained in Orbis, we compute a weight for the firms for which we have an Orbis profile to correct for the over or under representation as shown in Table 4. These weights, which are elaborated by accounting for specific known totals regarding the whole set of EO firms detected by TES (which are supposed to extensively cover the firms active in EO) allow us to draw conclusion for the whole set of TES EO firms. This procedure, typical of survey analysis, is here implemented in order to fill the informational gap determined by the fact that not all the firms have been detected in the Orbis database.

The implementation of the algorithm of post-stratification allows us to just reweight the obtained observations based on two variables. The first one, i.e. number of firms per geographic area, permits to account for possible biases in Orbis due to the geographic location of the firms. The second one, i.e. patenting classes, is here intended as a proxy of firms' performance and therefore permits to account for possible biases in Orbis regarding the relevance of the firms. The distribution, by macro area and patenting class, of the firms for which no Orbis profile is detected and for the firms for which the EO profile has been detected, is reported in Table 4. In this table it is possible to observe that the two subsets are not unbalanced. Nevertheless, the post-stratification weight procedure allows better estimation of the economic variables that are present in the Orbis dataset.

In order to assess in which part of the value chain the detected players are mainly contributing, we elaborate a variable assessing the content of the activities performed by players. Initially, the query terms used to identify economic activities belonging to EO are grouped in three subsets, depending on which part of the value chain the considered query term refers for the most. The defined subsets of query terms are the following:

- **upstream** query terms subset includes *advanced very high resolution radiometer*, *alos AND satellite*, *aster AND satellite*, *enhanced thematic mapper*, *eros AND satellite*, *fiber optic sensor AND satellite*, *geoeye AND satellite*, *ikonos AND satellite*, *imaging sensor*, *imaging spectroscopy*, *insar AND radar OR technique*, *interferometric synthetic aperture radar*, *landsat*, *lidar AND satellite*, *light detection and ranging*, *moderate resolution imaging spectroradiometer*, *modis AND satellite*, *ndvi AND index*, *noaa AND satellite OR sensor OR imagery*, *photodetector AND satellite*, *remote sensing*, *satellite imagery*, *spot AND satellite*, *surface plasmon resonance imaging AND sensor*, *synthetic aperture radar*, *thematic mapper AND sensor*

- **downstream** query terms subset includes *continuous raster*, *delaunay triangulation AND gis, digital elevation mode, digital line graph, digital surface model, digital terrain model, geodesy, geodetic measurement, geographic imagery, geographic information system, georeferencing, geospatial, gis application, gis software, global earth observation system of systems, spatial data*

- horizontal query terms subset includes *copernicus programme*, *earth observation*, *eo market*, *full db*, *weather forecast.*

As each detected document can contain one or more of these query terms, and as each player can be associated to more documents, the result is that each player can be associated to more than one of the listed subsets. In order to cope with this situation and univocally assign the players to only one specific position of the value chain, the following rules are implemented:

- if the player is associated to query terms of the groups ***upstream*** and ***horizontal***, then it is considered as an ***upstream player***;

- if the player is associated to query terms of the groups ***downstream*** and ***horizontal***, then it is considered as an ***downstream player;***

- if the player is associated to query terms of the groups ***upstream*** and ***downstream***, it is considered as an ***upAndDownStream player;***

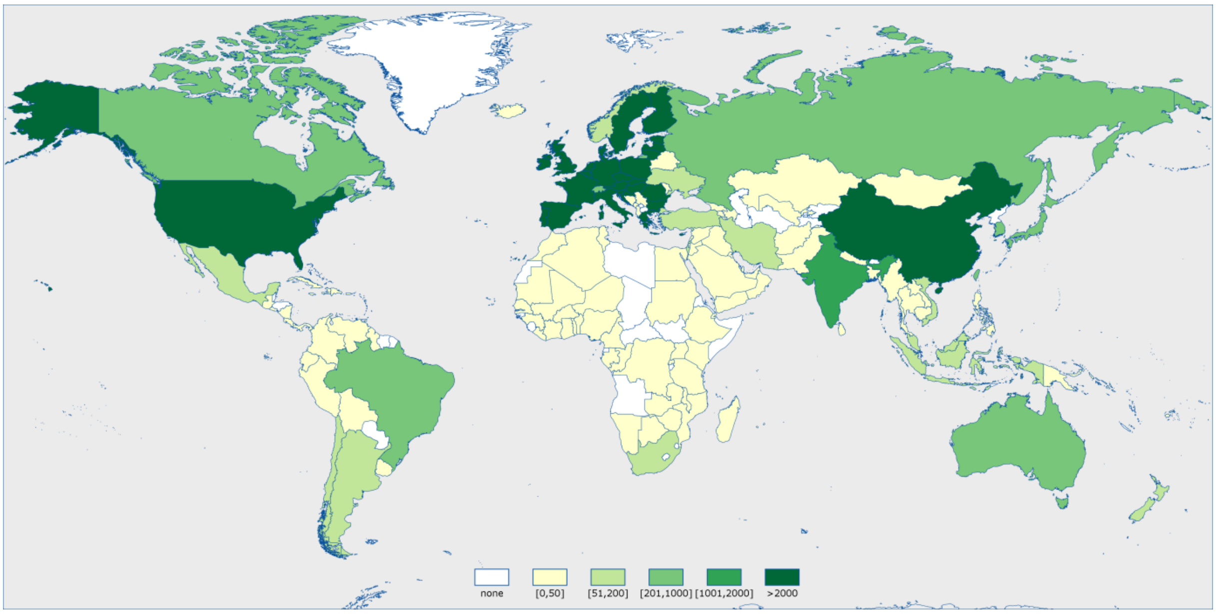
- if the player is exclusively associated to query terms of the groups ***horizontal***, it is considered as an ***horizontal player***.

The rationale of this categorisation is related to the association of specific technological subjects (represented by the query terms) to different position of the value chain. Although this categorisation is exclusively based on the use (or not) of certain query terms by firms, it is able to provide initial elements for the investigation of the EO value chain.

3 The TES EO landscape

3.1 Global EO landscape

Figure 2. Global distribution of EO players



Source: JRC EO TES DATASET 2019.

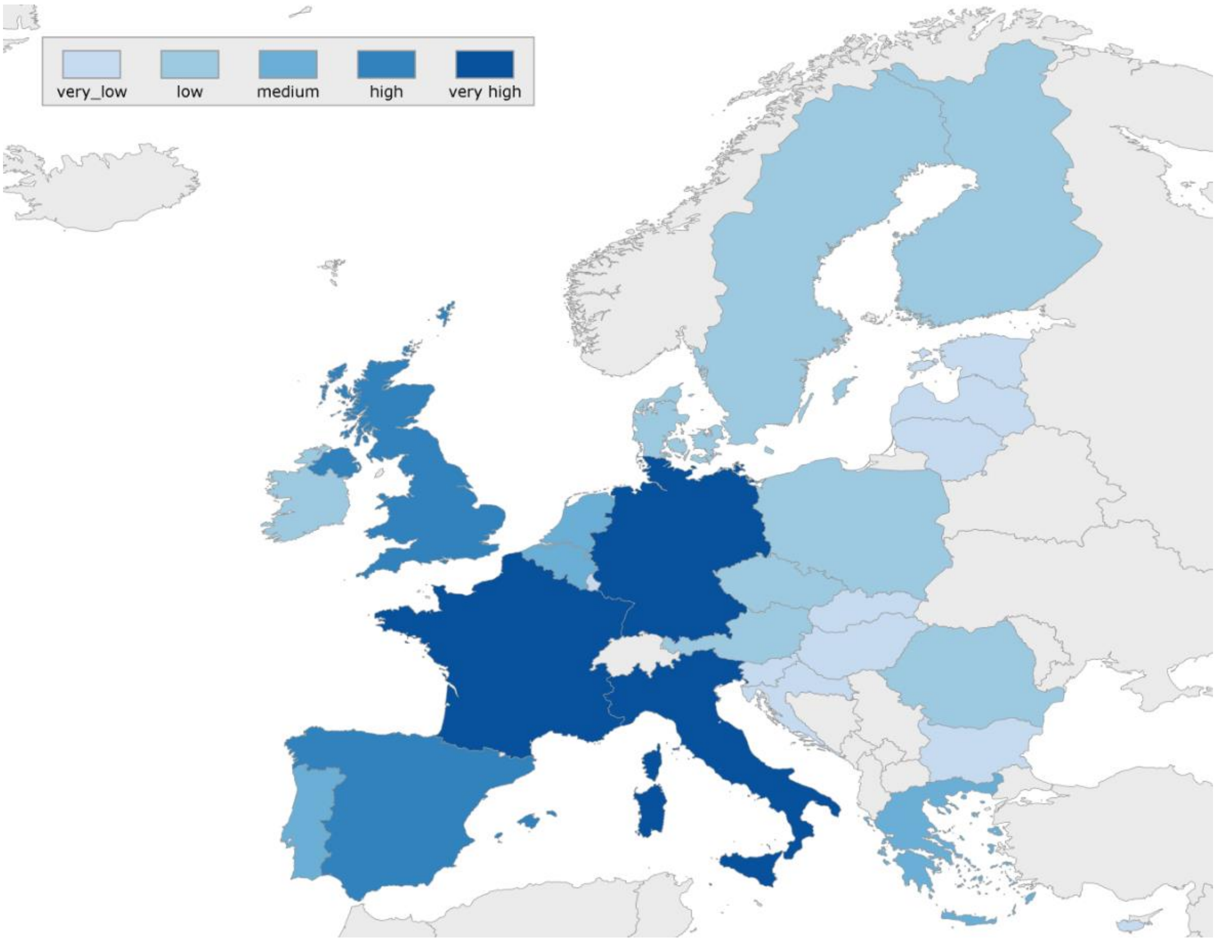
The map presents a global distribution of EO players as detected by EO TES.

The three regions with the higher concentration of players are the United States, China and the EU (aggregated number of players of the EU28 Members). India takes precedence before the third tier countries, i.e. Canada, Brazil, Switzerland, Russia, Japan, South Korea, Taiwan and Australia. Next tier of countries include Mexico, Chile, Argentina, South Africa, Norway, Ukraine, Turkey, Israel, Iran, Indonesia, Vietnam and New Zealand. Then follow the remaining countries of South America, remaining non-EU European countries, Africa, Middle East, Central Asia and South-East Asia. It is highly probable that the countries that appear with no EO players, namely Libya, Chad or Angola, do have companies and public institutions using EO data. However, those entities would not appear on the map if they are not in the targeted databases of companies or/and do not take part in R&D activities. Public institutions, on the other hand, would not appear on the map if they use EO-based solutions developed by entities from other countries or/and do not take part in R&D activities.

3.2 European EO landscape

3.2.1 Distribution of EO players in the EU

Figure 3. Distribution of EO players in the EU



Source: JRC EO TES DATASET 2019.

The map (Figure 3) represents the distribution of number of EO players in the EU28. The foremost countries in the EU are France, Italy and Germany. The UK follows closely and Spain closes the group of the five leading countries. The high positions of these five countries do not come as a surprise. They are the biggest EU countries in terms of the population and biggest EU economies. Moreover, all of them have long established positions in the space sector.

Table 5. Number of EO players by EU country

Country	Number of players
France	934
Italy	813
Germany	806
United Kingdom	693
Spain	505
Netherlands	308
Belgium	206

Portugal	171
Greece	162
Poland	144
Sweden	131
Austria	120
Finland	109
Czechia	94
Romania	76
Denmark	66
Ireland	57
Hungary	47
Bulgaria	40
Croatia	35
Slovenia	33
Estonia	30
Luxembourg	26
Cyprus	23
Slovakia	23
Lithuania	17
Latvia	15
Malta	9

Source: JRC EO TES DATASET 2019.

Although our definition of EO is wider than the space sector alone, it is clear that this sector plays ever prominent role in EO which partly explains the results shown. The leading role of France and Italy in the space industry has its long history. Italy was the first European country outside the two-party space club, namely Russia and the US, which launched an in-house built satellite using the US launching vehicle (1964). One year later France, as a third country in the world, proved operational its own launching system by placing in orbit Astérix satellite. As for Germany, its research on the rocketry systems before and during the Second World War highly advanced the space exploration. The defeat of Germany (and migration of its scientists to other countries, mainly to the US as part of Operation Paperclip) was probably the sole reason why Germany was not a main space power already in the early space race. Nevertheless, even if not at the front lines, Germany has been developing its own space capabilities well embedded in the wider economic and scientific context. As far as the UK is considered, its first satellite programme started in 1959, with the Ariel series of British satellites, built in cooperation with the U.S. and launched using American rockets. The first British satellite, Ariel 1, was launched in 1962. The British space programme has always stressed unmanned space research and commercial initiatives. Later, also Spain joined the space-faring states. It launched its first satellite in 1974. In 1975 all five countries became founder members of the European Space Agency (ESA), along with the Netherlands, Belgium, Sweden, Denmark and Switzerland.

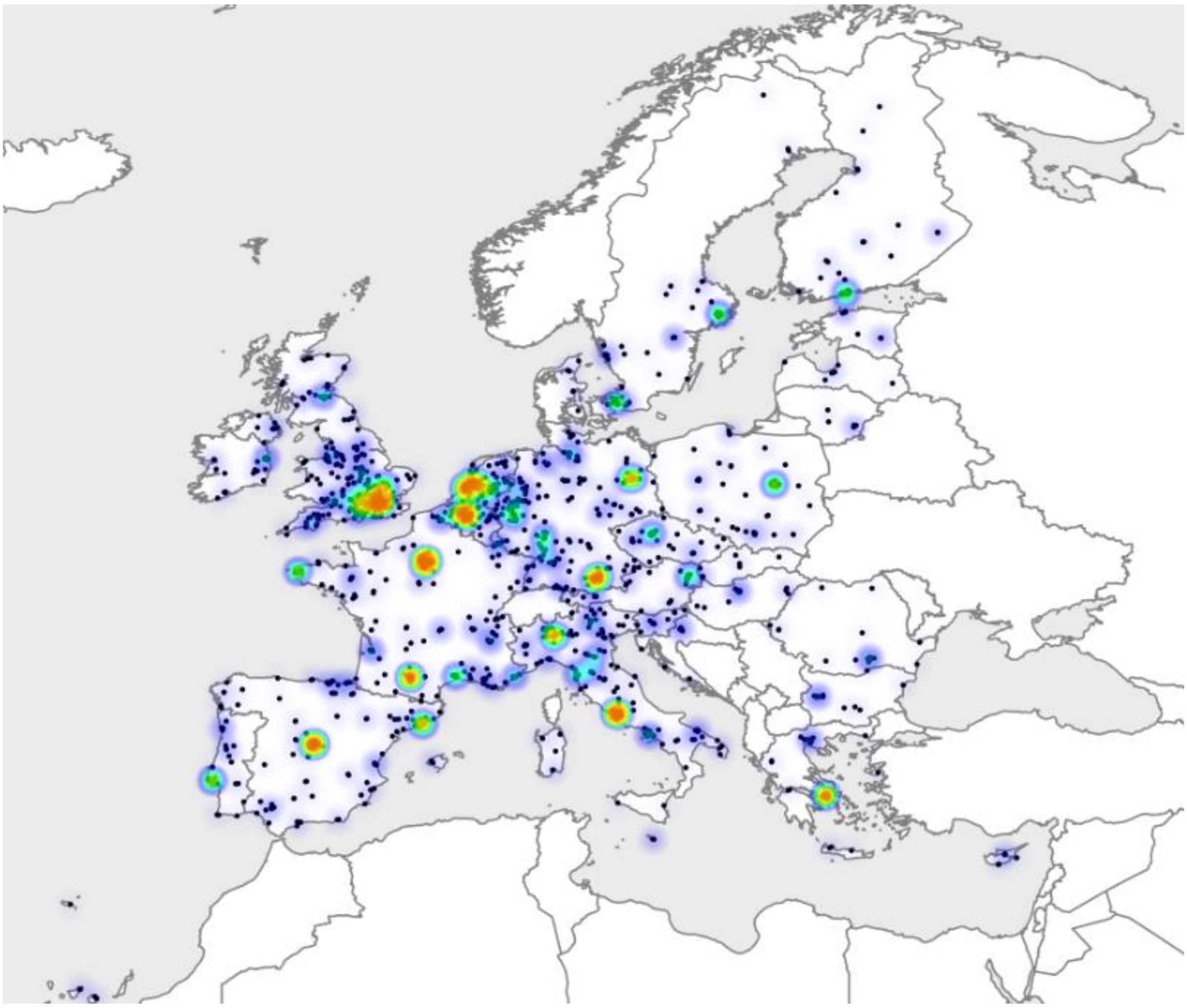
Netherlands, Belgium and Portugal appear within the range of the countries with the medium number of the EO players. The Netherlands may seem to score exceptionally well given the size of the country. However, the high position on the list is linked to the big size of Dutch economy and the rank is well aligned with it.[7] High position of Netherlands and Belgium can also be at least partially explained by the fact that both

[7] https://www.heritage.org/index/country/netherlands

countries were the founding members of the ESA, which gave impetus to the sector bringing new opportunities to the national institutions and companies. As far as Portuguese space sector is considered, joining ESA was a determinant factor for a dynamic and competitive, albeit small, industrial and technological sector to flourish. [8] In general, the EU countries have and still are benefiting from the high degree of internationalisation derived from the pan-European effort of the ESA and EU space programmes, such as Copernicus and Galileo.

3.2.2 EO hotspots in the EU

Figure 4. EU EO hotspots



Source: JRC EO TES DATASET 2019.

The map pictures the centres of high concentration of the EO players. The hotspots are scattered across the EU with the central part of the EU enjoying the highest concentration. In particular, the EO players concentrate in the triangle drawn by London, Amsterdam and Paris.

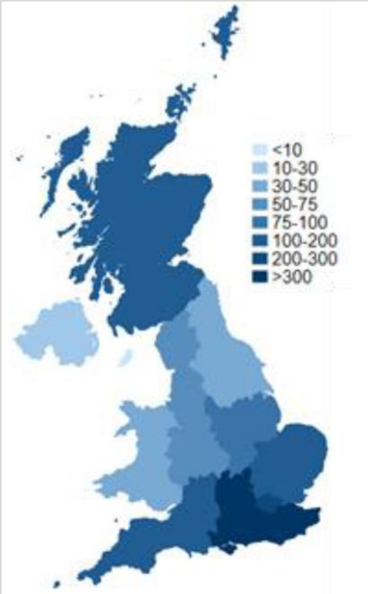
The detected hotspots are still tightly linked to the presence of space industry. Yet this relation is expected to change. The biggest of the hotspots is located in the South East England and London area in the UK. The case of the South East England and London

[8] https://www.fct.pt/apoios/cooptrans/espaco/sectorespacial.phtml.en, https://www.portugal.gov.pt/download-ficheiros/ficheiro.aspx?v=4d3e830a-a0ca-4c83-b65b-c091fc9f8415

being the biggest concertation of the EO players in the UK is aligned with the results of the London Economics (LE) Report to the UK Space Agency (UKSA) (2019).[9]

Box 1. UK space organisation population by region, 2016/17 (source: The LE Report for the UKSA)

Region	Number of organisations
South East	368
London	218
South West	173
East of England	146
Scotland	132
East Midlands	83
North West	75
West Midlands	74
Wales	47
Yorkshire and the Humber	44
North East	34
Northern Ireland	26
Crown Dependencies	4
TOTAL	**1424**



The UK space industry is dominated by large organisations, with just 13 organisations accounting for 83% of total space-related income in the industry and 935 (distinct) organisations accounting for just 17% (948 in total). This total number differs from the total above because, above every site of an organisation was counted as separate (for example Airbus has more than 25 sites).

Although the scope of the LE Report differs from the EO TES, the alignment contributes to the validation of the EO TES due to the dynamics between space sector and Earth observation described in the sections above. Again, the results of the LE Report are not surprising because the southern part of England is more industrialised than the northern part. Nevertheless, the EO TES did capture a hotspot in the area of Edinburgh. The LE Report confirms the high rank of Scotland on the list of the regions with high number of space industry organisations.

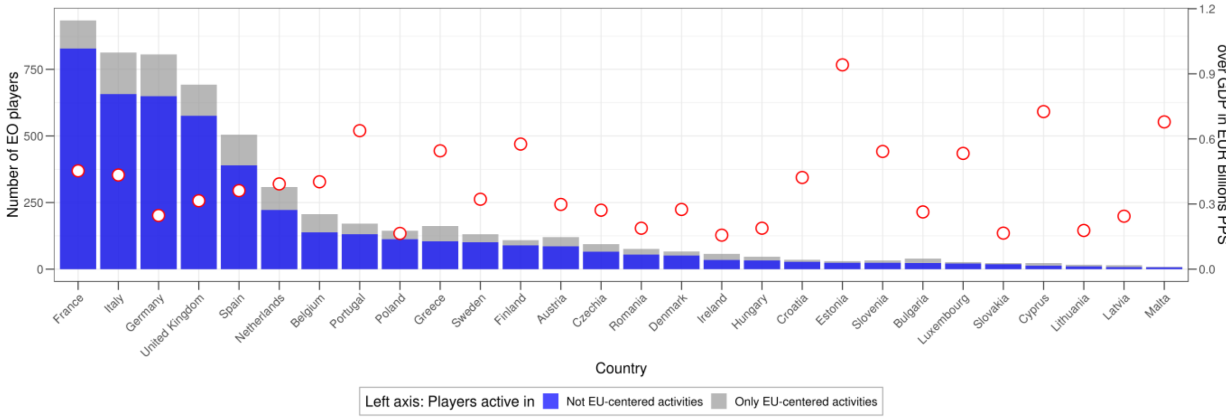
The main hotspots in France are located in Paris, Toulouse, Montpellier, Brest, Cannes and Bordeaux. Among those Paris ranks first. In Paris we find the headquarters of the ESA, CNES, Thales Alenia Space site, Airbus, Geosystems, Sodern/Ariane group and many others. Concentration of big players gives boost to the development in the space sector and in the EO domain in particular. In Toulouse we find a main office of Airbus and its main production plant. Also there ESA has established its Business Incubation Centre (BIC) that helps to build market around EO data. In Montpellier we find the ESA BIC and the Centre Spatial at the University of Montpellier. In Brest, Cannes, Bordeaux ESA has also established its BIC centres, which is an indicator of the increased engagement of city/region in the space and EO-related activities.

The big hotspot located in the Netherlands is not so much driven by the space sector but by a combination of different factors including high performance of the country in the intersection of the economics, technology and innovation.

[9] http://www.barsc.org.uk/wp-content/uploads/2019/02/LE-SHUKSI_2018-SUMMARY_REPORT-FINAL-Issue4-S2C250119.pdf

3.2.3 EO players and size of economies

Figure 5. Intensity of EO players



Source: JRC EO TES DATASET 2019.

Figure 5 conveys twofold information: the absolute number of EO Players in each of the EU28 countries and how this number relates to the size of their economy. Bars represent number of players. The grey part of a bar indicates a number of players who appear *only* in the EU funded projects such as FP7, H2020, otherwise it is captured in the blue part of a bar.

The question of the absolute number of EO players in the EU countries (the height of the bars in this case) has already been discussed in section 3.2.1. Apart from the absolute number of EO players the graph communicates how well a country performs when the number of its players is compared to the size of its economy. This information is represented by the red circles indicating a number of players divided by the GDP (relative number of players).

The widest gap between the absolute and relative numbers is visible in case of Estonia. While Estonia scores low in the absolute number of EO players the number of players is still disproportionately high when compared with the size of its economy. As digital economy is often argued to be fuelled by big data, the number of players in the EO ecosystem may reflect the level of innovation or priority given to the innovative technologies and solutions. The case of Estonia is a good example of a small but highly innovative economy.

Other countries with low absolute numbers and high relative numbers are Luxembourg, Slovenia, Cyprus and Malta. Portugal, Greece and Finland, in comparison, have higher absolute numbers of EO players but still the gap between them and relative values is well pronounced.

In two cases (Poland and the Netherlands) the country’s absolute and relative values are well aligned.

Germany holds a high third rank in the absolute number of EO players; however, it scores quite low in the relative number.

4 R&D in the EO domain

The subsections below discuss aspects that relate to innovation in the EO domain. They focus on the R&D activities undertook by the EO players. The R&D activities consist of EO-related patents, publications in the top EO-related journals (frontier research) and in a selection of specialised conferences. In case when analysis focuses solely on the EU, the participation in European Programmes is also included (data source "EU Funded projects (FP7 + H2020)").

4.1 Global EO R&D

The three most active macroregions in the field of EO research and development are China, EU28 and the US.

Figure 6. EO TES hubs in the global R&D network

Source: JRC EO TES DATASET 2019.

The graph above represents research and development activities in the EO domain aggregated to the level of macro areas. The orange dots represent the number of R&D activities in the EO domain, namely patents and publications. The blue lines indicate the intensity of collaboration between the macroregions. Collaboration in our understanding means the involvement of more than one player in the same activity, so in this case the result of co-patenting and co-publishing.

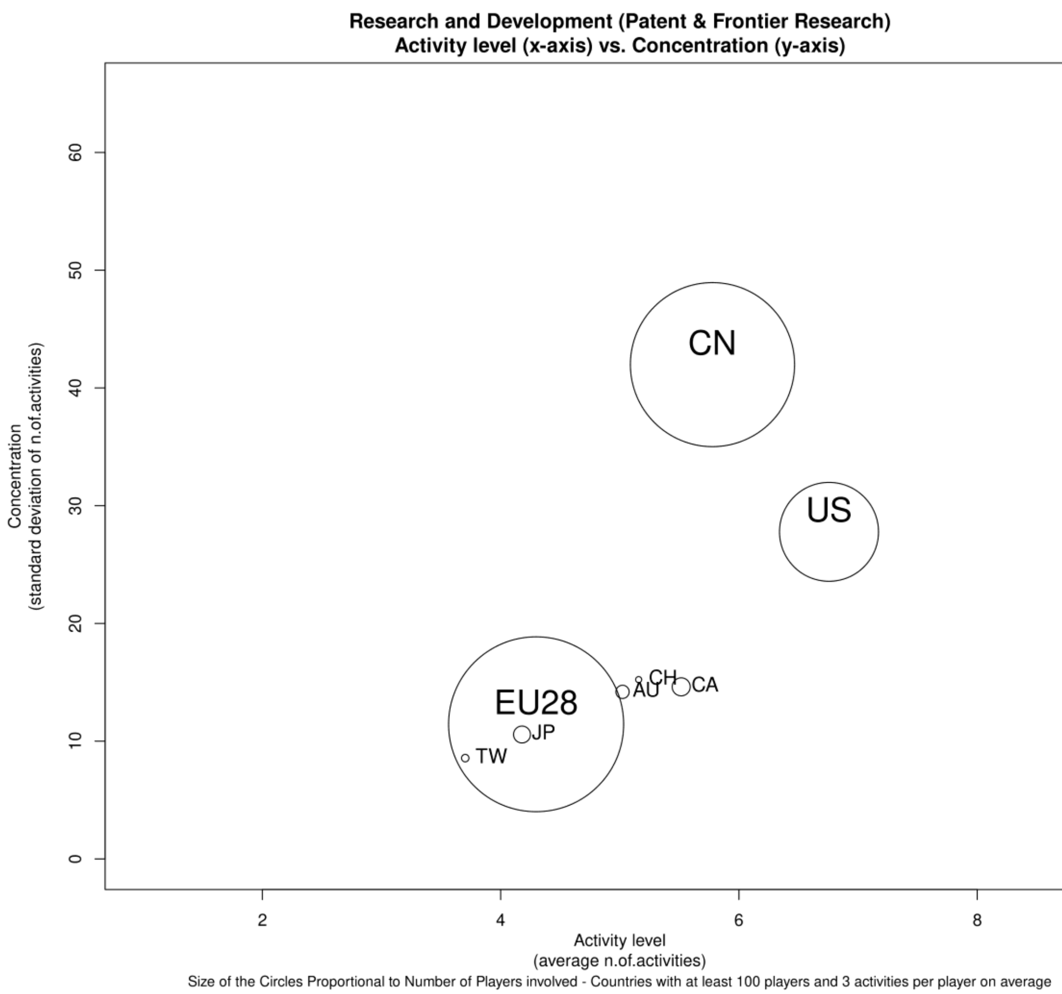
Tracking relations among players allows gaining insights on where the most influential areas (or players) are situated. The graph above confirms that the most influential countries/regions in the global EO R&D are China, EU28 ant the US. The numbers of activities related to those three macroregions outdistance the ten remaining ones.

The interesting part is to see the intensity of collaboration among these three macroregions and with the less active ones. The strongest collaboration in the EO R&D has been developed between EU28 and the US. Second strongest collaboration is between the US and China, and third one between the EU and China. The US is the biggest partner for both the EU28 and China.

4.1.1 Excellence in worldwide research and its network of collaboration

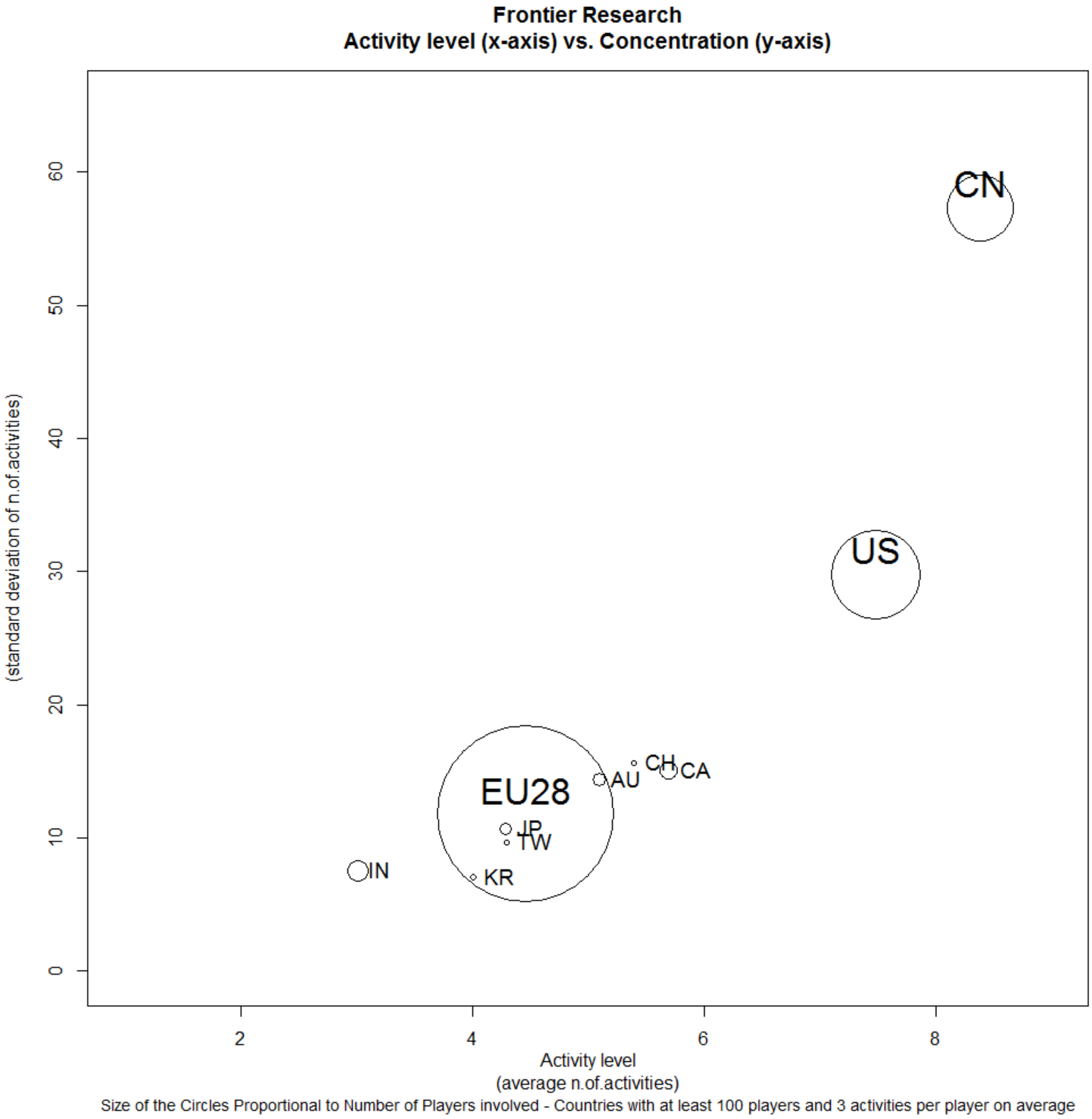
The distribution of EO activities and concentration of those activities look quite different in the three leading macro areas, which is illustrated by the following figures.

Figure 7. Activity level and concentration in R&D



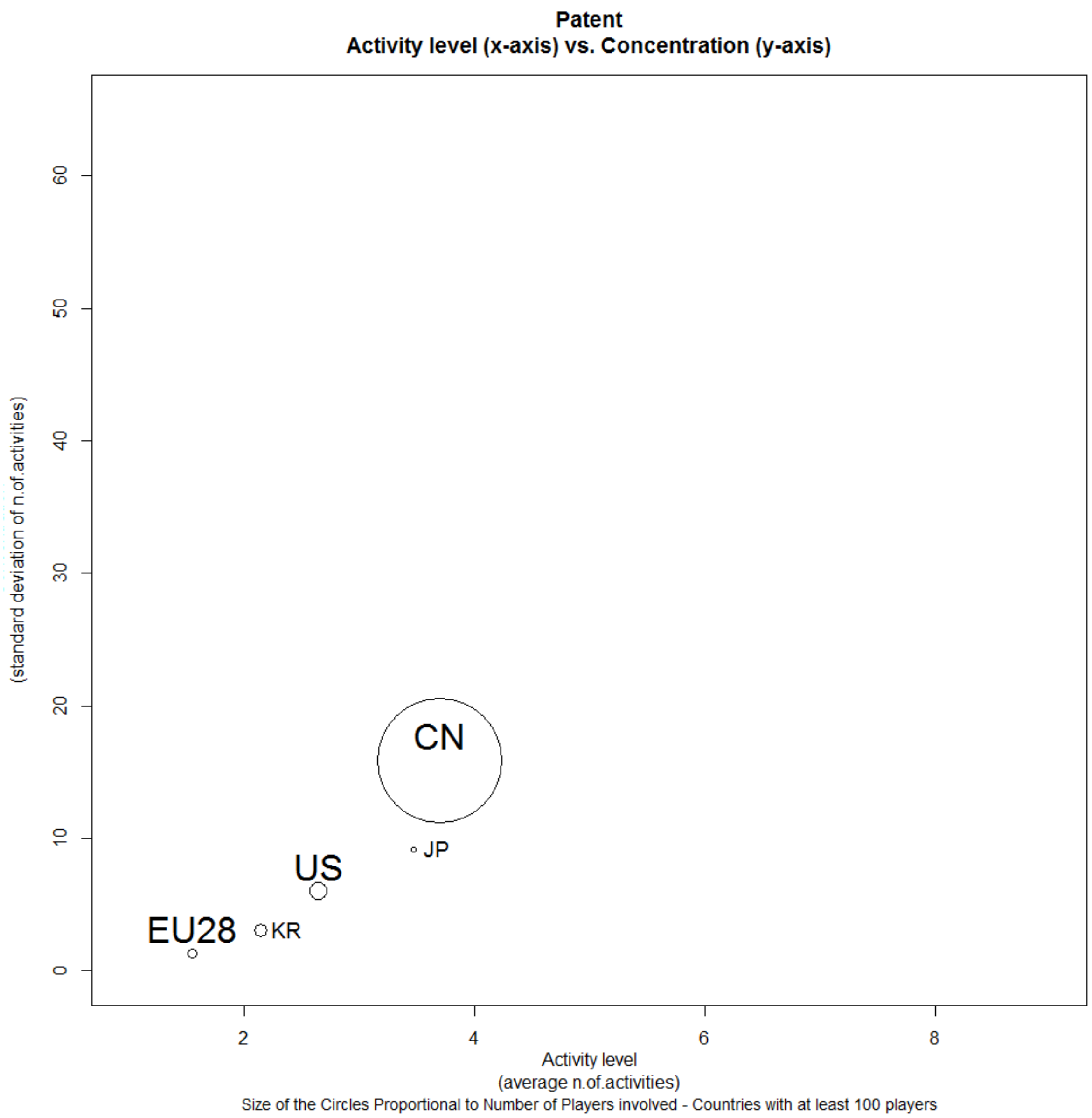
Source: JRC EO TES DATASET 2019.

Figure 8. Activity level and concentration in Frontier Research



Source: JRC EO TES DATASET 2019.

Figure 9. Activity level and concentration in patents



Source: JRC EO TES DATASET 2019.

Figure 7 illustrates the distribution of all R&D activities among players. Figure 8 takes into account only publications in the top EO journals and Figure 9 the patents. The distribution in all the graphs is expressed as an average number of activities per player (axis X) and as a standard deviation in number of activities (axis Y). The size of the circles corresponds to the number of players involved. Only countries/regions with at least 100 players are taken into account.

While China comes as first in terms of the number of EO-related R&D activities (Figure 6), it is the EU28 that has the highest number of players when all the types of R&D are taken into account (Figure 7). EU28 also has the highest number of players involved in the Frontier Research (Figure 8) but it scores quite low if only the patens are taken into account (Figure 9). Given the high number of EO activities, the EU presents relatively low average number of activities per player and very low concentration of activities leading to the conclusion that the democratisation of the EO activities is the highest in the EU28.

Out of the three big players, the US has the smallest number of players involved in the overall EO R&D and only slightly more players than China in case of Frontier Research.

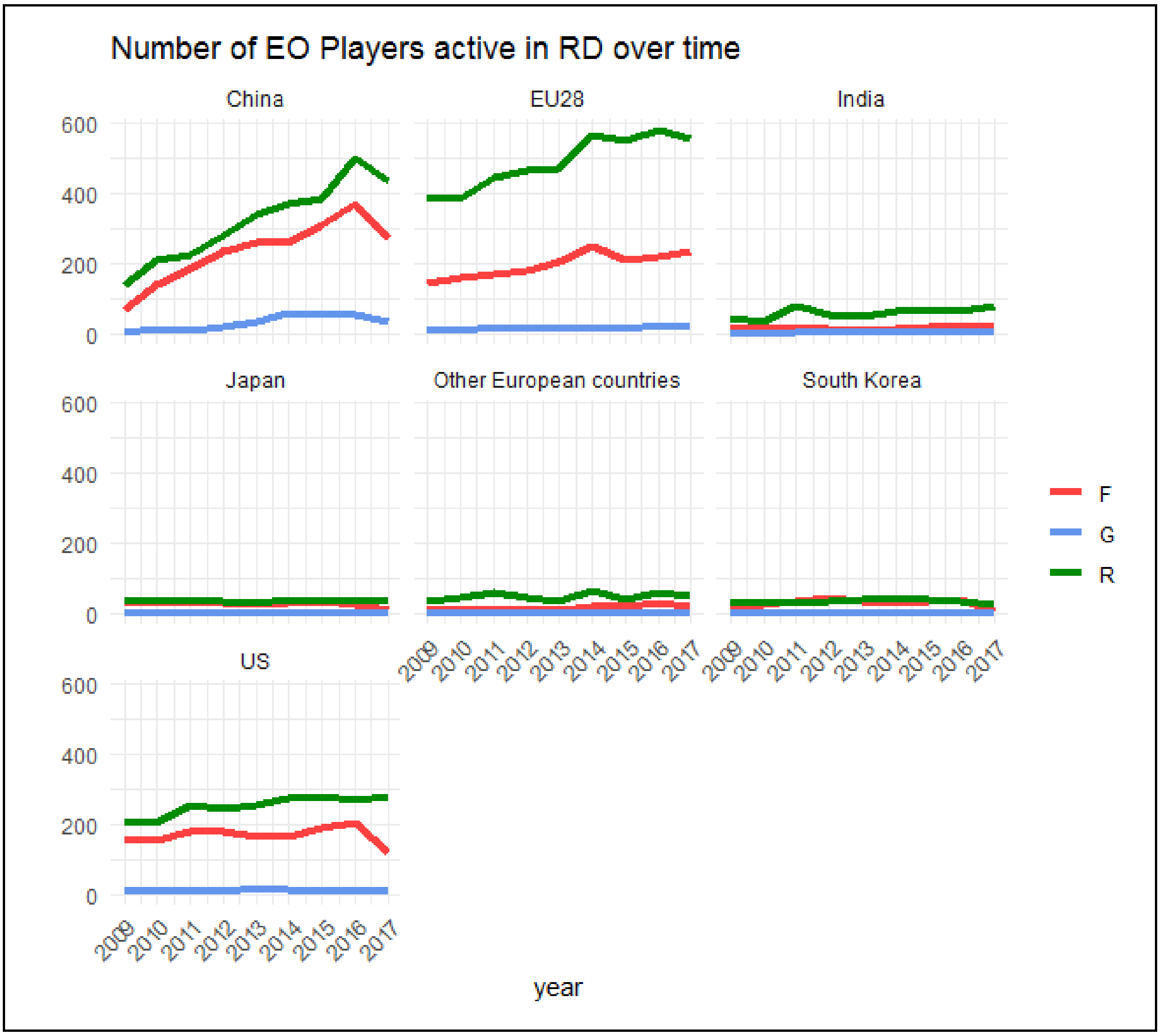
The R&D activities in the US concentrate in the hands of a smaller number of players than in the case of the EU.

China's position in all the figures differs the most. In all cases, China scores highest in terms of standard deviation. China's standard deviation rises sharply in Figure 8 with the number of players falling significantly. It indicates that few players are involved in the Frontier Research and that distribution among them is highly unequal.

As far as patenting activity is concerned, Figure 9 shows that China has not only the biggest number of players engaged in the patenting but also the highest average number of patents by a player and highest standard deviation of the number of patents. It indicates high concentration in hands of relatively few players.

The number of EO players engaged in the EO activity differs depending on the type of the organisation.

Figure 10. Number of EO players (by type) involved in R&D activities (EU projects excluded) over time (2009-2017)



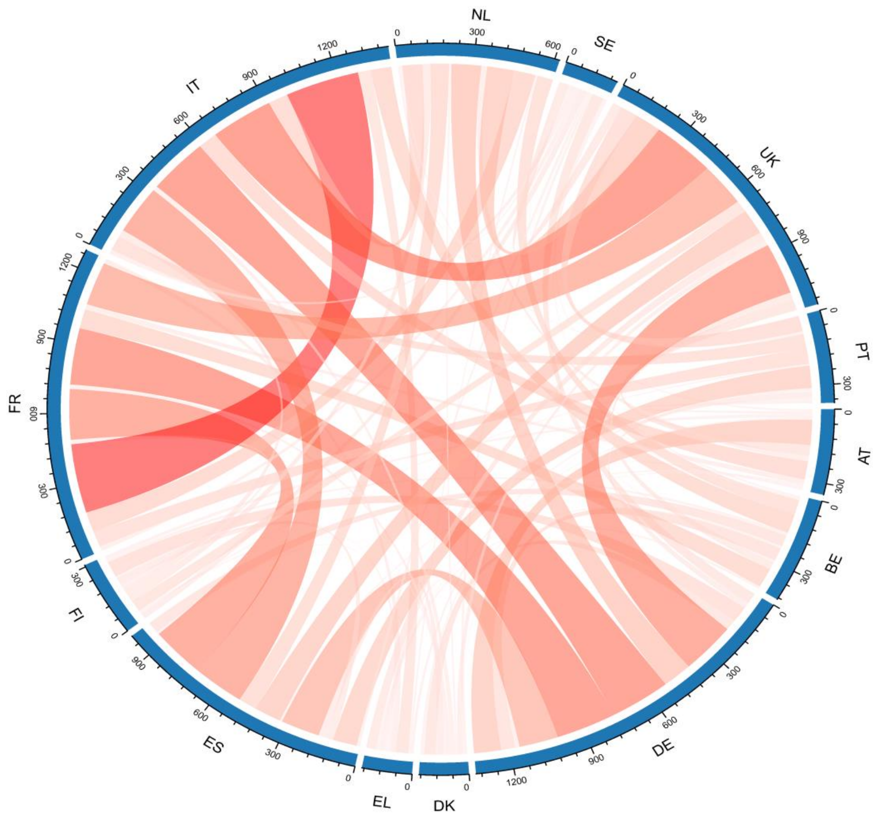
F = Firms, G = Government, R = Research

Source: JRC EO TES DATASET 2019.

Figure 10 represents the evolution of the number of firms, government and research institutions involved in EO R&D activities over time. As expected, in all the plotted macro areas, the major role is played by research institutes. However, different patterns emerge. In particular, while the number of active research institutes couples with the number of active firms both in the US and in China (for all the period considered), this discrepancy is larger in the EU28. It is also relevant to observe that while the number of EO R&D players from the US is constant over time, an increase is observable both for the EU28 and China, with the latter registering a larger positive variation.

4.2 European collaboration in EO R&D

Figure 11. Collaborative R&D network



Source: JRC EO TES DATASET 2019.

The figure above illustrates collaboration among the top 13 EU countries in EO R&D. As previously stated, collaboration in R&D is defined as co-patenting and co-publishing. Both, the width and saturation of lines relates to the number of collaborations. The most collaborative countries according to the number of collaborations are Italy, Germany, France, the UK and Spain. Overall, the most pronounced collaboration is noticed between France and Italy and then between France and Germany, Italy and Germany, and Italy and the UK.

As it can be seen, Italy is the most collaborative country. It maintains strong relations with the other big players, namely France, Germany, the UK and Spain, and probably strategic collaboration with Belgium. Its collaboration with other countries' players is distinctively smaller. Unlike Italy, Germany seems to be collaborating more with smaller neighbouring players. In this case, its collaboration with the Netherlands and Austria is quite notable. France also seems to prefer big players plus the strategic cooperation with Belgium. Italy and France are Belgium's strongest partners.

The UK clearly prefers collaborations with Italy closely followed by Germany. Cooperation with France is less established, even if France occupies a third position as a UK's partner. The UK also quite strongly collaborates with Netherlands, Spain and Portugal.

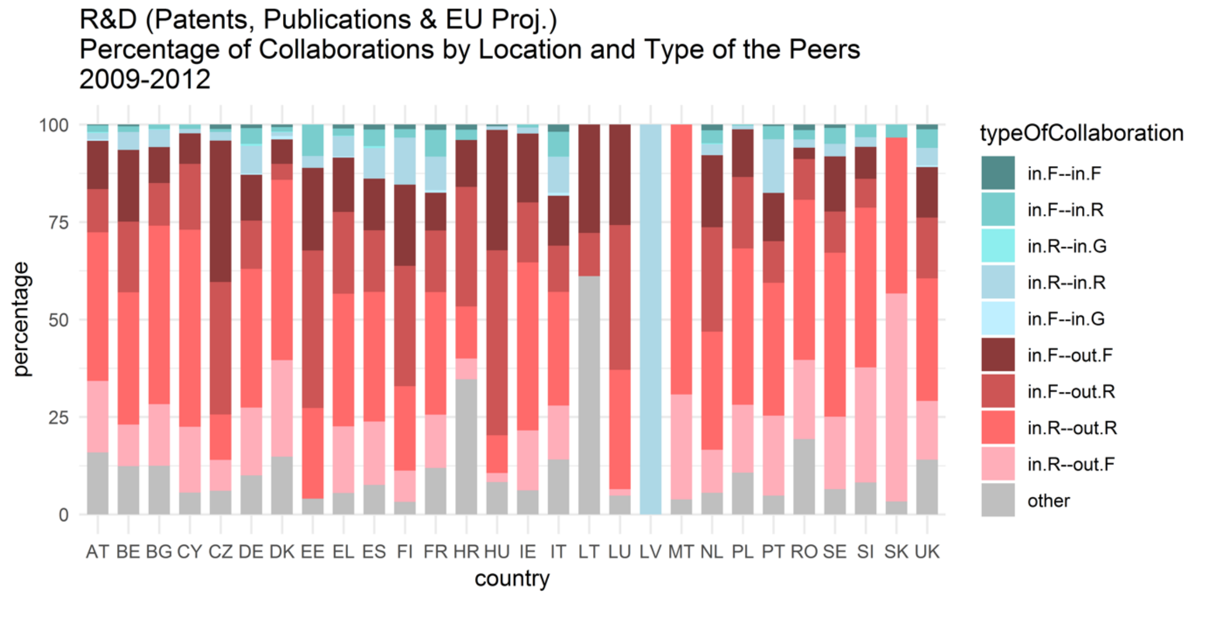
Spain's collaboration with France and Italy is distinctively well established. Then follows the collaboration with Germany, and then with the UK, Portugal and the Netherlands.

Germany is the favourite partner for the highest number of EU countries, namely for the Netherlands, Denmark, Finland, Sweden and Austria.

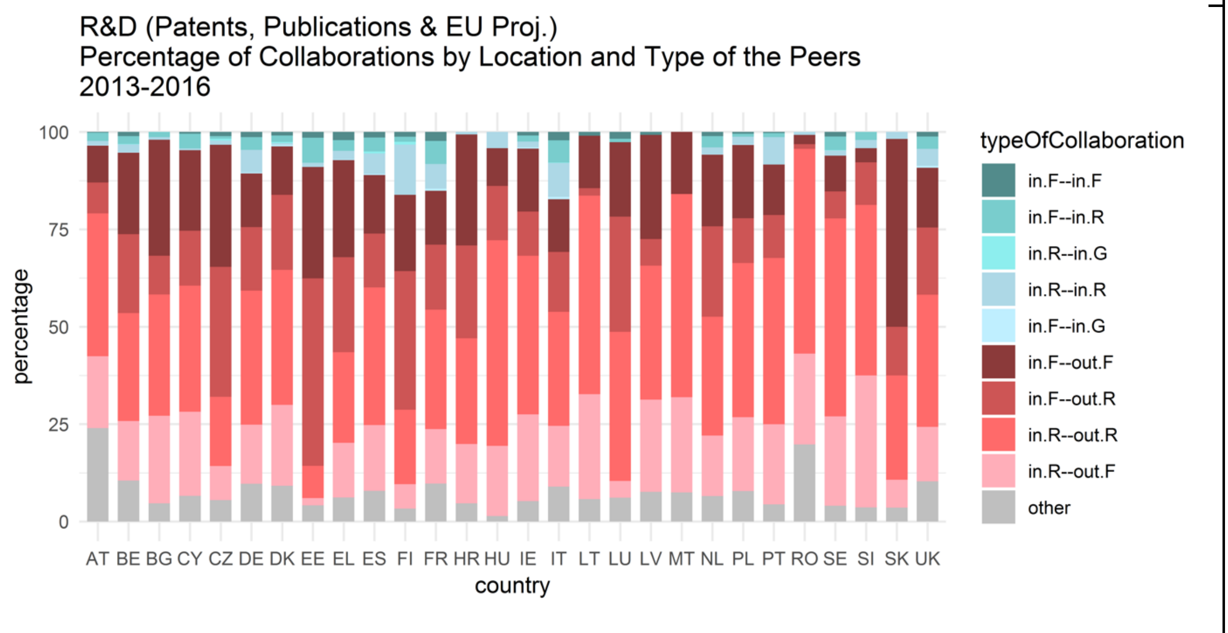
Figure 12 below represents the number of collaborations developed in the context of R&D activities, by country (EU28) and in two different periods, namely 2009-2012 and 2013-2016. It shows the different types of collaborations by location ("in" refers to players located in the corresponding country, while "out" refers to players located out of the corresponding country) and organisational type ("F" indicates firms, "G" governmental institutions, "R" research institutes) of the players involved. Even if each country should be considered in detail, it is possible to observe an expansion of the "in.F—out.F" collaborations, i.e. between firms of the considered country and firms of a different country (indicated with darkest red), from the first period to the second one. In a context, that of R&D, dominated by the presence of collaborations developed by research institutes, even a slight increase of the number of collaborations between firms is worth consideration.

Figure 12. EU28: R&D collaborations by location and type of the peers (EU Project included)

2009-2012



2013-2016



F = Firms, G = Government, O = Other, R = Research

Source: JRC EO TES DATASET 2019.

5 EO industry

The developments of the EO industry used to be driven by the demand in the public sector. The existence of biggest EO companies was conditioned by the sale to the public institutions mainly in the defence and security, which, in turn, was secured by laws and public contracts (PwC 2016).

The last decade has seen the EO industry being impacted by the developments in technology. The miniaturisation of satellites and UAVs led to the significant increase in the volume of EO data, cloud computing enabled better access to data and AI provided analytical powers necessary to process the data. In parallel, policies worldwide focus on promoting, enabling and facilitating the use of EO data. These technology developments coupled with supportive policies are expected to lead to the growth of the EO industry and functioning global EO market.

This section provides insights to the current state of the EO industry worldwide and in the EU.

5.1 EO global industry insights

The analysis of the EO industry is based on the following indicators: number of players and its growth rate as well as characterisation of firms' age, size, position in the value chain, and sector. The analysis also uncovers collaborations in the industry.

The results of the EO TES are dependent on the data sources and keywords used (see section 2.5). Table 6 below shows the percentage distribution of EO firms in particular macro areas for two sets of data sources. The first set of data sources includes both vertical and horizontal data sources without "EU Funded projects (FP7 + H2020)". Set 2 includes only horizontal data sources, namely Crunchbase, BvD Orbis, Venturesource by Dow Jones and EPO PATSTAT).

Table 6. Share of the number of EO TES firms, by geographic macroareas and by specific set of data sources

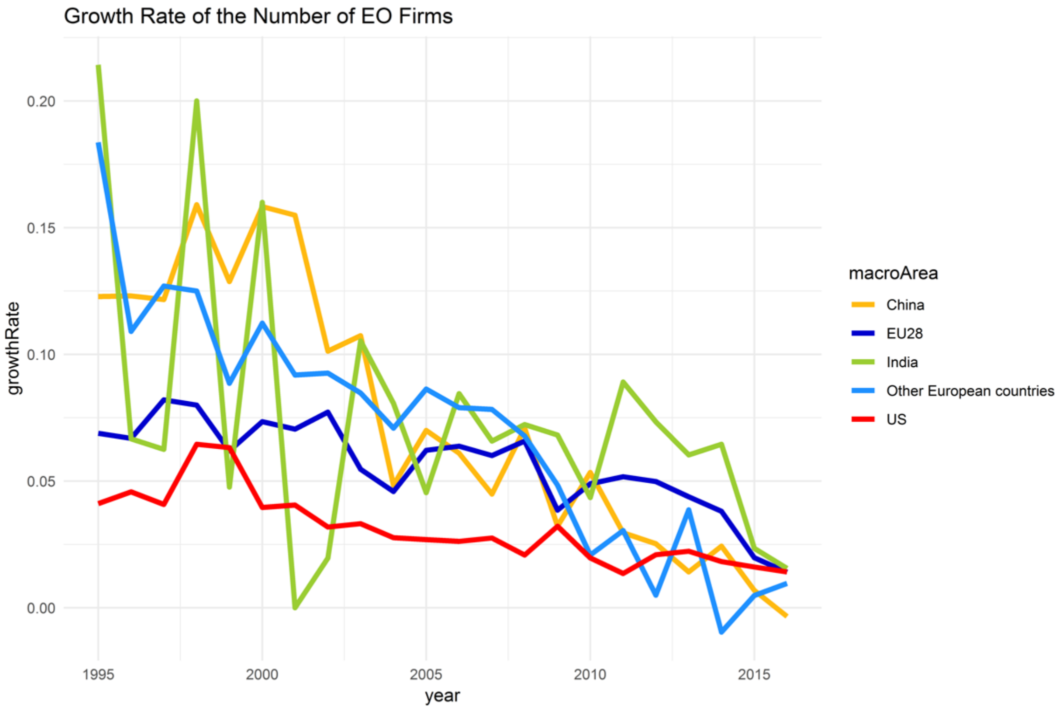
World macro areas	Set 1: All data sources minus "EU Funded projects (FP7 + H2020)"	Set 2: Horizontal data sources
EU28	33%	18%
China	20%	33%
US	17%	19%
India	7%	5%
Other European countries	4%	4%
Canada	3%	3%
Other Asian countries	3%	4%
South Korea	2%	4%
Oceania	2%	2%
Other American countries	2%	2%
Africa	2%	2%
Japan	2%	3%
Middle East	2%	1%

Source: JRC EO TES DATASET 2019.

When comparing the two sets in Table 6, one notices that in both cases the EU28, US and China outpace other regions in the number of EO firms. The results on the US is both sets are similar. In case of the EU and China the differences are significant.

The inclusion of the vertical data sources (Set 1) turned out to yield disproportionally more information on European industry. While those data sources are valuable for the analysis of the EO industry in the EU, they may distort the actual geographical representation of the number of players (see discussion in section 2.5).

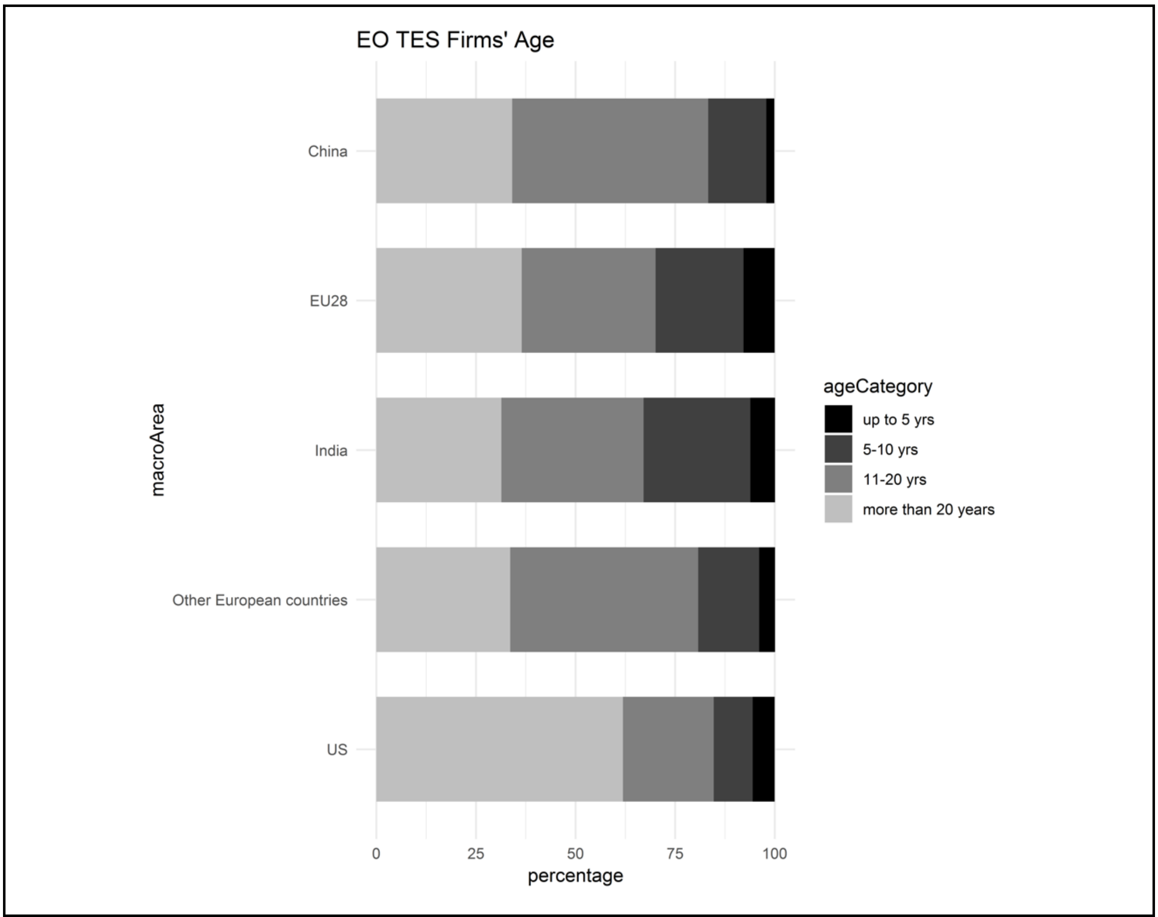
Figure 13. Growth rate of the number of firms



Source: JRC EO TES DATASET 2019.

Figure 13 illustrates the growth rate of the number of EO firms existing in the chosen macro areas. The graph shows that there are new EO firms appearing every year, yet at an overall decreasing rate. The biggest fluctuations are observed in case of India, while the US is a most stable. Also EU28 is considerably stable, but at a higher rate than the US. China, despite a large growth rate in the beginning of the period, then experiences a noteworthy deceleration in terms of number of new firms per year. Figure 14 below presents the percentage distribution of firms by age category for each macro area.

Figure 14. Firms' age by macro area

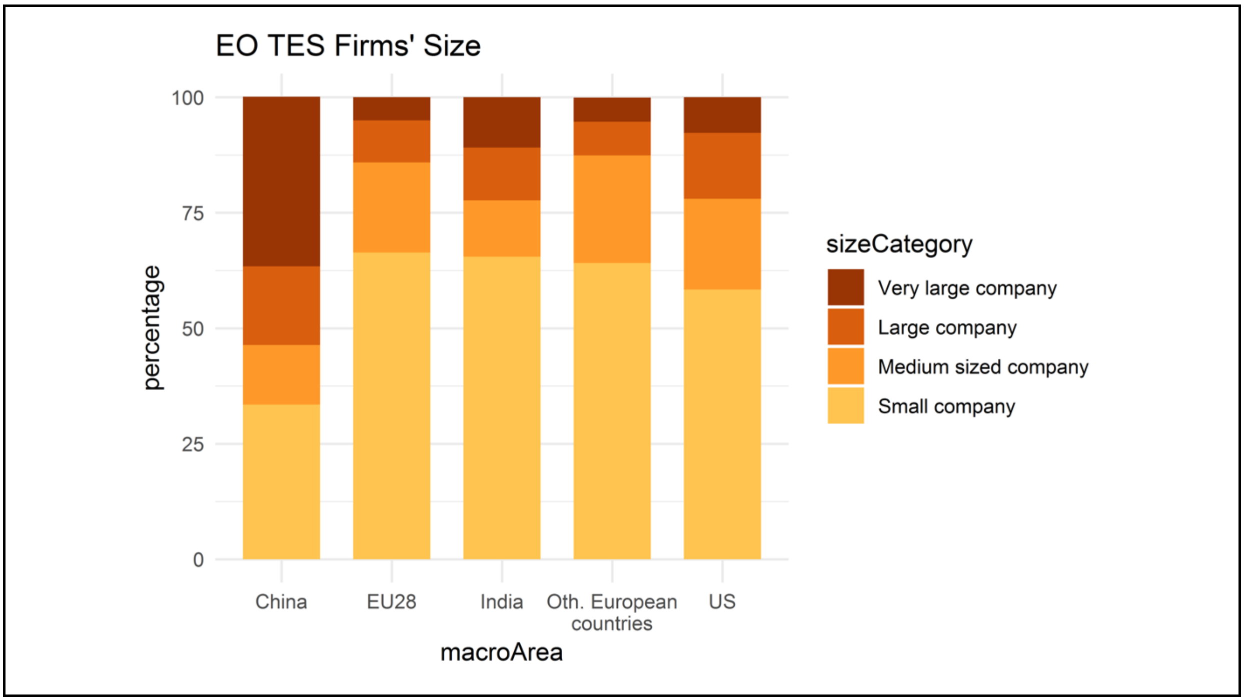


Source: JRC EO TES DATASET 2019.

Based on the information collected by means of Orbis, the set of firms identified by the EO TES has been categorised in four groups: those that are founded up to 5 years ago, those from 5 to 10 years ago, those from 11 to 20 years ago, and those 20 years or more ago. By considering the first two categories, it is possible to observe that the EU28 and India are the macro areas with the largest percentage of firms being, at max, 10 years old (first two categories). On the other hand, China and the rest of European Countries present the largest percentages of medium-old firms (11-20 years). Finally, US is the macro area in which for the most the presence of established and consolidated firms can be observed, as more than the 60% of them are active for at least 20 years.

Figure 16 below shows the distribution of firms based on their size as plotted by macro area. For the size categories the existing Orbis definition was applied (https://help.bvdinfo.com/mergedProjects/68_EN/Data/Coverage/CompSizeCat1.htm).

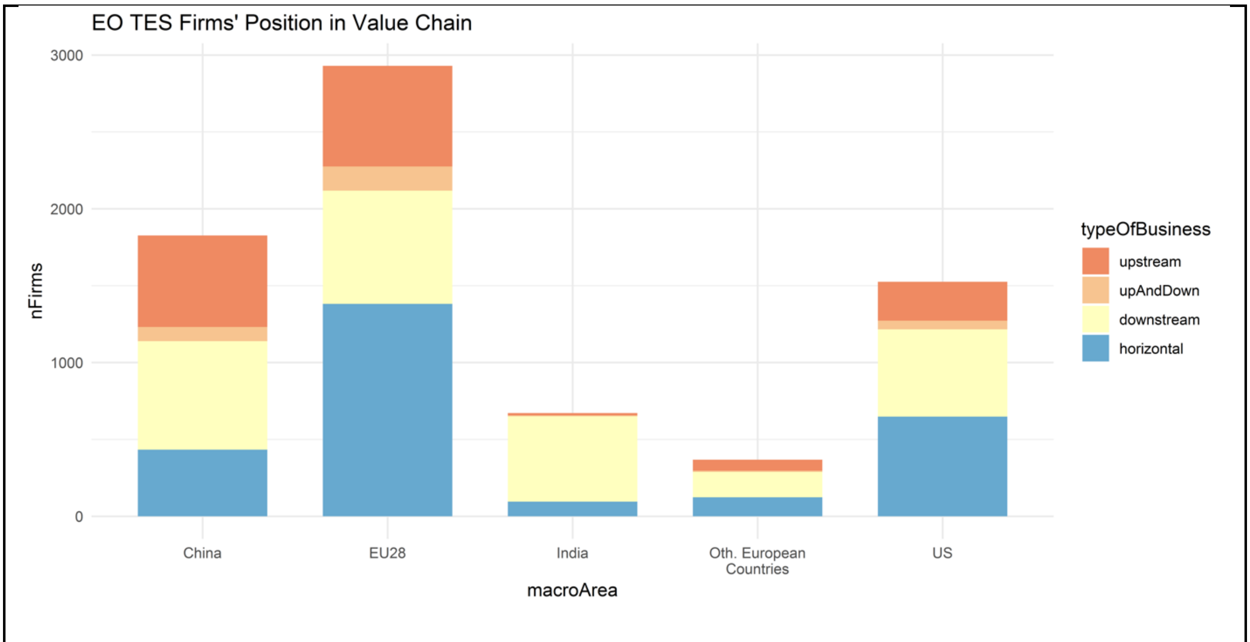
Figure 15. Firms' size



Source: JRC EO TES DATASET 2019.

In the Figure above on can observe that for all macro areas but China, the largest percentage (always above 50%) is determined by small companies. The US appears to have a large belt of large companies, and India a relatively large number of very large companies. However, the most appearing element that the graph shows is the noteworthy involvement of large and very large companies in China.

Figure 16. Firms' position in the value chain

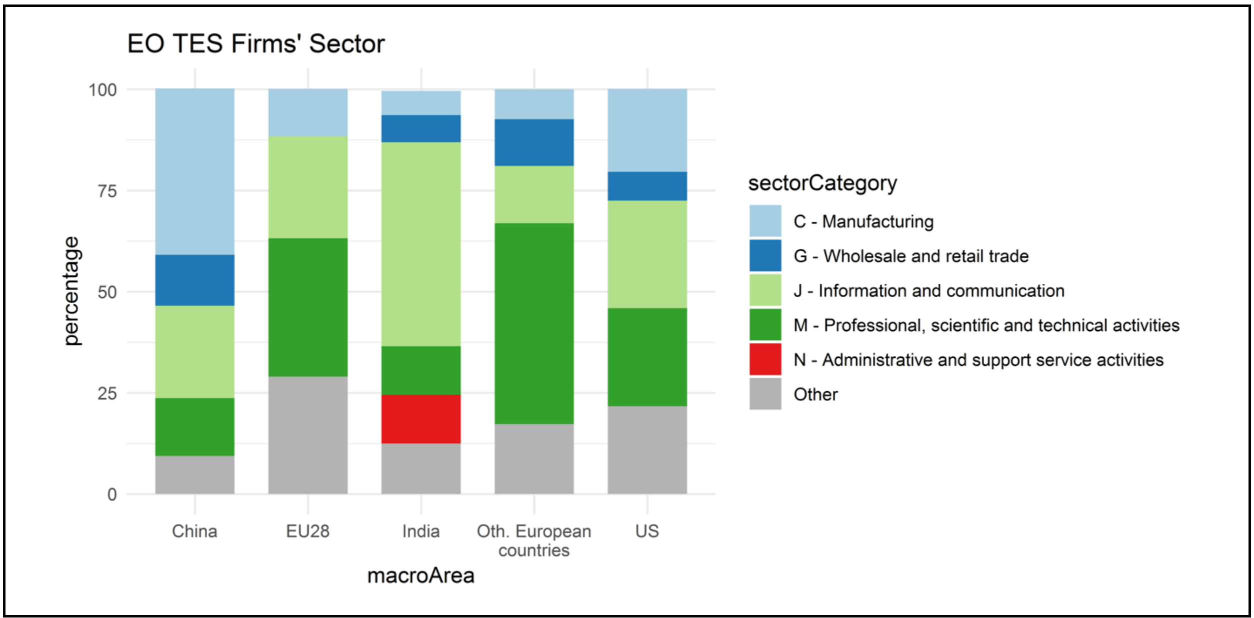


Source: JRC EO TES DATASET 2019.

Figure 16 shows the distribution of EO firms across the EO value chain. The graph is a result of analysis based on the structured list of keywords used for the identification of the EO players. The companies that strongly occupy positions in the upstream, downstream or the whole value chain were identified as Upstream, Downstream and UpAndDown respectively. The horizontal category contains firms identified as EO players based on the horizontal keywords, not allowing for the clear identification of a firm's position in the value chain. What this graph shows is a large presence of horizontal players in the EU28. EU28 is also leading in number of firms in the upstream part of the value chain and has a notable presence of firms in both upstream and downstream (UpAndDown).

Figure 17 below depicts the distribution of firms per sector, as they are declared and collected in Orbis. Only the main sectors appearing in EO are visualised, while the remaining are included in the category "Other".

Figure 17. Firms' sector



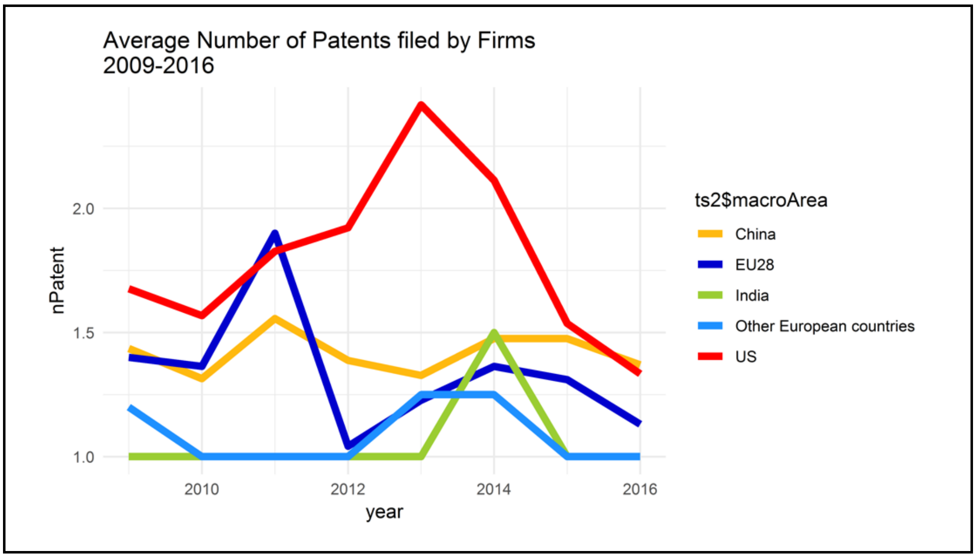
Source: JRC EO TES DATASET 2019

The most visible information to be taken from the above graph is that Chinese firms are mainly belonging to the manufacturing sector. This could suggest a large involvement of China in EO because of the production of sensors and devices supporting the technology. EU28 and the US are structured in similar ways, in the sense that for the most their firms belong to the Information and Communication sector ("J"), or the Professional, scientific and technical activities ("M"). However, the US show larger percentages both for the Manufacturing sector ("C") and the Wholesale and retail trade sector ("G").

5.1.1 Collaborations in the global EO industry

Collaborations in the EO industry are explored in the area of patenting. Figure 18 below shows the average number of EO patent applications filed by firms with at least one patent, in the period 2009-2016 and by macro area. Data are available until 2018, but because of the delay in reporting patents filing (usually of two years), only the period up to 2016 is considered.

Figure 18. Firms' patenting performances

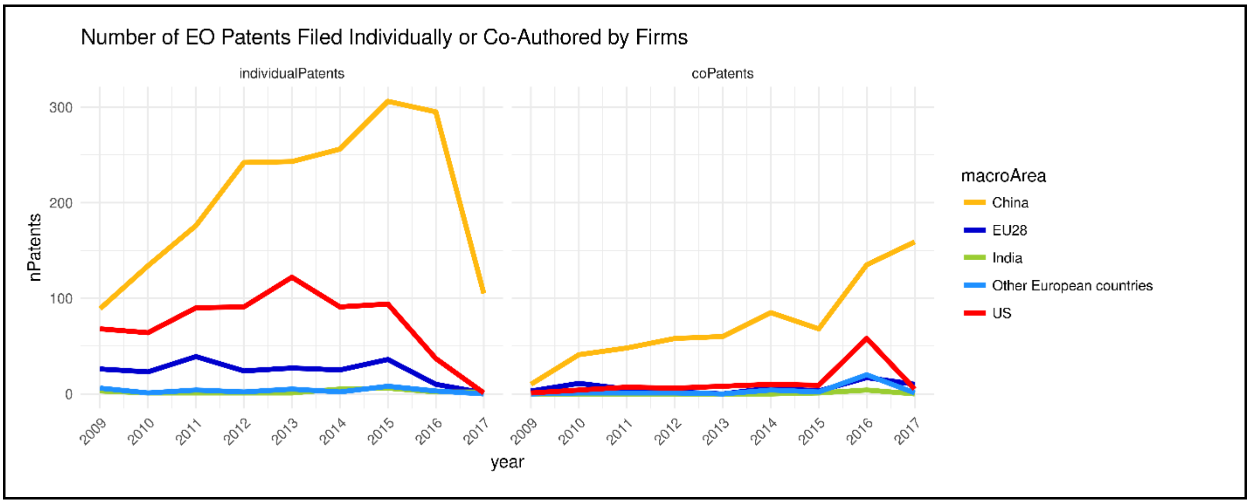


Source: JRC EO TES DATASET 2019.

What is observable is that for almost all the considered period the best performing patenting firms are located in the US, in which a peak of almost 2.5 patents per patenting firm in 2013 is observed. EU28 fluctuates intensively between 2009 and 2013, and in 2014 resumes the level of 2009, apparently in a more stable way. Regarding China, it is the macro area in which the patenting firms seem to have the most constant performance, always around 1.5 patents per year.

As far as the number of patent applications is considered, China displays the highest number of registered patents (Figure 19). As seen from the graph co-patenting in Chinese firms is increasing and individual patenting decreasing, which may point to the establishment of a more collaborative approach to innovation. In case of the EU as well as the US, there are more firms patenting individually than in cooperation.

Figure 19. Number of EO patents filed individually or co-authored by firms

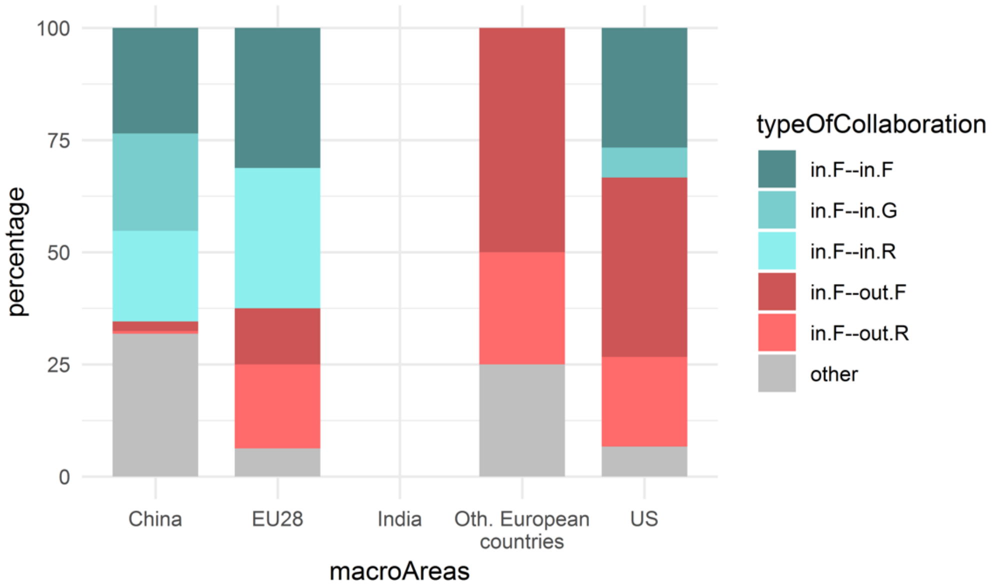


Source: JRC EO TES DATASET 2019.

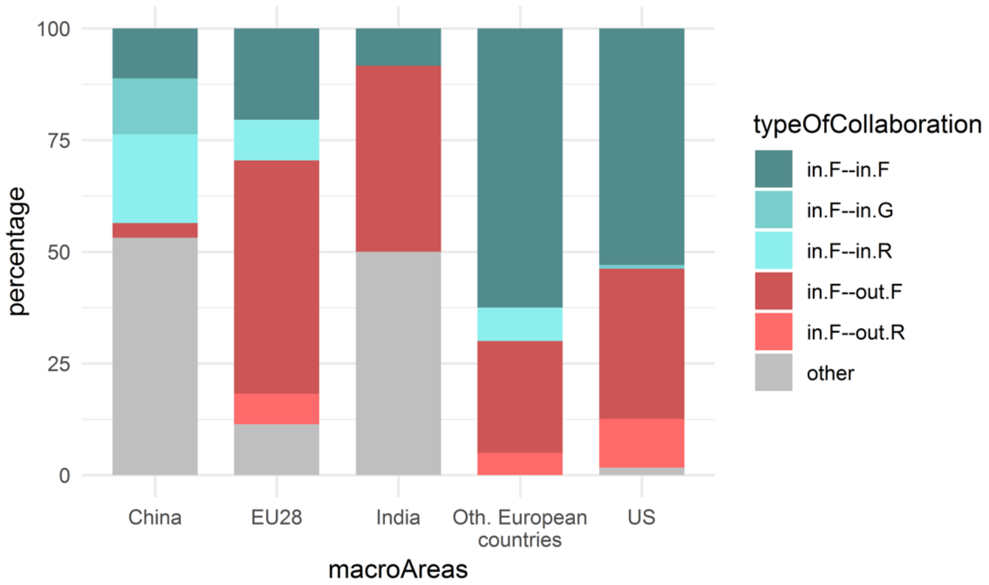
The figure below sheds more light on the type of collaboration developed by companies across different macro areas.

Figure 20. Patents: Collaborations (in % by country total), by location and type of the peers

2009-2012



2013-2016



F = Firms, G = Government, O = Other, R = Research

Source: JRC EO TES DATASET 2019.

The elaborations presented in Figure 20 describe the percentage of collaborations registered in patenting activity in terms of the players involved (peers, as they are collaborating). More specifically, the collaborations are distinguished by the location ("in" refers to players located in the corresponding macro area, while "out" refers to players located out of the corresponding macro area) and organisational type ("F" indicates firms, "G" governmental institutions, "R" research institutes) of the players involved. In this way, it is possible to observe the level of geographical internal (in blue-ish colours) and external (in red-ish colours) collaborations for each macro area, also with information about the types of players involved. In general, it is possible to observe that moving from the period 2009-2012 to 2013-2016, the percentage of collaborations exclusively involving firms increases (darkest blue and darkest red) for all macro areas except for China. The case of China, with a very large proportion of "Other" in the second period, is due to the large reinforcement of two types of collaborations: (i) between Chinese research institutes and Chinese governmental institutions, and (ii) between Chinese governmental institutions. Regarding EU28, the internal collaborations decrease over time and a large increase is observable in the collaborations between local firms and firms abroad. Finally, the US presents a remarkable positive increase in the percentage of collaborations between local firms.

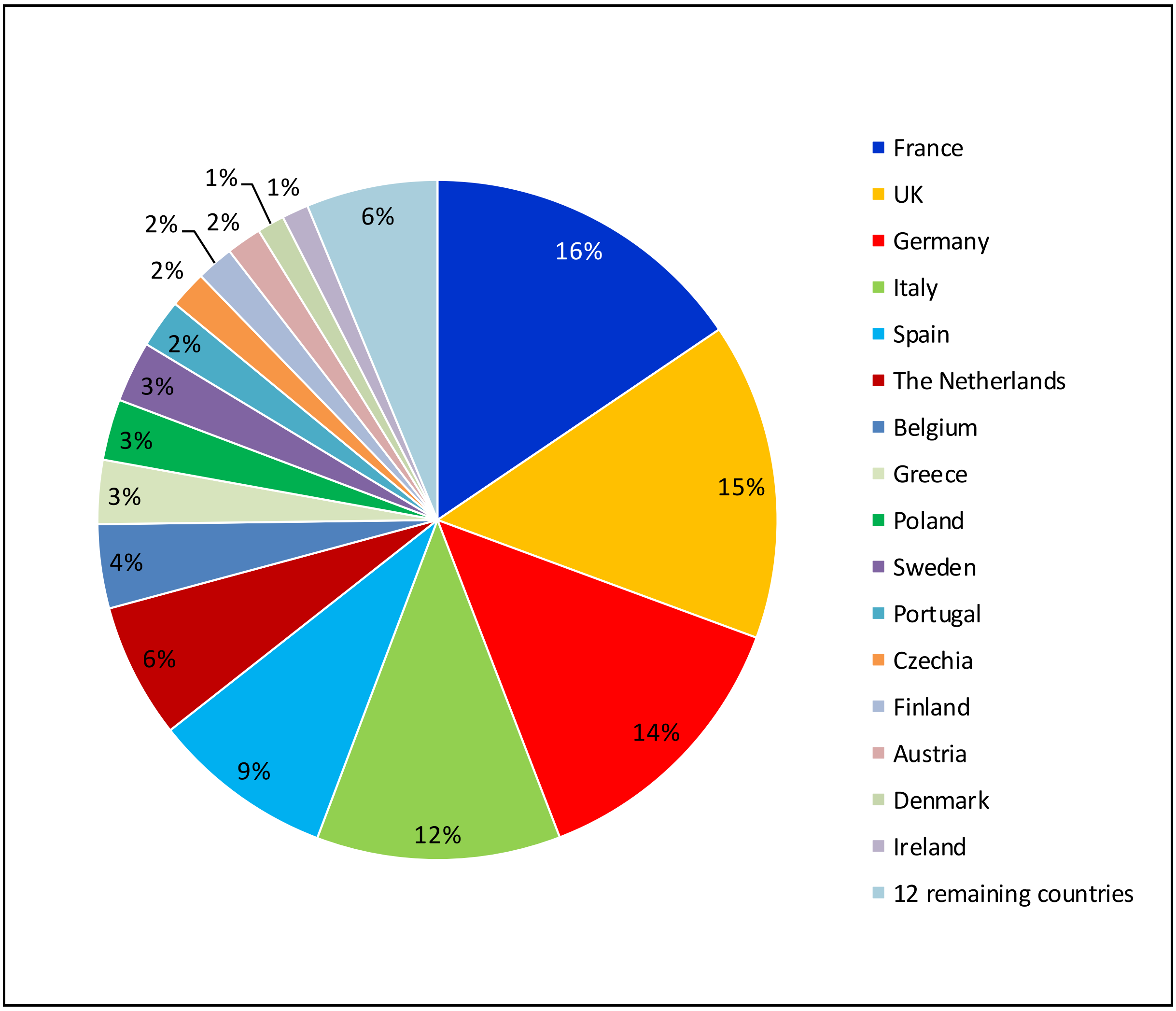
5.2 EO industry in the EU

This section focuses on the characteristic of the EO industry in the EU28.

In general, the European EO industry is better established in the countries with strong positions in the space sector. Nevertheless, as it will be shown later, one can notice more development taking place in the downstream segment, which is not necessarily fuelled by the home-built upstream segment.

Figure 21 below shows the distribution of number of all EO firms across the EU countries.

Figure 21. Share of EO firms for EU28 countries



Source: JRC EO TES DATASET 2019.

Table 7. Share of number of EO firms in the EU28

EU28 countries	Share
France	15.5%
UK	15.1%
Germany	13.5%
Italy	11.6%
Spain	8.6%
The Netherlands	6.4%
Belgium	4.0%
Greece	3.0%
Poland	2.9%
Sweden	2.9%
Portugal	2.3%
Czechia	1.8%
Finland	1.8%
Austria	1.7%
Denmark	1.3%
Ireland	1.3%
Romania	0.9%
Bulgaria	0.8%
Hungary	0.7%
Slovenia	0.6%
Estonia	0.6%
Croatia	0.6%
Luxembourg	0.6%
Slovakia	0.4%
Lithuania	0.3%
Cyprus	0.3%
Latvia	0.3%
Malta	0.2%

Source: JRC EO TES DATASET 2019.

Figure 21 and Table 7 show the distribution of EO firms within the EU. The four biggest EU countries make up for more than 50% of the EO firms in the EU. France ranks number one regarding the number of firms as the number of all EO players (). The UK occupies second position in the table above compared with fourth position in the overall rank, demonstrating a stronger firm activity. Also Greece, Poland and Sweden have bigger shares in case of firms than in the case of all EO players. It may mean that despite not having developed strong public institutional side or a strong R&D position, the industry thrives there benefiting from the regional programmes and initiatives and horizontal collaboration within industry. In some cases it may also mean that the country has not developed a home-built position and its industry mainly consists of the national representatives of global players.

On the other hand, Italy and Portugal have lower ranks in the firm comparison, highlighting much stronger presence of its public sector in the EO domain. Spain, the Netherlands and Belgium hold the same positions in both cases. Poland and Sweden come as number 9 and 10 in the above industry ranking.

Interesting conclusions can be drawn from the comparison of the EO TES results to the Countries Geospatial Readiness Index (CGRI) - 2019 (see box 4). The Index reflects the capability of the countries to develop mature geospatial industry sector. The index is a good indicator of how the countries may perform in the future in the relation to the EO industry sector. The Table 8 provides the CGRI ranking of the European countries: country's score as well as global (overall rank) and regional ranks.

Table 8. CGRI-2019: Europe

EUROPE RANKINGS			
COUNTRY	OVERALL SCORE	OVERALL RANK	REGIONAL RANK
United Kingdom	62.16	2	1
Germany	49.51	3	2
The Netherlands	47.03	4	3
Denmark	44.06	6	4
Belgium	41.11	9	5
Switzerland	40.94	10	6
France	40.11	11	7
Ireland	38.60	14	8
Austria	37.54	16	9
Sweden	37.14	17	10
Norway	36.82	18	11
Spain	36.79	19	12
Finland	35.54	21	13
Russia	35.27	22	14
Poland	35.18	23	15
Italy	34.12	24	16
Portugal	31.71	26	17
Greece	26.20	29	18
Estonia	25.25	30	19
Ukraine	23.62	32	20
Bulgaria	23.23	34	21
Hungary	22.68	35	22
Regional Average	36.57		

Source: Geobuiz Report 2019.

Box 2. Countries Geospatial Readiness Index

CGRI has been developed by the Geospatial Media and Communications, first introduced in 2017.The index provides for the comparative framework of key parameters important for the development of the geospatial sector. The assessed parameters include: *Industry fabric* (networks, promotion, capacity), *Data infrastructure* (data infrastructure, positioning infrastructure, platforms and portals, standards), *User adoption level* (enterprise level, system integration level, analytics and workflow, asset management, mapping of service level), *Institutional capacity* (research and postgraduate courses, graduate, diploma and certificate courses), *Policy framework* (geospatial policy framework, enabling policy framework).

According to the CGRI the UK significantly outpaces other European countries. Germany and the Netherlands follow the UK with good regional and global ranks. The unquestionable leader of the EO TES, namely France, occupies lower position (regional rank 7, global rank 11). While France's position is just lower than in the EO TES, Italy plunges down significantly in the CGRI (regional rank 16, global rank 24). Spain's position is also not as good as in the EO TES.

According to the CGRI the UK significantly outpaces other European countries. Germany and the Netherlands follow the UK with good regional and global ranks. The unquestionable leader of the EO TES, namely France, occupies lower position (regional rank 7, global rank 11). While France's position is just lower than in the EO TES, Italy plunges down significantly in the CGRI (regional rank 16, global rank 24). Spain's position is also not as good as in the EO TES. While the CGRI does not necessarily reflect the actual condition of the EO sector in terms of the number of players (which EO TES does) it does communicate developmental capability and could be a valid indicator of the future performance. Currently, the health of the general industry fabric, policy framework, technological innovation and operative data infrastructure have becoming more important factors impacting future development of the EO industry, especially in the downstream.

The recent impetus in the growing number of the EO players in Europe, as well as globally, is not any more so tightly linked to the high national spending in the upstream segment. It is also driven by the developments in the ICT technology such as IoT and cloud computing as well as by the analytical advancements linked to AI.

In the EU those trends have a strong policy support. In 2010 the EU passed its Digital Agenda[10] recognising the importance of Digital economy and Digital Single Market (DSM). Since then the EU has worked on the creation of a systemic framework enabling development of the European digital industry and data economy. The EU digital agenda also fuel the development of the EO downstream sector, yet from a different direction.

The development of the modern EO industry in the EU is specifically targeted by the Copernicus Programme (see Box 3). The Programme provides founding, enables collaboration and provides free access to the collected data fuelling the development of the EO industry across the whole value chain (see PwC 2019).

[10] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A Digital Agenda for Europe, COM/2010/0245 final.

Box 3. The Copernicus Programme

An important driver of the evolution of the European EO VA industry activities in the last and coming years is the Copernicus Programme with its policy of open access to the EO data.[11] Copernicus is the European Union's Earth Observation Programme. It is coordinated and managed by the European Commission and implemented in partnership with the Member States, the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium-Range Weather Forecasts (ECMWF), EU Agencies and Mercator Océan.

Vast amounts of global data from satellites and from ground-based, airborne and seaborne measurement systems are being used to provide information to help service providers, public authorities and other international organisations improve the quality of life for the citizens of Europe. The information provided by the Copernicus services can be used by innovative business private to develop satellite-enabled products and services, which not only creates highly skilled jobs in Europe, but also finds a wide range of applications in a variety of areas, such as urban area management, sustainable development and nature protection, regional and local planning, agriculture, forestry and fisheries, health, civil protection, infrastructure, transport and mobility, tourism, insurance and many more. The information services provided are freely and openly accessible to its users.[12] The Data and Information Access Services (DIAS) were launched in 2018 to facilitate further a user-friendly access to the Copernicus data.

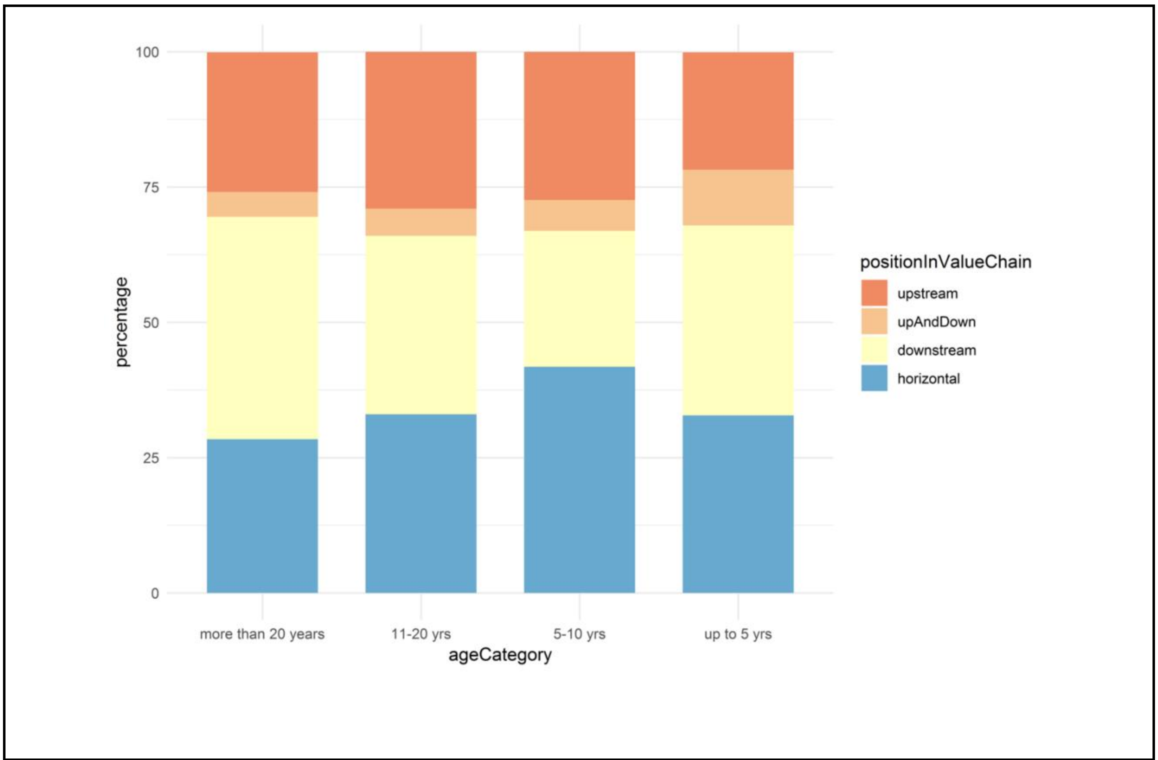
Landsat in the US plays a similar role as the Copernicus Programme in Europe. The release of free Landsat data since 2008 led in 2012 to tenfold global increase in the number of registered users. The Landsat value assessment demonstrated that a large portion of Landsat's value comes from the free and open data policy that gives users copious amounts of no-cost data, and that charging even small amounts for data would dramatically reduce the number of data users, hindering innovation and thereby societal and economic benefits. The annual benefit of the Landsat program to US users in 2011 was estimated at approximately USD 1.8 bln, which already was twice the cost of building and launching the Landsat 8 Operational Land Imager (Miller et al. 2013).

Figure 22 below shows that the downstream segment is where the most of the new EO companies appear. It displays that while the percentage of the downstream sector was decreasing for some time before, more downstream companies have been founded in the last 5 years in the EU coinciding with the Copernicus initiative of open access.

[11] EU, Regulation No 377/2014 of the European Parliament and of the Council establishing the Copernicus Programme and repealing Regulation (EU) No 911/2010, OJ L 122/44 (Copernicus Regulation).

[12] https://www.copernicus.eu/en/about-copernicus/copernicus-brief

Figure 22. EU28 EO TES firms' age by position in the value chain

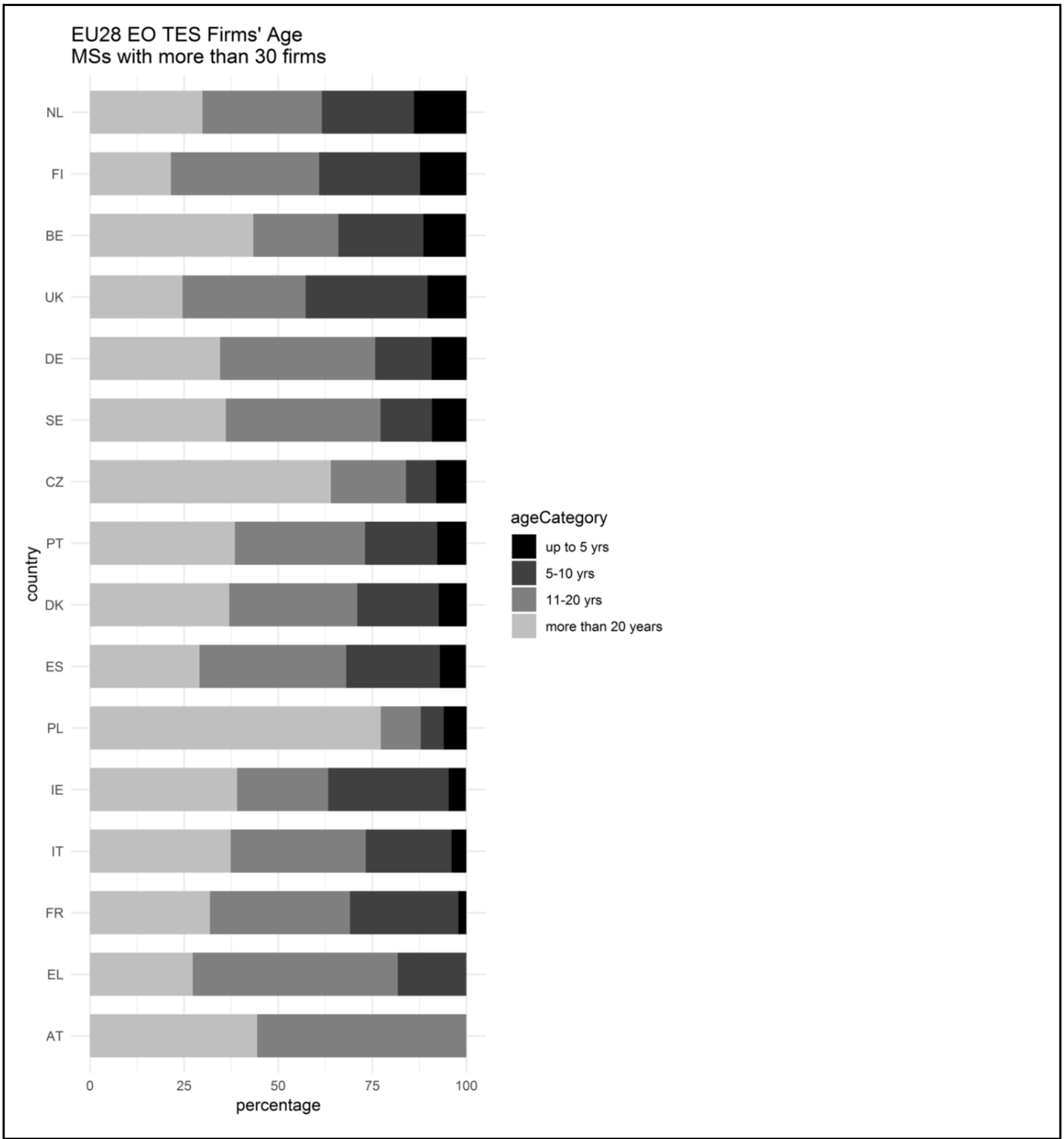


Source: JRC EO TES DATASET 2019.

The distribution of the age of EO firms differs across the EU member states. As shown in Figure 23, Finland, Netherlands and Belgium have a higher percentage of firms entering the market within the last 5 years. While in the UK and Ireland many EO firms were founded in the period after 2000. On the contrary, in Austria, Greece and France firms are largely well established.

Overall, in the EU less than 10% of firms in the EO domain are in the youngest age group. It is interesting to compare them to ICT firms registered in the same firm dataset of Orbis. 30% of ICT firms are in the youngest group. On the other hand, less than 15% of ICT companies are older than 20 years, while 36% of European EO companies are active for more than 20 years.

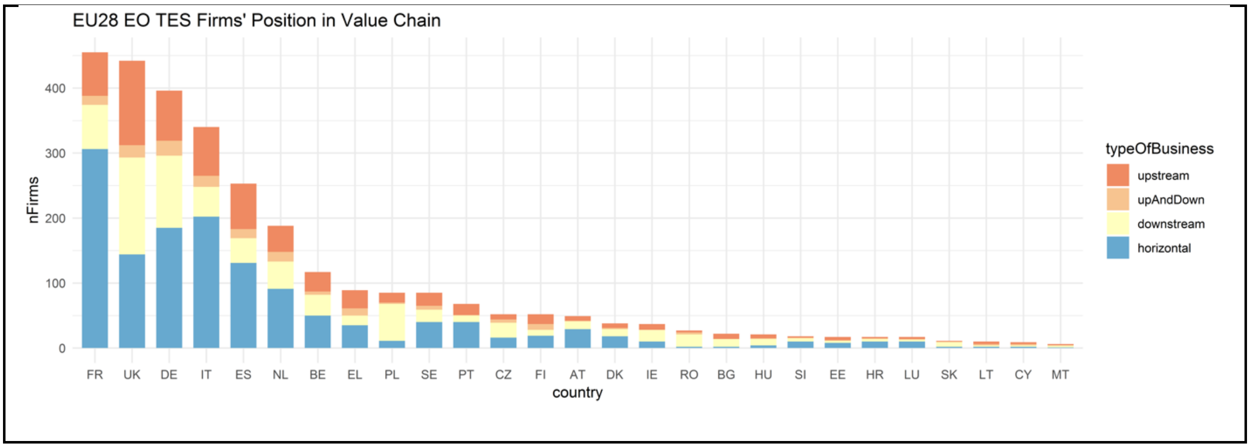
Figure 23. Firms' age in the EU28



Source: JRC EO TES DATASET 2019.

Figure 24 below shows the composition of firms for European countries with respect to the position in the value chain.

Figure 24. EU28 firms' position in the value chain

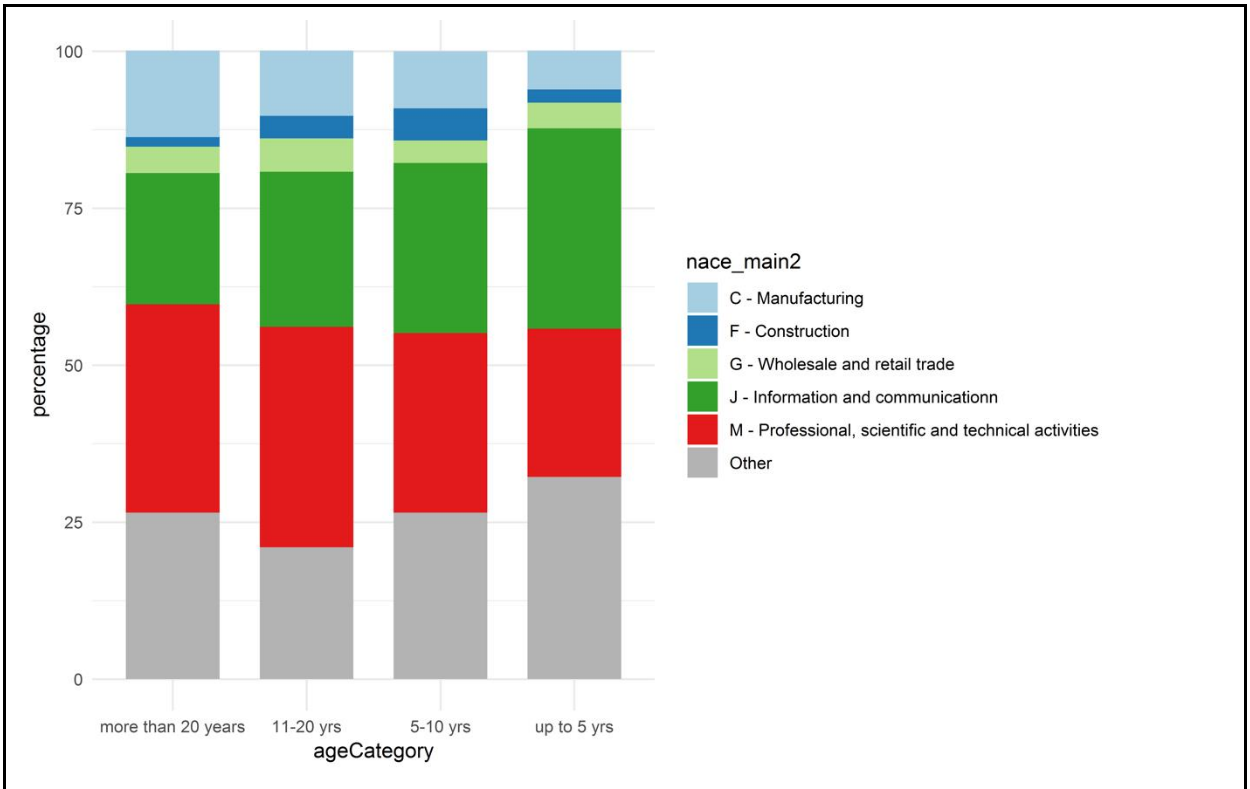


Source: JRC EO TES DATASET 2019.

The UK has the highest number of firms in the upstream and also downstream sector. France, on the other hand, dominates the horizontal category. Also Italy's firm landscape has a high presence of EO firms active in horizontal category. Poland has a high percentage of downstream firms.

Figure 25 takes a closer look at the structure of the EO firms to understand how younger companies are different from more established firms within the EU. It shows the sector distribution of firms by founding year. It shows clearly that new companies have increasingly been founded within the ICT sector, reflecting the impact of the digital economy on the EO domain.

Figure 25. EU28 EO TES firms' age by sector

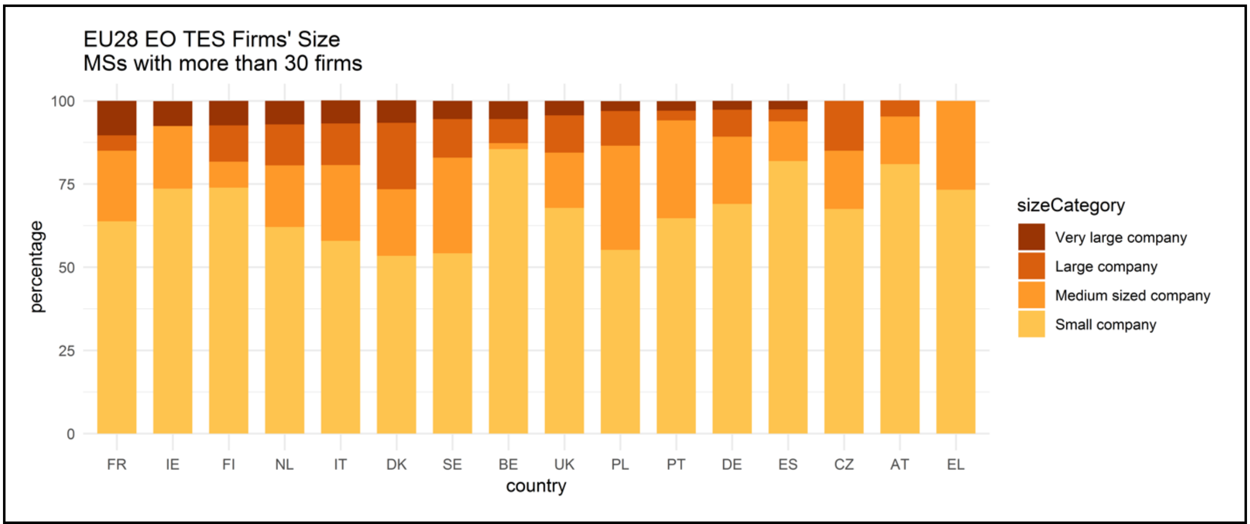


Source: JRC EO TES DATASET 2019.

As far as size of the firms is considered, the section on the global industry has shown that EU firms active in EO are small firms compared to the firm structure in other regions. Figure 26 below shows the distribution of firms' size within EU countries and orders them by the percentage of "very large company".

Figure 26 shows that France, Ireland and Finland have very large companies active in EO, while the companies in Greece, Austria and Czechia tend to be smaller.

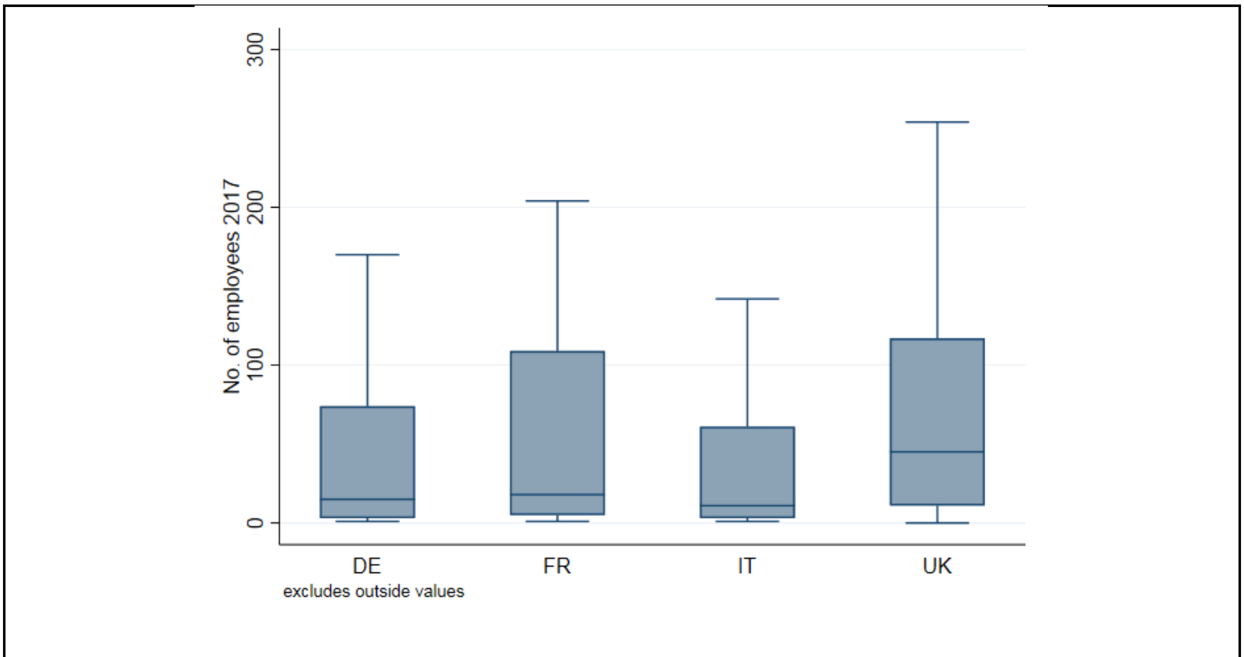
Figure 26. Firms' size (EU28)



Source: JRC EO TES DATASET 2019.

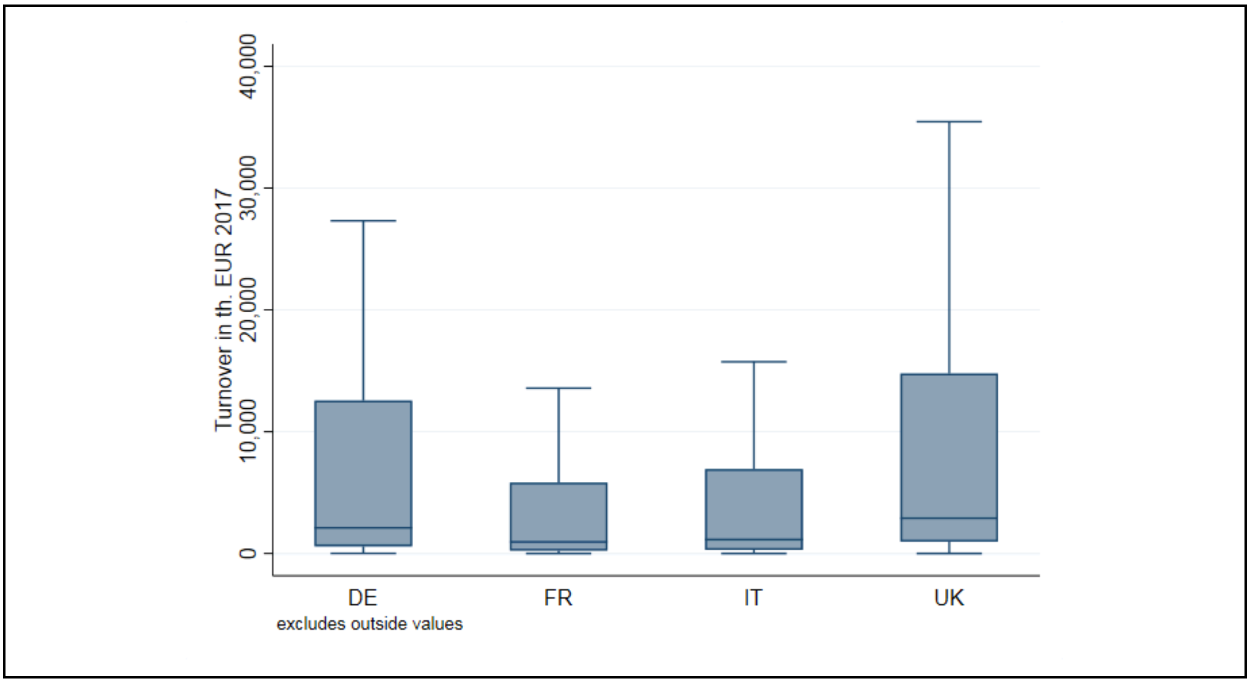
Figure 27 and Figure 28 below give a more detailed picture of the size of EO companies looking at employment and turnover in the four largest countries. The boxplot shows the median, the 25 and 75 percentile ad the upper and lower adjacent values of the firms in each represented country. UK companies are the biggest regarding turnover and employment. While France has more employee intensive firms than Germany and Italy, it has the smallest regarding turnover.

Figure 27. EU28 Firms' employees (distribution)



Source: JRC EO TES DATASET 2019.

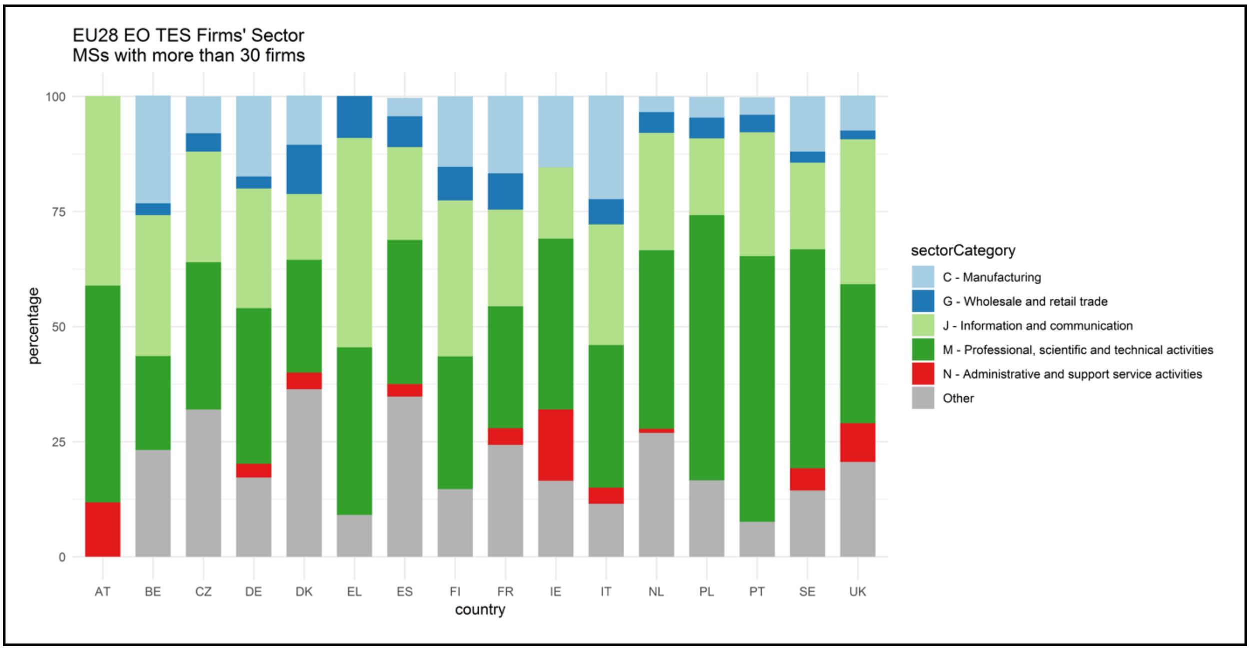
Figure 28. EU28 firms' turnover (distribution) (Germany, France, Italy and UK)



Source: JRC EO TES DATASET 2019.

Figure 29 shows the distribution of EO firms among NACE sectors by EU country. It reveals that Italy and Belgium have a comparatively strong hold of EO companies in the Manufacturing sector. Polish and Portuguese companies are mainly active in Professional, scientific and technical activities.

Figure 29. Firms' sector (EU28)



Source: JRC EO TES DATASET 2019.

6 Conclusions

The EO TES enriches the picture of the EO domain through providing a quantitative representation of the global and regional dynamics in the EO ecosystem of players, activities and collaborations.

The TES EO ecosystem shows a very diverse global landscape with three distinguished global hubs, namely EU28, China and the US, as possible incubators for EO-linked innovation. Those hubs have the largest number of players in case of R&D and well as in case of industry. Nevertheless, the distribution of EO activities and concentration of those activities look quite different in the three leading macro areas.

As far as the R&D activities are considered, the EU28 has the highest overall number of players involved in the all types of R&D, but scores quite low if only the patents are taken into account.

Out of the three big players, the US has the smallest number of players involved in the overall EO R&D and stable position in number of patenting. In case of China, the largest number of R&D activities is concentrated in the hands of relatively few players.

When it comes to the EO industry worldwide, the number of new EO firms grow from one year to another, yet at an overall decreasing rate across all macro areas. Out of all analysed macro regions, the EU has the biggest number of EO players and the biggest share of young firms. The share of small companies in all macro areas is similar except from China where the biggest presence of large and very large companies is found. Most Chinese EO firms belong to the Manufacturing sector. Indian EO firms mostly belong to Information and communication sector. The EU28 and the US have similar shares of EO firms located in the Information and communication sector and in the Professional, scientific and technical activities, with the US displaying a stronger position in Manufacturing sector. As far as the EU28 in considered, the biggest share of the young companies was established in the downstream segment within the Information and communication sector.

Collaborations in the EO industry were illustrated based on co-patenting. The EU28 and the US display significant increase in the collaboration within industry. In case of the US the big increase is observable for collaborations within the home industry mostly at the expense of collaboration with external industry. It is interesting to see that when it comes to the collaboration between industry and research, the US companies choose collaboration with external research institutions. In contrast to the US, the EU28 witnessed an increase of collaborations between firms within and outside of the EU28. In India companies used to publish individually, while in the last years collaboration have become more common, usually with industry players outside of India. While Chinese firms collaborate very little with the outside world. They overwhelmingly focus on internal collaboration, where the biggest share goes to collaboration with internal research institutions.

In general, there has been an increase in the global collaboration within the industry, which, to an extent, may indicate decoupling of the downstream segment from government procurement. It may also be an early harbinger of maturing of the EO market with the boost coming from the information and communication industry sector. In the EU28, most of the young companies have been created within the downstream segment, which coincides with the Copernicus initiative of open access. The technological pull from the ICT sector combined with a policy push could be, therefore, an important factor contributing to the growth of the number of EO players in the downstream EO segment in the EU, in particular in the case of non-spacefaring states.

In conclusion, the findings of this report confirm a general expectation about the growth in the EO downstream segment, however so far (until 2017) the growth has not been staggering. Since 2017, there have been continuous policy efforts to increase the uptake of EO data with the aim of more significant growth in the EO market.

The results presented in this report point to the way to develop the EO TES. This report showed that more attention is needed to the geographical balancing of the data sources in case of global analysis. Further developments on EO TES will optimise this aspect. Efforts will focus on capturing globally the downstream and midstream EO sector, with special focus on the young firms. A systematic screening of job portals has been taking place in order to monitor the take up of EO technology and data by a larger audience. Moreover, more international conferences and journals will be taken into account to double check the effectiveness in capturing the most dynamic players. In addition, EO TES will explore to larger extent the geospatial market by expanding from the current selection of keywords, which cover the EO domain within its traditional, narrower scope. This may allow to better capture the most recent uses of EO data that go beyond the traditional scope of the EO domain.

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List of abbreviations

AI	Artificial Intelligence
CAGR	Compound Annual Growth Rate
CGRI	Countries Geospatial Readiness Index
CNES	Centre National D'Etudes Spatiales
CRCSI	Research Centre for Spatial Information
DIAS	Data and Information Access Services
DSM	Digital Single Market
EARSC	European Association of Remote Sensing Companies
ECMWF	European Centre for Medium-Range Weather Forecasts
EDA	European Defence Agency
EDM	European Data Market
EO	Earth observation
EPO	European Patent Office
ESA	European Space Agency
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GEO	Group on Earth Observation
GEOSS	Global Earth Observation System of Systems
GIS	Geographic Information System
GMES	Global Monitoring for Environment and Security
GNSS	Global Navigation Satellite System
ICT	Information and Communications Technology
IOT	Internet of Things
ISA	Interoperability Solutions for European Public Administrations
ITU	International Telecommunication Union
JRC	EU Joint Research Centre
LE	London Economics
NACE	Nomenclature of Economic Activities (EU)
NGO	Non-Governmental Organisation
NRC	National Research Council
OECD	Organisation for Economic Co-operation and Development
OJ	Official Journal
PSI	Public Sector Information
PwC	PricewaterhouseCoopers
RS	Remote Sensing

SDG	Sustainable Development Goals
SDI	Spatial Data Infrastructure
SLR	Satellite Laser Ranging
SME	Small Medium Enterprises
TES	Techno-economic segment
TFEU	Treaty on the Functioning of the European Union
UAV	Unmanned Aerial Vehicles
UNEP	United Nations Environment Programme
UNGA	United Nations General Assembly
VC	Venture Capital
VOI	Value of Information
UKSA	UK Space Agency

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