Space-borne sensing and green applications

Patent insight report

Europäisches Patentamt
European Patent Office
Office européen des brevets

ESPI European Space Policy Institute

IN COLLABORATION WITH

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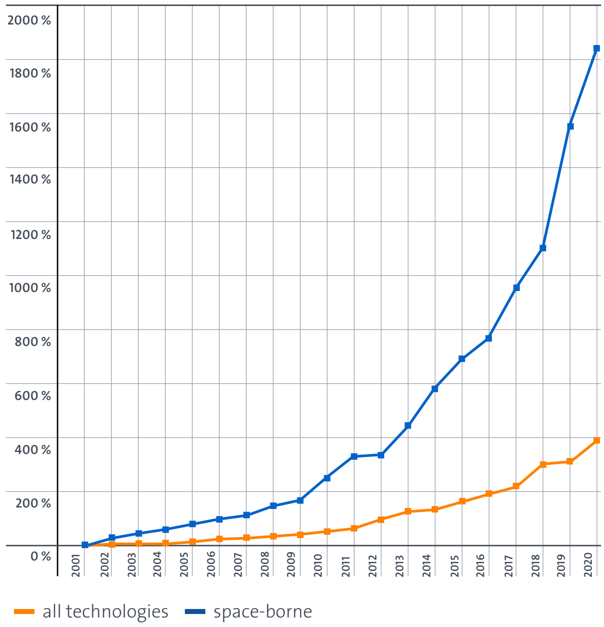
1. Executive summary

This study, the third in the series of collaborative patent insight reports by the European Patent Office (EPO) and the European Space Policy Institute (ESPI) in collaboration with the European Space Agency (ESA), investigates global patent filing trends (2001-2020) in the domain of "green applications" of space-borne sensing.

Remote sensing via satellites in space increasingly serves a variety of public and private users, supporting important public policy objectives as well as diverse business endeavours. This study puts a particular spotlight on the utility of space-borne sensing as an indispensable tool for an effective implementation of green policies and objectives. These can be applications of remote sensing data in support of mitigating climate change, predicting weather, detecting pollution, protecting biodiversity or monitoring the environment. More specifically, space-borne sensing technologies provide essential tools in support of the 2030 Agenda for Sustainable Development.

Figure 1:

Growth rate of patent filing activity (by publication year) in green applications of space-borne compared with filing in all technologies



>75.500 000	29.295	14.529	2.125
Overall patent families across all sectors	Patent families in the space-borne sensing domain	Patent families in green applications of space-borne sensing	Patent families filed in more than one jurisdiction[1]

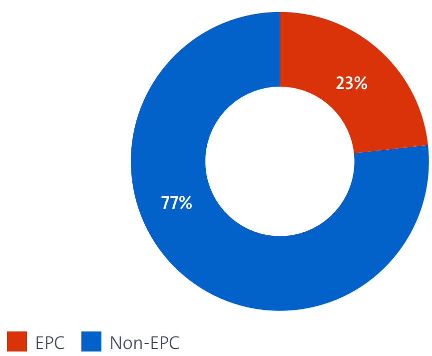
The analysis of global patent filing statistics highlighted the following key trends:

— Filings of patent families in green applications of space-borne sensing increased in 2020 by 1 800% compared with the numberof filings in 2001. This is very high compared with the growth of global patent filings in all technology fields, which amounted to 400% in the same period.

— Chinese patent filing activity prevails in the overall perspective, driven by domestic patent filing, while US applicants lead in international patent families.

Figure 2:

European patent filing activity vis-à-vis the rest of the world (international patent filings only)



1 International patent families – as a reliable proxy for inventive activity providing a control for patent quality by only representing inventions whose value the inventor considers to be sufficient to seek protection internationally.

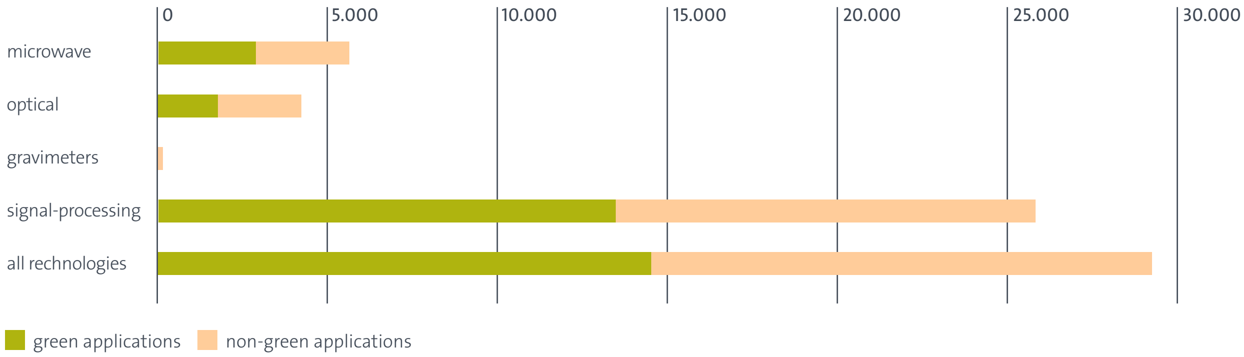
— Patent applications related to signal processing (software rather than hardware) drive the majority of patent filing activity.

— European activity remains limited and seems to stagnate in the global outlook, with most activity originating from traditional spacefaring European countries such as France, Germany and the United Kingdom.

The vast utility of space-borne sensing in addressing profound societal challenges, as evidenced by sustained public investment and emerging commercial ventures, will likely provide fertile ground for continued growth in patent filing activity.

Figure 3:

Technology breakdown of patent filings considered in the report



2. Introduction

2.1 Remote sensing via satellites

Today the international community, in developed and developing countries alike, is dependent on space technologies due to the huge socio-economic and security benefits they provide for day-to-day life on Earth. Data and services enabled by satellites have become an integral part of modern society, serving a variety of public policy objectives, but also commercial needs, as evidenced by the continuing growth of the sector. Among different space-enabled applications (e.g. localisation, navigation, time synchronisation and long-distance communications), space-borne remote sensing has long been one of the most prominent applications of the use of space technologies.

Remote sensing can be broadly characterised as gathering data "about an area or phenomenon through a device that does not touch the area or phenomenon under study"[2]. Remote sensing via satellites in space can reveal long-term environmental trendlines, detect illegal activities, monitor industrial and agricultural production or provide early warning in support of national security and myriad other useful applications.

Space-borne remote sensing is one among different data sources in the geospatial intelligence realm. Compared with other forms of sensing used to provide insights into activities, developments and long-term trends on Earth (e.g. in-situ or aerial sensing), the use of satellites offers some unique advantages (e.g. freedom of operation of spacecraft in Earth's orbit, coverage, opportunity for regular revisits...), enabling different use cases and business opportunities.

Simultaneously, employing satellites for various types of applications, including remote sensing, comes at a cost of specific technology problems, regulatory challenges as well as a significant financial burden. Nevertheless, thanks to advances in technology, solutions enabled by space-borne remote sensing data are increasingly accessible, including for non-technical end users. In turn, rapidly evolving satellite data is providing new opportunities for people, businesses and governments around the world.

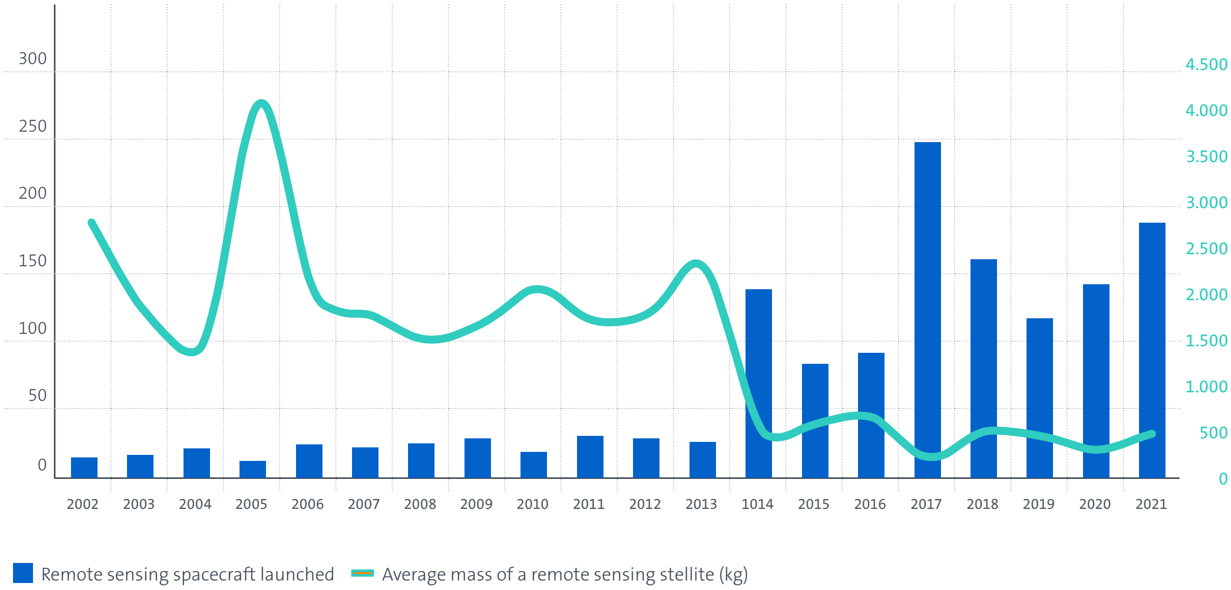
Over the last 20 years, 1 460 satellites have been launched for remote sensing purposes, addressing a variety of application areas, including weather, science, disaster management, and security and defence. A large majority of these spacecraft have been put into orbit[3] in the last eight years, notably benefiting from miniaturisation of space technology, which is a major trend in the space sector at large. Satellites launched into orbit are increasingly small devices (less than 500 kg). Smaller size generally drives down the production and launch costs, although it can have a profound impact on the capabilities of a given spacecraft. Furthermore, this also facilitates launching remote sensing satellites in larger constellations, enabling better revisit times with more satellites across the globe.

2 nasa.gov/content/remote-sensing/

3 Mostly the lower portion of the Low Earth Orbit, with mean orbital altitudes of less than 1 000 km.

Figure 4:

Number of remote sensing spacecraft launched per year over the past two decades, compared with average size (Source: ESPI Database)



2.2 Green applications

This study puts a spotlight on the utility of space-borne sensing for effective implementation of "green" policy objectives. These can be applications in support of mitigating climate change, predicting weather, detecting pollution, protecting biodiversity or monitoring the environment. As remote sensing data can also help to make human activities (e.g. economic activity, or activities in the fields of energy or transportation) more environmentally and climate friendly, they are critical for sustainable development. To facilitate the analysis in the latter part of this report, three broad groups of green applications of space-borne sensing have been identified:

1. **Understanding climate change (UCC)** – Space-borne sensing provides essential contributions to any sustainable solution to climate change, across the key phases of monitoring, understanding, modelling, predicting and acting.
2. **Enabling the green transition of economies and industries (GTE)** – Space-borne sensing enables the transformation of economic activities into more sustainable and efficient and less polluting activities.
3. **Protecting biodiversity, ecosystems and the environment (BEE)** – Space-borne remote sensing is a powerful tool in support of the protection and preservation of the environment.

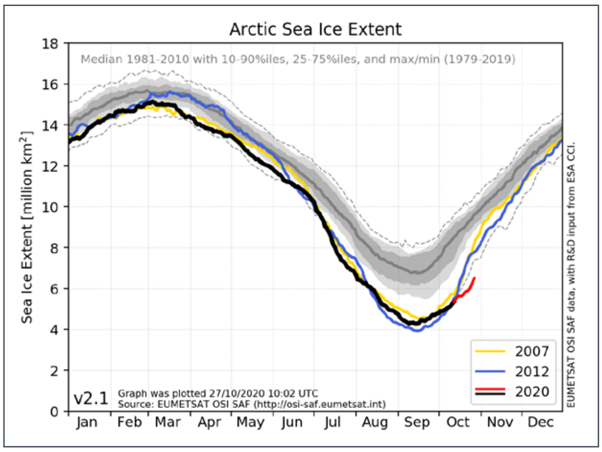
While there naturally are some functional overlaps between the three groups, the list below demonstrates a few selected use cases for each group:

Understanding climate change

Use case: Measuring arctic sea ice extent

A four-decade time series using data from multiple satellite missions over this period highlights that the arctic sea ice extent has been substantially lower in recent years than the median observed between 1981 and 2010 (lines in grey). This suggests a significant climate change-related issue, which is also at the heart of one of the Sustainable Development Goals, namely SDG 13: Climate Action

Image Credit: EUMETSAT



Enabling the green transition of economies and industries

Use case: Enabling precision and smart agriculture

Crop and farming analytics based on satellite data improve agricultural production by providing informed views on where and when to sow, fertilise, harvest, etc. In this and other industrial use cases, private providers often provide their services to end users directly, relying on tailored and proprietary software solutions.

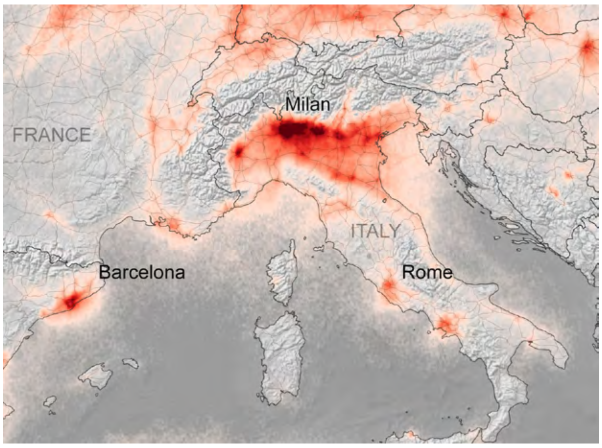
Image Credit: Airbus

Protecting biodiversity, ecosystems and the environment

Use case: Monitoring atmospheric pollution

Data from the Copernicus Sentinel-5P satellite provide insights into nitrogen dioxide concentrations in the atmosphere over northern Italy, contributing to our understanding of this air pollution that negatively impacts the health of animals and humans (e.g. by causing respiratory problems), degrades the environment and contributes to the development of other air pollutants.

Image Credit: modified Copernicus Sentinel data processed by KNMI/ESA



More broadly, **space-borne sensing technologies provide valuable tools in support of the 2030 Agenda for Sustainable Development,** closely linked to several of the 17 United Nations Sustainable Development Goals (SDGs), in particular:

It is the responsibility of governments to set and meet national targets that collectively will help to achieve the global ambition. Addressing the SDGs involves data- and statistics-driven strategies. In this regard, there is huge potential for space-borne remote sensing data to support the aim of the UN 2030 Agenda, as space-borne observations are, by their very nature, borderless, impartial and inclusive. Space-borne sensing is also a crucial data source for many of the indicators describing environmental aspects of the planet, and as a spatial disaggregation method of other geospatial statistics[4]. This crucial importance of space-borne sensing for SDGs is further reflected upon in the patent data analysis part of this report.

2.3 Fundamentals of the space-borne sensing value chain

The United Nations' Remote Sensing Principles of 1986[5] note that the term "remote sensing activities" means the operation of remote sensing space systems, primary data collection and storage stations, and activities in processing, interpreting and disseminating the processed data. At the heart of space-borne remote sensing, there are the fundamental questions of sensor type and performance, as different spectral ranges of electromagnetic radiation or gravitational forces reveal different insights.

At the same time, remote sensing from space is a data-driven domain, increasingly facing issues related to the generation of massive volumes of data and their storage, processing and analysis, thus posing specific technology challenges.

In general, the value chain of space-borne remote sensing solutions consists of the following key steps:

Mission and spacecraft design	Specification of the fundamental technology and operational characteristics framing the boundaries of what a given satellite or satellite constellation could achieve during its time in orbit
Manufacturing, testing, launch and deployment of satellite(s)	Necessary activities in (not only) the space-borne sensing value chain, translating the system from whiteboard design to a full-fledged operational system in Earth orbit
Satellite operations and data acquisition	A key set of activities intended to meet the mission objectives, such as planning of observations, tasking, data acquisition and transmission to ground infrastructures for further processing
Data processing and analytics	Activities related to the processing of raw data generated by the spacecraft into meaningful information and actionable value-added products and data sets (including image restoration, noise abatement, image enhancement, etc.)[6]
Delivery of final products or services to end users	Processes related to the provision of space-borne sensing products to end users (data, analytics, software subscribed service/SaaS, etc.). These processes can take various forms, such as contractual deliveries, commercial transactions or public service provision

4 eo4society.esa.int/wp-content/uploads/2021/01/EO_Compendium-for-SDGs.pdf
5 unoosa.org/oosa/en/ourwork/spacelaw/principles/remote-sensing-principles.html
6 nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/

Practice in the space-borne remote sensing sector suggests that public or private stakeholders can be engaged across all the activities in the value chain, but can also specialise in one or two specific steps. In particular, some public actors and private companies appear to focus exclusively on data analysis and subsequent activities in the value chain, without being engaged in the previous steps at all.

Such actors could either procure data from satellite data providers or benefit from public programmes, such as Copernicus[7] in Europe or Landsat in the US, which implement free data policies, including for commercial purposes. This reduces the entry barrier and improves business perspectives as companies entering the sector are not faced with the need for massive capital expenditures related to the deployment of dedicated space hardware.

2.4 Evolving investment dynamics and commercial perspectives

For decades, governments have sustained public investments in various satellite remote sensing programmes. In the European context alone, there are several ongoing space-borne sensing initiatives implemented by various organisations:

— the Copernicus programme, co-funded by the EU and ESA, providing Europe with comprehensive remote sensing capabilities, freely available data and tailored services for a variety of users

— ESA's series of science-driven Earth Explorer missions

— EUMETSAT's series of meteorology satellites Meteosat and Metop

— national or collaborative satellite missions by individual European countries, especially for the armed forces and intelligence communities.

The importance of space-borne sensing for governments could be further evidenced by recent activities around the world. Some examples:

— In 2021, China's civil and military institutions deployed more than 40 remote sensing satellites.

— Also in 2021, Canada launched a dedicated national Earth observation strategy, noting the critical role of satellite remote sensing in day-to-day evidence-based decision-making and planning.

— In 2022, Australia announced the launch of a National Space Mission for Earth Observation (NSMEO) programme with four satellites, worth close to AUD 1.2 billion.

In addition to developing and operating actual satellites, public actors engage in other parts of the remote sensing value chain, fostering greater uptake of data by more users, entrepreneurship and commercialisation of space-borne sensing data.

Beyond the public dimension, in recent years the space-borne sensing domain has showcased particular business dynamics. Leading economic assessments of the satellite-enabled Earth observation sector converge in:

— noting a considerable increase in the number of companies engaged in the sector and expansion in terms of sales, revenues and investment; and

— anticipating a continuing growth trendline (>5% CAGR) over the next decade, particularly in North America and Europe.

With regard to market size assessment, and in particular the data and value-added services dimension, recent estimates on market size and revenues in space-borne sensing range from EUR 2.7 billion to EUR 5 billion, , depending on the scope and methodology of reporting.

7 Europe's Earth observation programme Copernicus, headed by the European Commission (EC) in partnership with ESA, is the world's most comprehensive satellite Earth observation programme. It is composed of a series of Sentinel satellites, accompanied by contributing third-party satellites. Copernicus provides a unified system through which vast amounts of data are fed into a range of thematic services: land management, the marine environment, the atmosphere, emergency response, security and climate change.

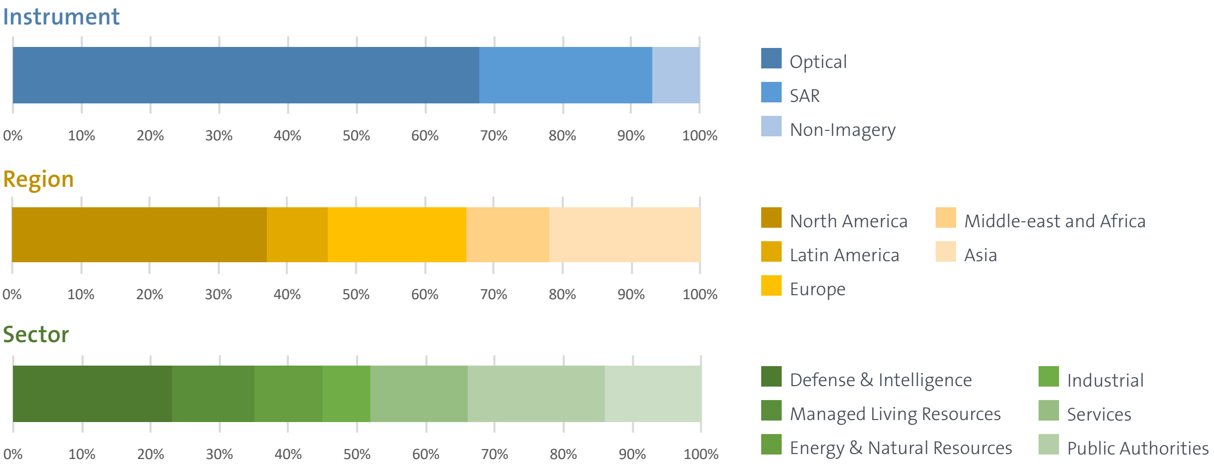
According to data from the European Association of Remote Sensing Companies, 2020 saw a 24% growth in the number of companies associated with the Earth observation industry compared with 2019.

The accessibility of the sector provides fertile ground for engagement of start-ups and SMEs, also in later stages of the value chain such as provision of data, products and services to customers.

Figure 5:

Earth observation market forecasts for the year 2028
(Source: NSR - NSR's Satellite-Based Earth Observation (EO), 11th Edition, 2020)

2028 global satellite-based Earth observation revenues



2.5 Key technology developments

Technology developments for space-borne sensing are manifold as specific technologies and needs exist for almost every application and mission. The targeted technologies for this study can be classified into four pillars:

Active and passive microwave instrument platforms and related	Active and passive optical instrument platforms and related subsystems	Gravimeters and related subsystems	Methods for signal processing

Overall, the ongoing and future technology developments will target key areas such as: [11]

— advancements in instrument performance, including higher spatial, spectral, radiometric and temporal resolution

— a beneficial cost ratio with regard to platform standardisation, increased flexibility and lifetime and lower overall cost

— miniaturisation of instruments and platforms

8 euroconsult-ec.com/press-release/towards-a-7-5b-earth-observation-data-service-market-by-2030/
9 euspa.europa.eu/european-space/euspace-market/earth-observation-market
10 earsc.org/wp-content/uploads/2021/10/EARSC-Industry-survey-2021.pdf
11 esa.int/Enabling_Support/Space_Engineering_Technology/Technology_Harmonisation

- advanced mission concepts for constellations, convoys and formation flight
- long-term data continuity
- advancements in machine learning and AI for pattern and feature recognition and Big Data analysis.

Other critical technology building blocks and market demands have been identified with the European Space Agency, the Technology Harmonisation Advisory Group and other stakeholders through the European Space Technology Harmonisation process.[12] The subsections below provide some additional details.

Lidar hardware

Lidar instruments have become an important new class of optical sensing tools which can be used in a large number of applications in the scientific, military, environmental and commercial domains, in both space-borne and ground-based settings. Key technology development issues that need to be resolved to ensure a high-power space lidar mission are:

- redesigned reference laser head with less stringent isolation requirements
- space-qualified ultra-stable master oscillator building block
- high-power low-distortion optical amplifier building block.

Microwave hardware

In the context of Earth observation, the cost of synthetic aperture radar (SAR) active antennas and related antenna subsystems remains a key issue, along with the overall thermal management of such antennas. Future concepts in space target multistatic SAR operations. In the altimetry domain, a critical design element has been identified in the RF amplifiers, where improved efficiency could help to reduce the number of output stages. For radiometry, a field of development lies in synthetic aperture radiometry and adapted data processing techniques. Future applications for microwave sensor hardware, including scatterometer radars, will be significantly driven by improved power handling.

Looking ahead to space-borne sensing of the 2030s

ESA is currently looking into proposals for the 11th mission within its series of “Earth Explorer” satellites, Europe’s flagship research missions, scheduled for launch in the early 2030s. Technology concepts and scientific objectives selected for further study as relevant candidates for this future mission include:

- first limb-sounder with infrared Fourier transform imaging technology in space (to foster understanding of the links between climate change, atmospheric chemistry and dynamics in the altitude range of about 5 to 120 km)
- an infrared Fourier transform imaging spectrometer and a visible imaging pushbroom spectrometer (for mapping reactive nitrogen on the landscape scale)
- dual-polarisation, conically scanning 94 GHz Doppler radar (to measure wind in clouds and deliver profiles of rain, snow and ice water)
- innovative squinted along-track interferometry for better observations of small-scale ocean surface dynamics in coastal seas, continental shelf seas and marginal ice zones.

Optical detectors

A main distinction in optical detectors for space technology is in the applicable wavelength. Optical detectors in the infrared range (IR) face different constraints, therefore, than optical detectors in the visible range (VIS).

Future IR detectors will have applications in manifold space missions, e.g. carbon measuring, atmospheric limb sounders, thermal infrared measuring and others. To meet the related needs and requirements, it is deemed necessary to enhance features such as the spatial and temporal resolution, the read-out speed and the operating temperatures and cooling of IR detectors.

VIS sensors for space applications are often full-custom developments or custom enhancements of high-end commercial products. Possible areas of improvement for charged coupled devices include black coatings, anti-reflection coatings, radiation hardness and higher resolution detectors.

12 Ibid.

Mirrors, active and adaptive optics

Due to increasing demands for higher resolution and contrast for future astronomy and Earth observation missions, the technologies related to active optics are considered key enabling building blocks for future large space missions or, more generally, missions requiring extreme contrast imaging. The three building blocks for future active optics concepts revolve around:

— deformable mirrors, tip/tilt mirrors (also known as corrective elements)

— wavefront sensing systems

— algorithms for correction calculation and control of the corrective element.

Furthermore, optical components will benefit from improvements in areas such as:

— mirror manufacturing for large monolithic mirrors

— coating design, manufacturing and testing

— measurement of surface accuracy.

Signal processing

Signal processing covers a broad domain of technologies associated with the modification and analysis of images, sounds or other signals. In remote sensing missions, signal processing occurs at different instances, such as payload data processing, on-board data management, general communication, ground data processing and further data exploitation.

In remote sensing missions, some key technologies for signal and data processing relate to

— data acquisition, integrity, archiving and quality control

— applications such as algorithms, models and intelligent data mining

— feature extraction, higher-level processing and visualisation.[13]

— As remote sensing of the Earth is becoming a more mature domain beyond institutional missions, an increase in big data volumes and speed of data generation is expected. This provides future challenges for algorithms to address automated information extraction, quality assurance, storage optimisation and interoperability of data formats.

2.6 The study

By virtue of their respective missions and activities, the EPO, ESPI and ESA share a common interest in the study of patent filing statistics to improve their understanding of trends affecting the space sector. In 2020 and 2021, the EPO and ESPI, in collaboration with ESA, published two patent insight reports:

1. The first report (July 2021) examined patent filing statistics over the past 30 years in cosmonautics to assess the relevance of that data to the identification of trends in the space sector.[14]

2. The second report (November 2021) addressed the evolution of patent filing activity in space applications of quantum technologies[15].

Building on that partnership, the present study launched in 2022 focuses on assessing patent filing statistics in the use of space-borne sensing in support of green applications. To do so, the study used various resources, including EPO patent databases and registers, ESPI publications, ESA technical expertise and other available public reports and scientific articles.

13 esamultimedia.esa.int/multimedia/publications/STM-277/STM-277.pdf
14 documents.epo.org/projects/babylon/eponet.nsf/0/E1DF0B13D852BB7BC12586FE0049DC4A/$FILE/patent_insight_report-cosmonautics_en.pdf
15 documents.epo.org/projects/babylon/eponet.nsf/0/BC7DEF9C8AE740C8C125877D004ED4C6/$File/patent_insight_

The European Patent Office examines European patent applications, enabling inventors, researchers and companies from around the world to obtain protection for their inventions in up to 44 countries. The EPO is the executive arm of the European Patent Organisation, an international organisation with 38 member states. The EPO's activities and budget are overseen by the Organisation's Administrative Council, which consists of representatives of the member states.

The European Space Policy Institute provides decision-makers with an informed view on mid- to long-term issues relevant to Europe's space activities. It provides recommendations, policy options and forward vision as to how Europe's engagement in space can bring maximum benefit to society. In this context, ESPI acts as an independent platform for developing positions and strategies.

The European Space Agency is an intergovernmental organisation with 22 member states. It is Europe's gateway to space. Its mission is to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the citizens of Europe and the world. By co-ordinating the financial and intellectual resources of its members, it can undertake programmes and activities far beyond the scope of any single European country.

2.7 Using patent information

Patents are exclusive rights that can only be granted for inventions in any field of technology, provided that are novel, inventive and industrially applicable. High-quality patents are assets which can help attract investment, secure licensing deals and provide market exclusivity. Inventors pay annual fees to maintain patents that are of commercial value to them and protect their inventions from being openly used by others, including competitors, in all protected markets. A patent can be maintained for a maximum of 20 years. In exchange for these exclusive rights, all patent applications are published, revealing the technical details of the inventions in them.

Patent databases therefore contain a wealth of technical information on both patent applications and granted patents, much of which cannot be found in any other source and which anyone can use for their own research purposes. The EPO's free Espacenet database contains more than 130 million documents from over 100 countries and comes with a machine translation tool in 32 languages. Patent filing statistics provide interesting indicators to measure and examine innovation, commercialisation and knowledge transfer trends. The protection of intellectual property is very well documented in national and international databases and registers, which track bibliographic and legal event data on patent applications.

Dedicated exploitation of these patent databases and registers can reveal new insights into sector trends and support informed decision-making processes. Patents provide means of observing technology trends, key innovators and policies in various jurisdictions. For this purpose, patent searches are useful to identify patent documents related to specific technologies. The result sets of these searches are generally appropriate for statistical analyses on patent aggregates such as company portfolios or comparisons between countries. Statistical analyses are not recommended for the assessment of single, specific patents.

This information can be combined with further public information such as national R&D budgets and specific market studies.

2.8 Methodology

The information, data and analysis provided in this study are primarily based on dedicated exploitations of EPO patent databases (e.g. PATSTAT) and registers covering relevant patent publications between 2001 and 2021. The EPO was responsible for creating the domain-specific queries and the structured dataset for the analysis, with assistance from several ESA experts to identify relevant technologies.

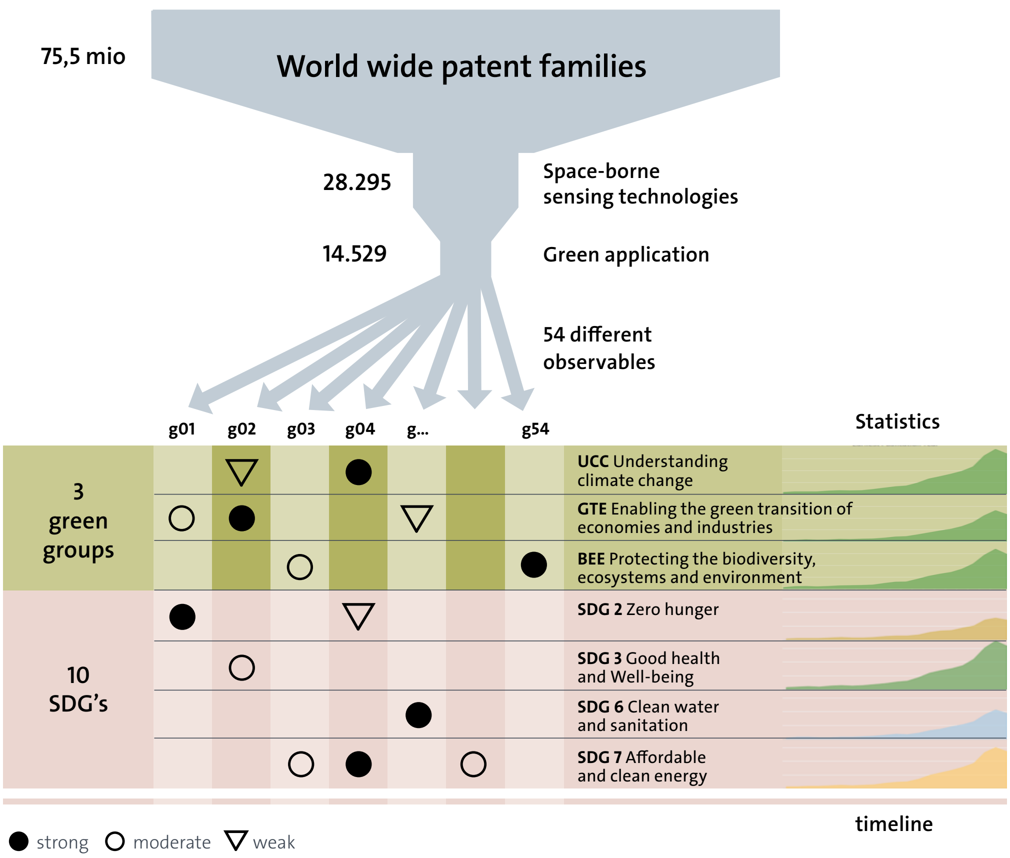
The search queries were developed and validated in the examiner tool ANSERA. The queries covered three dimensions: remote sensing technologies, their use in space and 54 green observables (e.g. soil humidity). Over 2 500 queries were automatically run in a Jupiter notebook that used ANSERA's concept management tool to tag all combinations of technologies and green applications.

Based on expert input, a matrix was created to link observables to climate, economy and environment as well as to the SDGs. To improve precision and reduce overlap it was assessed in detail whether the link of the observable was strong (100%), moderate (60%) or weak (20%).

This way it is possible to analyse the innovative contributions to the green application groups and SDGs on various statistical levels, from single patents to key actors and even countries.

Figure 6:

Outline of study methodology



3. Analysis

3.1 Patent filing activity in space-borne sensing has grown rapidly, notably surpassing the overall trendline

"Space-borne sensing and green applications" is a fast-growing domain, with filings of patent families increasing by 1 800% in 2020 relative to 2001. This is a very strong increase compared with the growth of global patent filings in all technology fields, which amounted to 400% in the same period.

This high growth is mainly caused by the increasing number of filings in the subdomain of signal processing, which also covers a majority of the patents in the analysed dataset.

The most prominent jurisdictions used in the study are China, the US, WIPO and the EPO, protecting the respective markets[16].

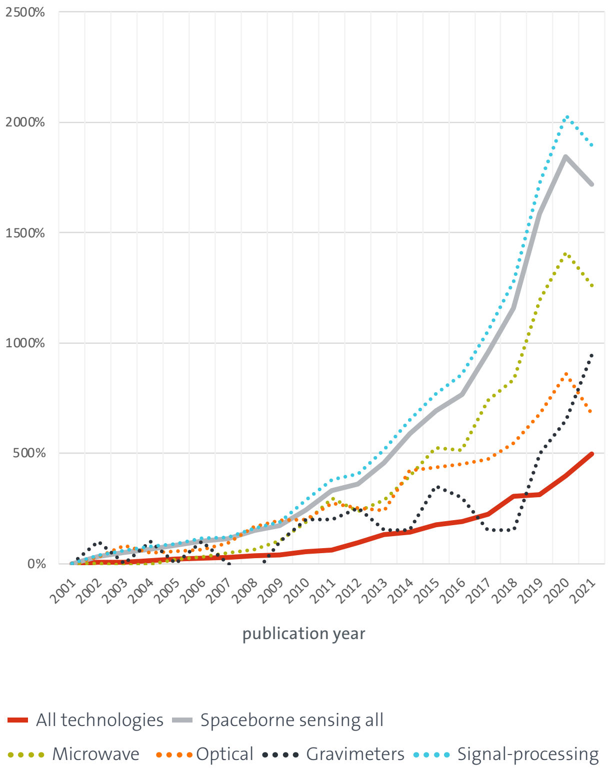
The striking presence of filings in China is discussed in section 3.3.

The vast utility of space-borne sensing in support of various business cases and public policies, accompanied

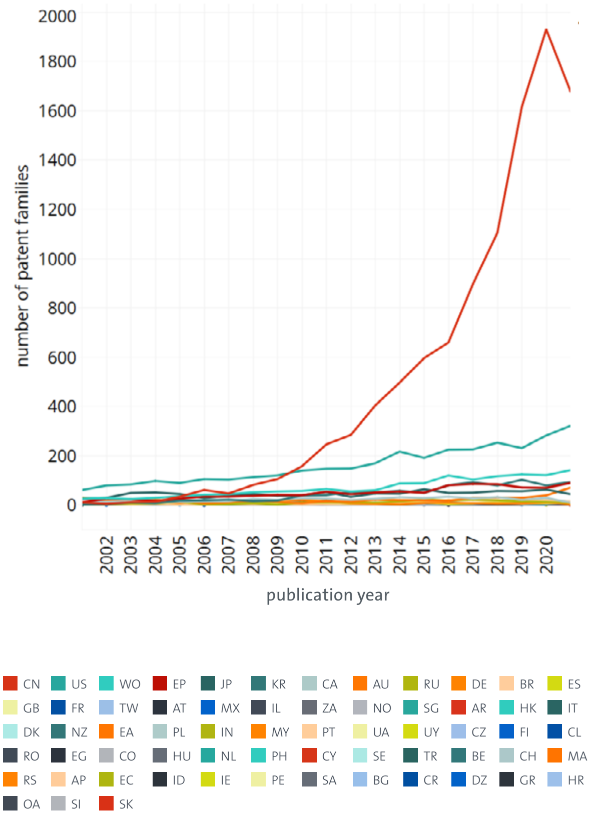
Figure 7:

High growth rate of patent filing activity in green applications of space-borne sensing

Growth of patent families compared to 2001



Worldwide patent families per jurisdiction



16 Please bear in mind that the data for 2021 is incomplete in all charts, since the spring edition of PATSTAT covers only data until week 49 of that year and some international data arrived later at the EPO.

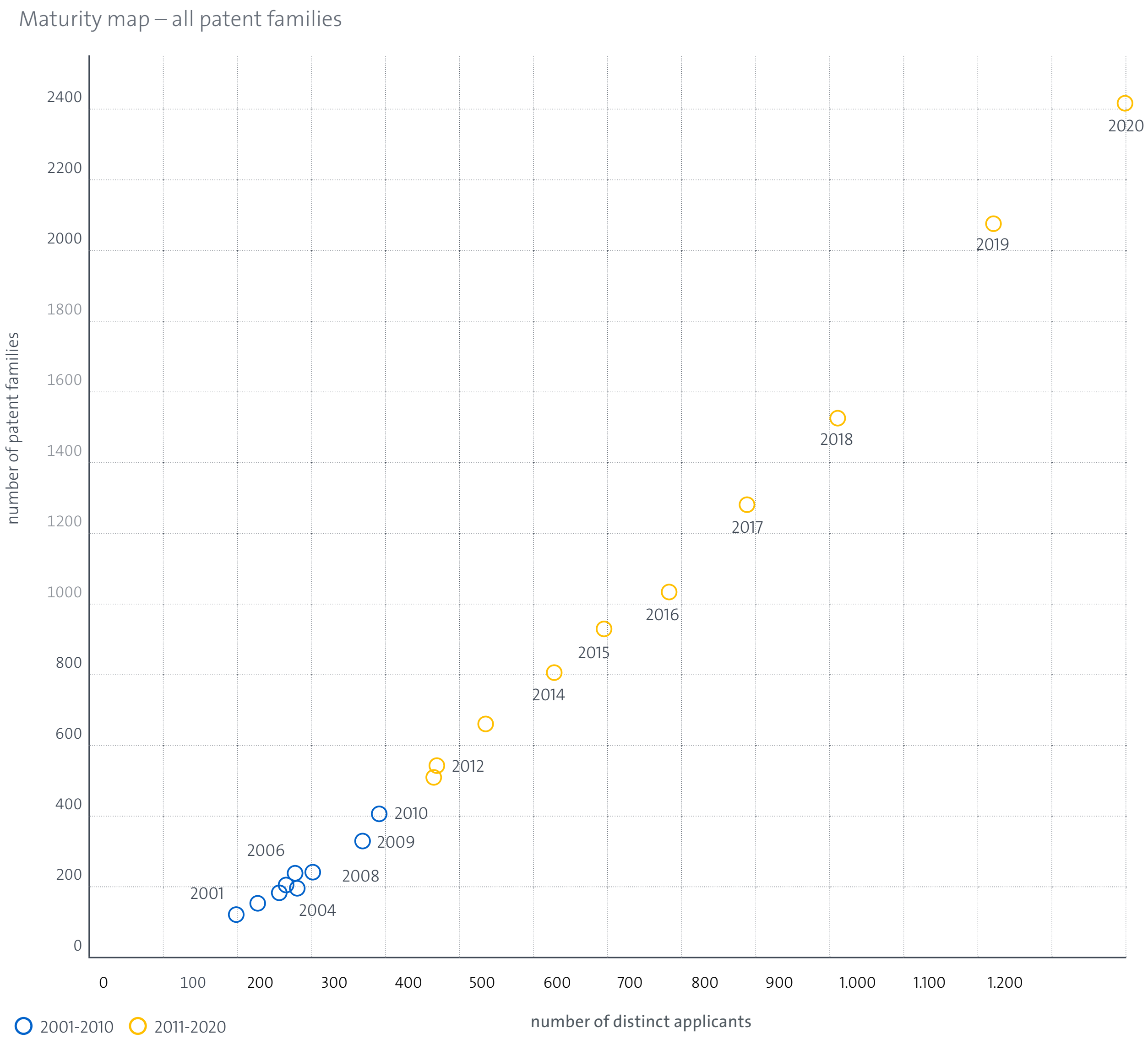
by profound societal challenges that could be addressed using satellite data, will likely provide a fertile ground for sustained growth in patent filing activity.

The maturity map compares the number of applications with the number of distinct applicants. The linear and accelerating growth is typical of a thriving industry. It is nevertheless remarkable to find such constant and continuous growth over a period of 20 years.

Similar to Figure 7, an increased rate of filings from a growing number of distinct players can be observed from 2011 onwards. It will be interesting to see whether this trend continues in the coming years.

Figure 8:

Maturity maps for patent filing activity in green applications of space-borne sensing



3.2 A diverse set of key observables drive patent filing activity

The methodology for this study included elaboration of more than 50 individual green-related observables across the land, water and air domains, which were individually elaborated in search queries for retrieval of patent filing data. The resulting dataset makes it possible to compare the number of inventions across individual observables. Interestingly, observables with the highest levels of patent filing activity for green applications of space-borne sensing include a rather diverse set of indicators, such as:

— crop productivity

— land use

— rivers / coastal zones

— water vapour / clouds

— extreme events.

These topics seem to spur far more patenting activity, since they promise far more commercial opportunities than the big environmental topics such as rising sea levels and global warming – which are highly significant for the future of mankind.

In contrast, the patent document statistics show relatively small numbers of patents for

— soil erosion and permafrost thaw

— deforestation

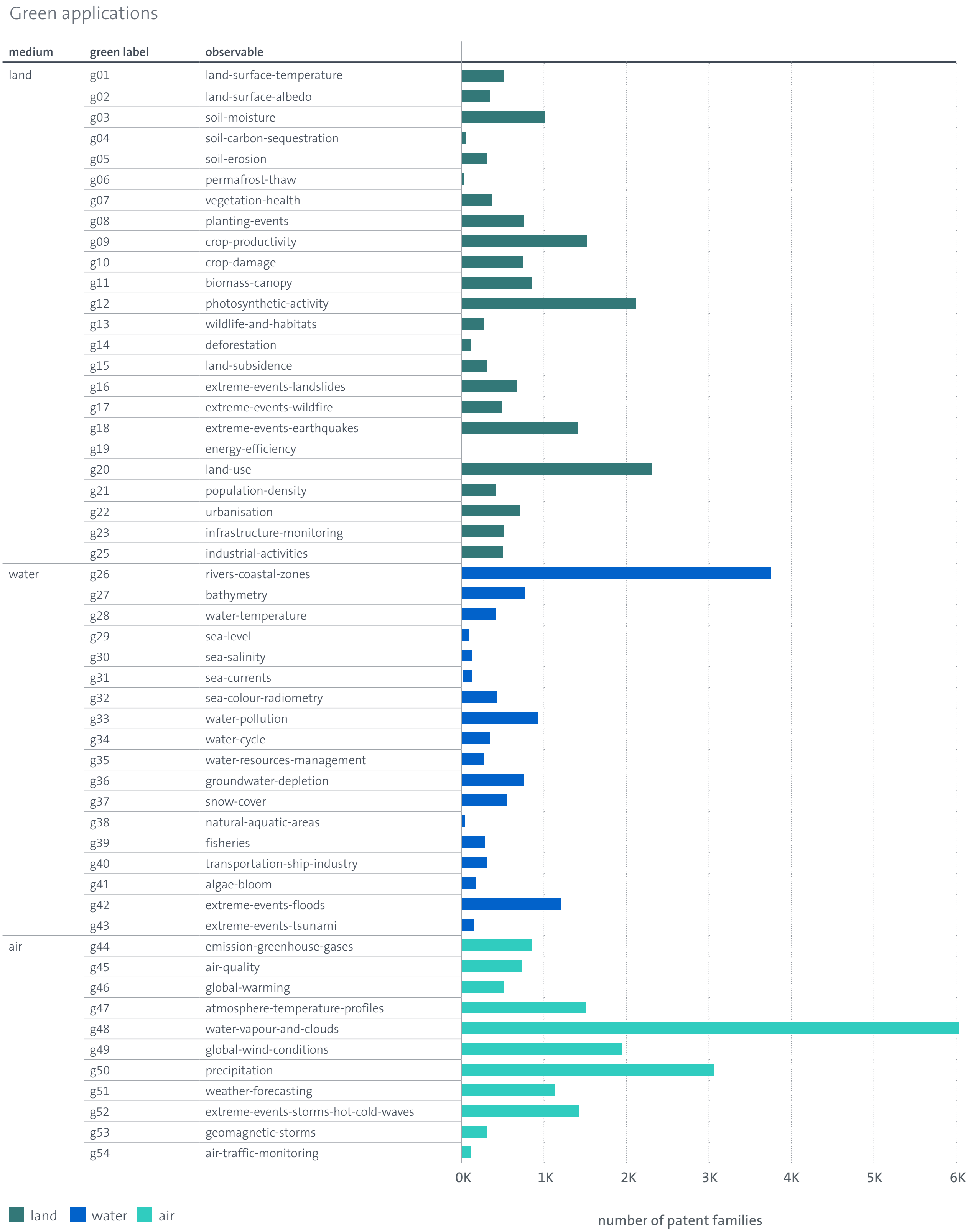
— sea level, salinity and currents

while such observables often play a prominent role in discussions about biodiversity and environmental protection.

Lastly, the predominance of some air-related observables reflects the importance of patents, and a mature economy, in the domain of weather forecasting and similar applications.

Figure 9:

Composition of the core dataset broken down into individual observables



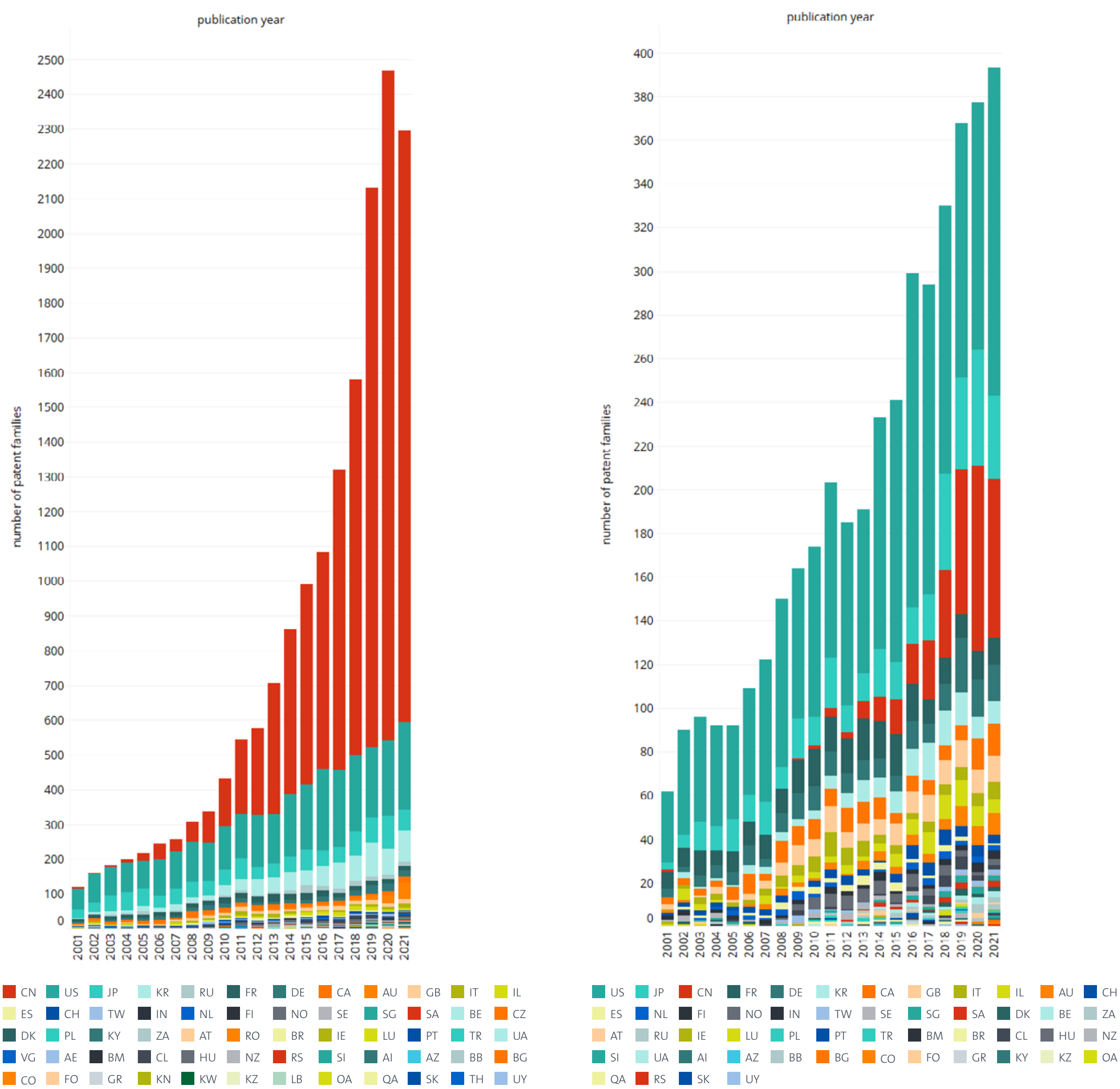
3.3 Patent filings from Chinese applicants prevail in the local perspective whereas US applicants lead in international patent families

The prominence of patent filing activity originating from China is particularly notable in recent years, marked by an accelerating growth rate.

Plausible explanations for this trend are to be found in both space sector trendlines and in the evolution of IP protection worldwide. In recent decades, China has significantly extended its space programme, investing in various capabilities, including in satellite remote sensing systems and related applications. As regards publicly funded programmes, China has led the global statistics in the past few years, continuing the deployment of

Figure 10:

Timeline of patent filing activity in space-borne sensing by country of applicant
(graph on the right considers international patent families only)



remote sensing satellites for meteorology, the military, resource management and other purposes. What is more, the Chinese space sector is increasingly engaged in commercial space-borne sensing endeavours, contributing to a worldwide trend.

Beyond the increasing development of remote sensing technologies and the progress of the Chinese space programme in satellite remote sensing, the number of Chinese patent filings may also be explained by other factors.

— The increase in domestically filed patents was defined as an official policy objective in the Chinese National Patent Development Strategy of 2011-2020. That strategy explicitly called for the establishment of measures that would incentivise the number of filings.[17]

— Patent applications have risen sharply as applicants are now rewarded with government subsidies, job offers, the attribution of high and new-technology enterprise (HNTE) status to filing institutions, a corporate tax reduction of 25%, etc.[18] In addition, patent application fees were abolished in 2018 to encourage and facilitate filings.

However, the rise in the number of patent filings is not necessarily an indication of significant scientific discoveries or innovation.

Public incentives to patenting often lead to a significant number of patents being granted to incremental or negligible advances or improvements of existing technologies rather than new inventions or innovations.

In the case of China, while applicants are encouraged to file for patents, there seems not to be an incentive to seek long-term protection for their inventions and usually discontinue the patents after a few years due to rising fees.

As a result, Chinese patents are mostly filed domestically.

First applicant country	Patent families	International patent families (ratio)	EP or WO (ratio)
CN	9 921	185 (2%)	130 (1%)
US	1 714	706 (41%)	674 (39%)
JP	928	251 (27%)	187 (20%)
KR	764	96 (13%)	58 (8%)
RU	159	5 (3%)	4 (3%)
FR	140	120 (86%)	113 (81%)
DE	120	100 (83%)	91 (76%)
CA	102	72 (71%)	53 (52%)
AU	98	32 (33%)	29 (30%)
GB	56	50 (89%)	50 (89%)
IT	55	42 (76%)	41 (75%)

The ratio of international filings is very low for Chinese, Russian and Korean applicants, rises to over 30% for Japanese and Australian applicants, to 40% for US applicants and to over 70% for Canadian and European applicants.

When filtering the data down to only “internationally” filed patent families (in two or more countries), the position of China in the analysed dataset changes significantly, leaving the US as the overall leader. Nevertheless, international patent filing activity from China has seen significant growth. As regards applicants from other countries, the yearly statistics show fairly stable patent filing activity in Japan, France, Germany, the United Kingdom and the Republic of Korea.

Concerning the top applicants for patents enabling green applications of space-borne sensing, the figures below provide a few insights, addressing the overall statistics and filtering for international patent families only. It can be observed that the prominence of Chinese patent filing activity in the overall perspective is largely driven by applications from universities. When the international patent families filter is applied, the list of top players primarily includes companies.

17 asia.ub-speeda.com/en/intellectual-property-china-global-leader-innovation/
18 cigionline.org/articles/what-do-chinas-high-patent-numbers-really-mean/#:~:text=Instead%20of%20being%20innovation%2Ddriven,as%20national%20high%2Dtech%20enterprises.

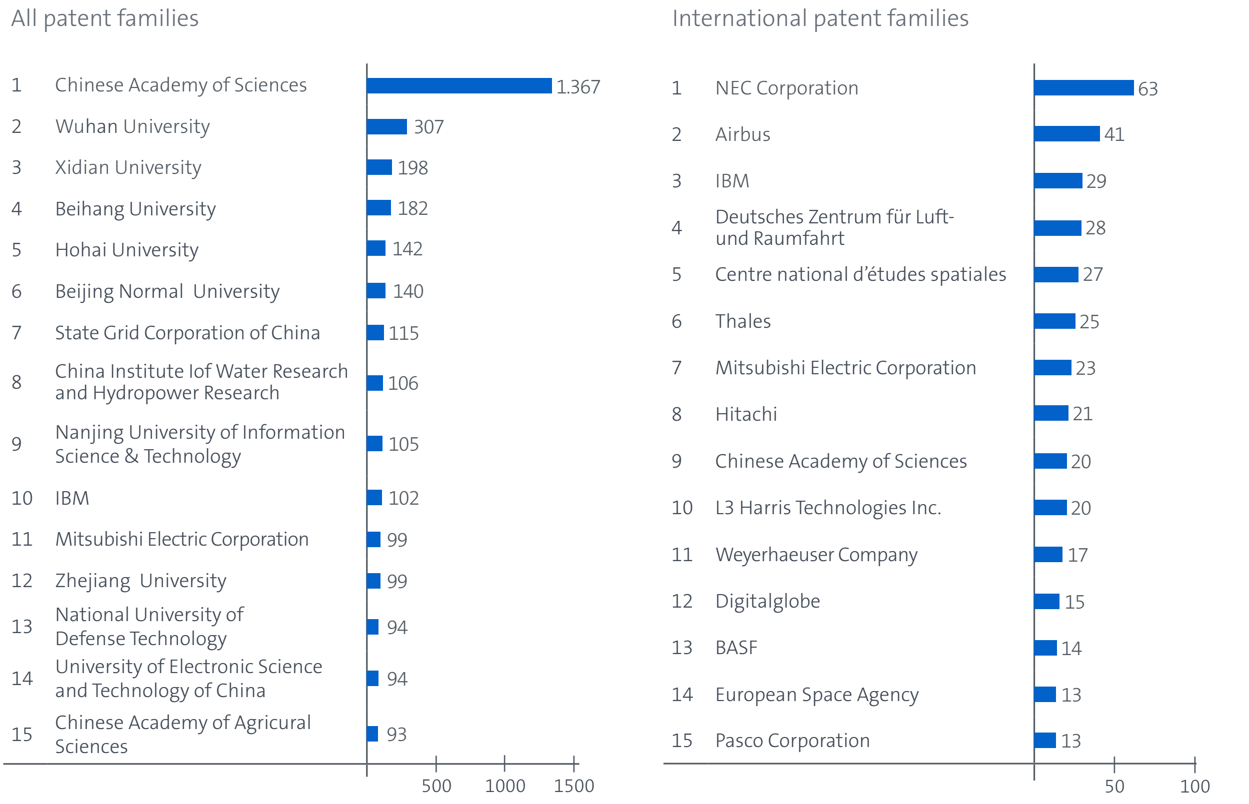
As already outlined in Figure 10, the rate of international filings by Chinese companies is very low, in line with the country statistics. With regard to the key top players, IBM, Mitsubishi Electric Corporation and Hitachi file less than a third internationally, NEC two thirds and the top European applicants up to 100%.

3.4 Patent applications related to signal processing (software rather than hardware) drive the majority of patent filing activity

With respect to the technology breakdown of the analysed dataset, this study found that the majority of patent families related to computer-implemented inventions, i.e. "signal-processing software", rather than "hardware", as evidenced in the figure below. The signal-processing group represents close to 70% of the total dataset, driven by patent filings in information extraction.

Figure 11:

Top applicants



This dominance of software patents is also influenced by the study design, in that the dataset was limited to green applications, which are much more likely to be mentioned downstream in the data analysis than upstream in inventions relating to hardware such as optical elements, cameras or antennae, which are often designed to serve multiple purposes.

Only a very small portion of patents from the retrieved dataset relate to gravimeters. As analysed in the "Quantum technologies and space" patent insight report[19], especially patents in the domain of quantum gravimeters seem very rare.

Furthermore, in contrast to Figure 5, the analysed dataset indicates almost equal numbers of patents in the SAR technologies (2301) and optical inventions (2074) domains. Another notable trait of the dataset is the pre-eminence of SAR-monostatic patents over bistatic concepts, which appear to be rarely mentioned explicitly in connection with green applications.

Figure 12:

Technology breakdown

Technology map

technology level 1	technology level 2	technology level 3	technology level 4	number of patent families
Microwave	Microwave-radiometers-passive	Microwave-radiometers-synthetic-aperture		11
		Microwave-radiometers-unspecified		108
	Radar	Athmospheric-radar		233
		GNSS-based-remote-sensing	GNSS-reflectometry	282
			Radio-occultation	133
		Radar-others		128
		SAR	SAR-altimeter	175
			SAR-bistatic	90
			SAR-monostatic	2.006
		Scatterometer		1.062
Optical	LIDAR	LIDAR-attitude		3
		LIDAR-imaging		317
		LIDAR-meteorological-use		149
	Passive-optics	Cameras		373
		Optical-components		251
		Optical-radiometry		957
Gravimeters	Non-quantum-gravimeters			91
	Quantum-gravimeters			2
Signal-processing	Information-extraction	Analysis	Analysis-others	8.825
			Image-analysis	1.405
			Information-retrieval	822
			Validation	222
		Modelling	Forward-models	1.051
			Inversion-models	1.067
			Modelling-others	8.469
			Processing-chain	1.067
	Pre-processing	1D-signal-pre-processing		20
		Calibration		874
		Image-enhancement		716
		Image-transformation		376

0K 2K 4K 6K 8K 10K

number of patent families

Technology level 1

Microwave Optical Gravimeters Signal-processing

19 documents.epo.org/projects/babylon/eponet.nsf/0/BC7DEF9C8AE740C8C125877D004ED4C6/$File/patent_insight_report_quantum_technologies_and_space_en.pdf

The majority of signal-processing patents are found in information extraction methods, which highlights the importance of data processing and product or service delivery for customers, as mentioned in section 1.3. The strong dominance of the category "others" for signal-processing analysis and modelling suggests a high overlap of different techniques that are combined for such inventions and are not clearly assignable to a specific category.

Open data and other trends at play

The value and utility of space-borne sensing revolves around the production of data and the provision of related services. Limited infrastructure enables various application uses by a plethora of actors. From the data perspective, the space-borne sensing domain is increasingly shaped by open-data policies. Adopted across the world, such policies facilitate access to and the exploitation of space-borne sensing-derived information. The segment of satellite meteorology has historically spearheaded an open-data approach.

More recently, this approach has been introduced for two giant remote sensing programmes: Landsat in the US (2008) and Copernicus in Europe (2013). Private actors also tend to increasingly engage in the provision of specific datasets for non-commercial use. Additionally, specific mechanisms exist for government-led sharing of space-borne sensing data at international level. The greatly increased availability of space-borne sensing data may be correlated to the major growth of patent filing activity in signal processing.

Several related trends invite further reflection on the link between open data and patent filings in space-borne sensing:

— digitalisation of the economy and of the space sector

— open-data policy in the economy in general

— EO hardware development and other technology development driving growth.

Figure 13 presents an advanced view by combining the mentioning of green observables with the technology domains specified in patent documents. For example, SAR technologies are often mentioned together with keywords for:

— earthquakes, land subsidence, landslides

— crop productivity, biomass canopy

— rivers and costal zones

— water vapour, clouds and precipitation.

Another noticeable trait of this technology mapping is the widespread mention of optical radiometry in air-related observables.

Such mentions may refer to the fact that certain observables are amenable to detection by such technologies, or have a certain advantage over other detection methods. In the case of SAR technologies, one of the main advantages of surface observation through SAR instruments is the possibility to permeate clouds, allowing for observation independent of cloud coverage and even at night[20].

20 Further examples of information on observables and technologies can be found at sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-1-sar/applications/land-monitoring for SAR remote sensing by Sentinel-1, as well as other Sentinel missions (sentinels.copernicus.eu/web/sentinel/home).

Figure 13:

Technology breakdown mapped to observables

Green applications and space-borne sensing technologies

		Gravimeters	Microwave							Optical						Signal-processing					
			Athmospheric-radar	GNSS-based-remote-sensing	Microwave-radiometers-synthetic-a..	Microwave-radiometers-unspecified	Radar-others	SAR	Scatterometer	Cameras	LIDAR-attitude	LIDAR-imaging	LIDAR-meteorological-use	Optical-components	Optical-radiometry	1D-signal-pre-processing	Analysis	Calibration	Image-enhancement	Image-transformation	Modelling
land	g01 land-surface-temperature	3	4	8	3	39		22	17	4		9	14	1	107	1	403	31	14	8	442
	g02 land-surface-albedo	1	11	5		7	1	19	16	7		26	9	6	53	1	273	43	12	4	319
	g03 soil-moisture	18	8	100	5	15	4	148	83	17		15	8	2	62	1	810	60	21	11	797
	g04 soil-carbon-sequestration							9	3			3	1		2		56	2	3		54
	g05 soil-erosion	2	3	3		1	1	37	14	6		3		1	12		290	18	17	7	252
	g06 permafrost-thaw	1		1			1	10	5			1	1		2		32	2	2		29
	g07 vegetation-health	4	1	3		4		35	10	5		6	2	1	25	2	338	12	30	7	303
	g08 planting-Events			4				69	20	7		4			52	3	667	37	26	7	583
	g09 crop-productivity	6	8	23		3	3	161	63	26		14	8	6	90	4	1.312	91	82	36	1.170
	g10 crop-damage	1	2	10		4		85	32	17		4	5	5	55	1	626	40	43	12	572
	g11 biomass-canopy	1	1	17		4	7	137	77	15		42	5	5	51		742	57	30	14	728
	g12 photosynthetic-activity	2	4	4		20	1	142	45	25		42	15	12	186	6	1.844	123	112	42	1.724
	g13 wildlife-and-habitats	1		4		1	1	25	11	7		9		4	15		255	8	10	4	222
	g14 deforestation	3		1			1	28	13	1				3	5		111	1	9	4	81
	g15 land-subsidence	4	3	3			10	224	154	3		1		1			269	10	2	2	246
	g16 extreme-events-landslides	2	3	18			13	235	149	8		1	1	1	18		561	17	15	10	501
	g17 extreme-events-wildfire	1	4	6		8	1	31	14	22		7	2	12	69		394	31	28	15	335
	g18 extreme-events-earthquakes	27	12	31	2	7	17	329	198	33		14	8	20	74	1	1.143	76	50	23	995
	g19 energy-efficiency			2		1	1	1		1		1	1		5		19	5	1	2	17
	g20 land-use	5	2	17		12	9	312	114	37		27	10	20	154	3	1.998	106	151	73	1.786
	g21 population-density	1	3	3		1	1	58	24	2		2	1	1	19		354	13	12	10	359
	g22 urbanisation	3	1	6		6	1	81	24	7			3	2	28		615	28	45	15	569
	g23 infrastructure-monitoring	3	6	13		3	7	71	43	10		4	1	3	18		423	27	9	5	373
	g25 industrial-activities		3	4		1	3	98	58	11		11	5	7	48		406	27	19	7	361
water	g26 rivers-coastal-zones	30	69	68		17	25	603	247	64		63	23	22	159	6	3.158	176	199	116	2.851
	g27 bathymetry	13	9	28			9	110	40	9		22	9	3	33	3	623	56	20	9	588
	g28 water-temperature	3	4	8		7	4	29	10	3		3	2	4	44		352	42	7	5	290
	g29 sea-level	7	4	8			6	15	4	1	1	1	1		4		77	6	2	1	74
	g30 sea-salinity	1	4	18	4	3	3	37	26	1		2	2		7		91	9	2		105
	g31 sea-currents	1	6	5		2	2	43	40			2	2		5		92	9	1	1	81
	g32 sea-colour-radiometry		6	2		6		27	9	5		18	5	15	65	1	356	45	16	6	331
	g33 water-pollution	6	13	19		3	1	98	36	18		11	2	15	70	2	790	51	36	7	682
	g34 water-cycle	13	15	16		7	1	29	15			8	12	1	23	1	270	12	7	6	321
	g35 water-resources-management	10	5	5		2		33	14	1		2	1		10		246	9	8	5	236
	g36 groundwater-depletion	28	8	10		6	4	137	74	8		10	8	2	32		658	42	18	16	596
	g37 snow-cover	10	23	43		7	5	118	70	5	1	25	8	4	26		413	28	26	11	402
	g38 natural-aquatic-areas			1		2		2	5	1		1	1		4	1	50	8	2	1	38
	g39 fisheries	4	5	18		2	1	28	14	4			1	1	33		228	20	11	2	179
	g40 transportation-ship-industry	1	2	24		2	6	119	44	4		1			4		217	7	22	5	207
	g41 algae-bloom		1	1		1		10	6	5				3	14		158	7	6	2	132
	g42 extreme-events-floods	14	30	12		2	4	225	78	18		14	6	8	34	3	1.024	49	57	21	919
	g43 extreme-events-tsunami	3	3	12			2	28	20	5		1		2	1		113	3	2	1	107
air	g44 emission-greenhouse-gases	3	4	11		7		64	22	20		20	28	26	142	1	683	98	12	4	622
	g45 air-quality	1	10	10		9	3	19	11	20		34	32	9	137	2	576	76	22	5	561
	g46 global-warming	4	8	12		5		56	28	9		13	18	6	69		430	40	12	2	381
	g47 atmosphere-temperature-pro..	11	53	74	6	45	10	92	60	16		40	46	29	237	1	1.111	143	14	8	1.128
	g48 water-vapour-and-clouds	17	136	132	5	59	36	777	389	180	3	182	109	88	452	9	4.688	435	396	193	4.440
	g49 global-wind-conditions	12	89	109		17	24	217	168	18		46	40	10	107	2	1.512	119	24	9	1.513
	g50 precipitation	32	145	77	4	21	30	387	221	48		34	35	26	149	5	2.424	159	82	35	2.304
	g51 weather-forecasting	8	82	54	1	12	2	60	49	11		5	28	4	82	1	889	49	8	11	817
	g52 extreme-events-storms-hot-c..	24	71	46	1	13	8	124	62	10		15	20	13	76	3	1.188	72	33	14	1.131
	g53 geomagnetic-storms	5	1	8			2	17	7	5		2	1	6	19		253	29	1	2	218
	g54 air-traffic-monitoring		5	23	1	1	2	10	13	4		1	2	5	5		73	9	1	1	75

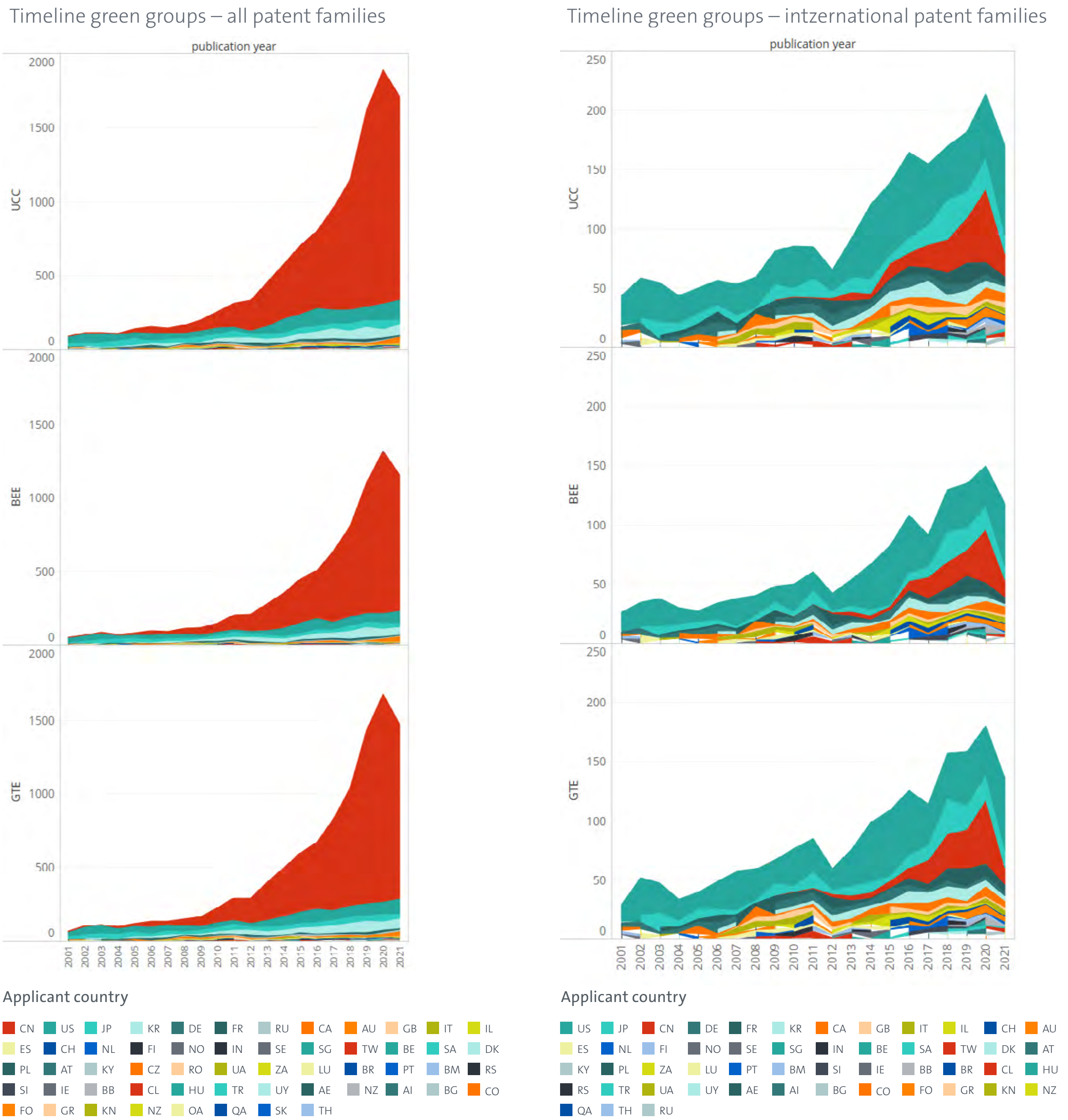
3.5 Comparable trendlines for three groups of green applications

The contributions of each patent via the green observables to the three groups (climate change, environmental protection and sustainable economy) were determined using the methodology outlined in section 1.8.

It is important to note that the application of this perspective to the data revealed a partial overlap among the three groups, meaning that a patent family suitable for one domain may also fall within one or both of the other domains. This observation may suggest a transversal applicability of space-borne sensing technologies across the different "green" application areas.

Figure 14:

Temporal development and primary countries of patent applications in the three groups of green applications of space-borne sensing (graph on the right considers international patent families only)



3.6 European activity remains limited and appears to stagnate in the global perspective, with the majority of patent applications originating in the traditional European spacefaring countries

In a regional perspective with a European focus (38 parties to the European Patent Convention), the analysis revealed two primary observations:

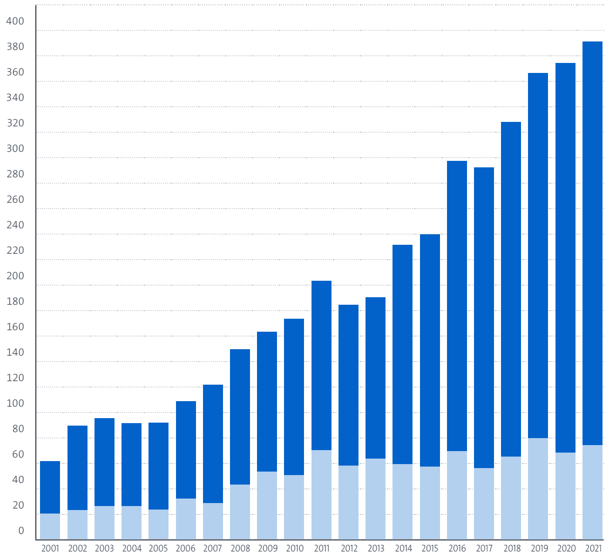
— In comparison with the rest of the world (including international patent families only), European patent filing activity remains at approx. 25% of the overall statistics. This figure would be lower if the analysis considered the complete dataset, which is dominated by domestic Chinese filings. What is more, from a temporal perspective this comparison also reveals that while European patent filings have stagnated in the last decade, the number of annual patent applications by non-European applicants has grown by a factor of two.

— European patent filing activity generally takes place in France, Germany and the United Kingdom, which are the traditional European spacefaring countries. Other notable countries in the dataset include the Netherlands, Norway, Italy, Spain and Switzerland.

Figure 15:

European patent filing activity in space-borne sensing

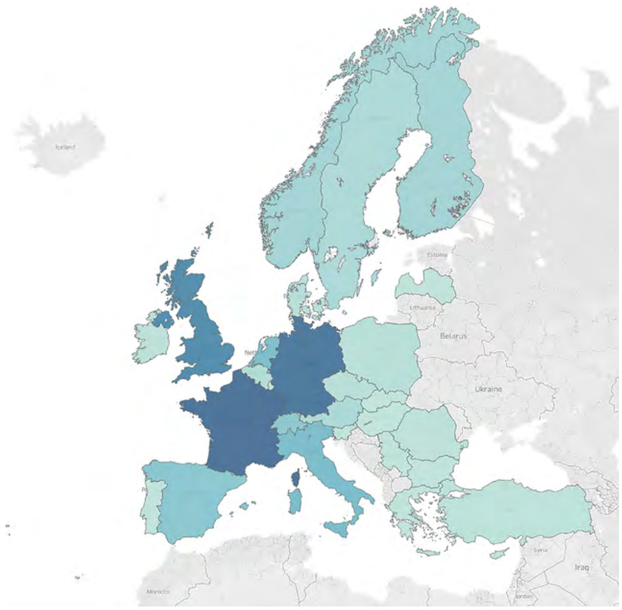
Applicant country – EPC



Applicant EPC

no yes

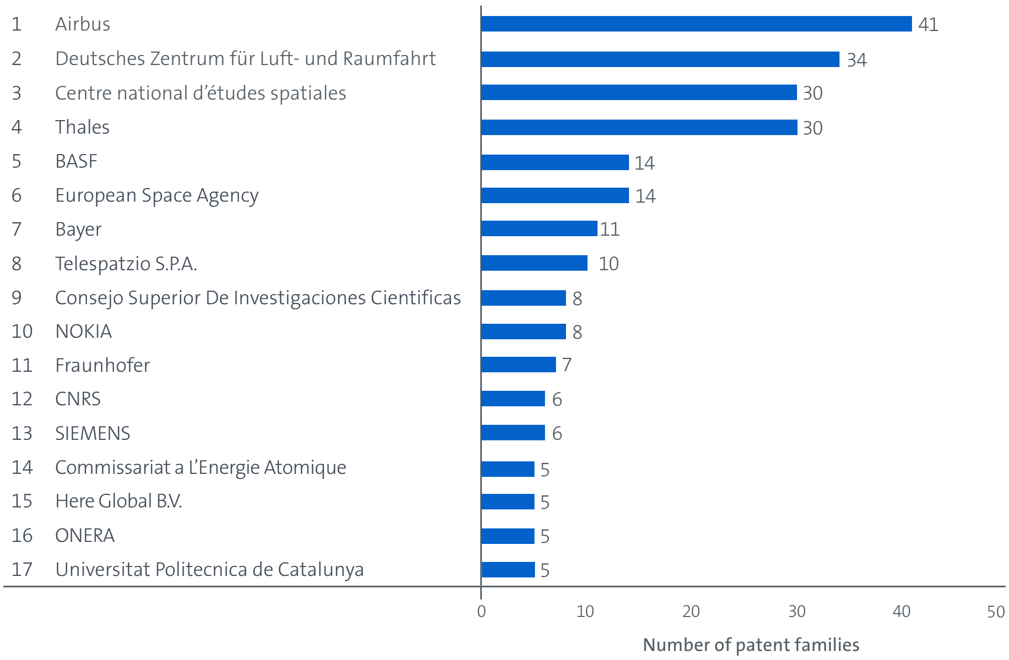
Applicant country EPC



The list of top European players in green applications of space-borne sensing includes major space actors, namely industrial players and space agencies. Furthermore, the data show that top applicants from EPC countries are also operating in other fields such as agricultural chemistry, geophysical and mapping services.

Figure 16:

Top players in Europe (with five or more patent families)



Examples of inventions to support green applications from the top EPC applicant list include:

- correcting a digital image by geometric adjustment for ground elevation models
- a method for the elimination of shadow effects in remote sensing data over land
- interferometric radio occultation for inferring physical properties of a portion of the atmosphere
- a decision system for a crop-efficiency product application using remote sensing-based soil parameters
- automatic detection of fires on the Earth's surface and atmospheric phenomena such as clouds, veils, fog, etc.
- systems and methods for refining aerial images.

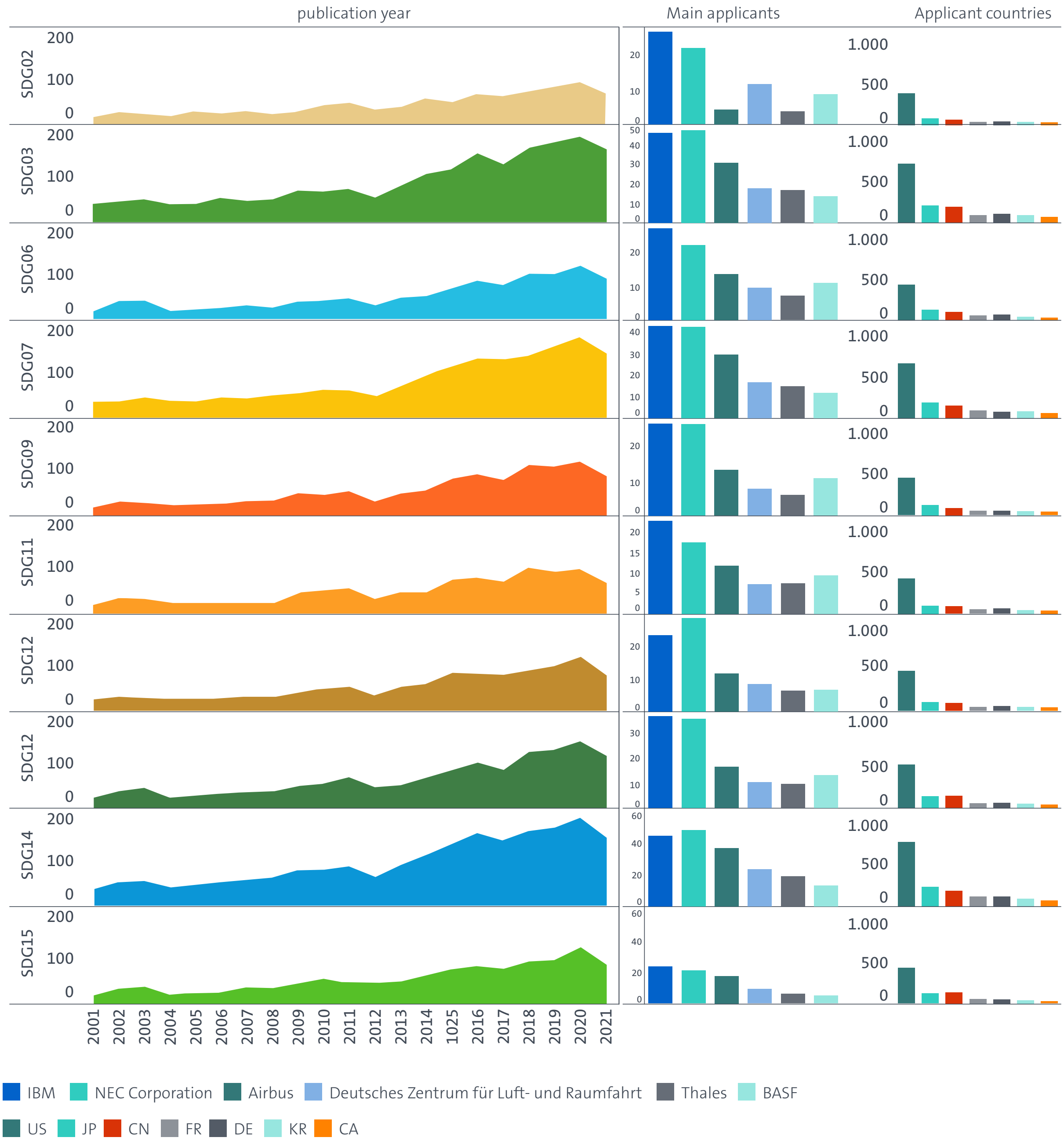
3.7 Spotlight on SDGs

The growth rate of international filings also translates into increased contributions[21] to the ten selected SDGs. The extent to which innovation activities support the fulfilment of the SDGs can be assessed by reference to the proportion of SDG-related patents in company portfolios and even in all applications from a particular country. The US leads the innovative contribution to the SDGs.

Figure 17:

Spotlight on space-borne sensing in support of SDGs

Contribution to SDGs of international patent families



21 The contribution to SDGs is a comparative measure summing the relevance values of the patents involved - high (100%), medium (60%) and low (20%).

4. Conclusions

Space-borne sensing is a data-driven domain whose societal value manifests across multiple policy domains and objectives. While governments across the globe continue to provide major public funding for satellite remote sensing programmes, the private sector is increasingly launching commercial ventures, often at the SME / start-up level, and addressing only the data-related steps of the value chain. This is likely due to the low entry barrier for data acquisition from remote sensing programmes, less capital-intensive development objectives, and broad commercialisation and service opportunities.

In terms of use cases, this report underlines that space-borne sensing is a particularly suitable tool for "green" applications, such as climate change, environmental protection or sustainable economy. Satellite data underpins more than half of the essential climate variables identified by the Global Climate Observing System. An engagement in the green agenda at the global scale (but increasingly at the local level as well) could hardly be effective without relying on insights obtained through satellite remote sensing data.

Against this backdrop, the patent filing statistics analysed in this report present a story of a rapidly growing technology domain. The growth rate of patent filings for green applications of space-borne sensing by far surpasses – by a factor of more than four – the overall global growth rate in patent filings for all technologies. Among other major observations, the analysis in this report also:

- identified major technical observables and indicators related to the green agenda
- showcased the significant breadth of Chinese patent filing activity, although mostly domestically
- revealed that the majority of inventions are related to the software dimension (signal processing).

While the space-borne sector continues to face major challenges in terms of driving the user uptake of data and services, the sustained public investments and emerging business dynamics will likely create a fertile ground for future innovation.

5. Limits of the study

This study provides a specific snapshot of a particular technology segment. The approach used could serve as an example of how to exploit patent filing statistics for analyses to deliver insights and information to assist decision-making in both the private and public sectors. This study makes best use of the EPO's publicly available data, search and other analysis tools.

Like many patent analyses, this study is based on search queries combining keywords and patent classification codes. These queries are designed to optimise recall (i.e. to retrieve as many relevant documents as possible) and to optimise precision (i.e. to exclude as many non-relevant documents as possible). In reality, for a large dataset it is impossible to obtain 100% recall and 100% precision simultaneously. This affects which documents we found, as did the need to use a number of disparate classification codes in the search.

For this report we limited our data sample to the period from the earliest publication year, 2001, up to 2021 to recover all relevant space-borne sensing technologies. We then manually checked a considerable number of patent families to improve precision and recall. However, as a result of the above parameters, "noise" in the dataset is inevitable and some relevant documents may have been missed. Nevertheless, we are confident about our methodology and assumptions.

The European Patent Organisation, the European Space Policy Institute and the European Space Agency cannot be held liable for any damages, cost, losses or third-party claims resulting from reliance on the data, information, findings, conclusions and interpretations presented in this report.

6. Glossary

ANSERA	Search tool for EPO examiners to search and analyse worldwide patent data and non-patent literature.
Applicant	A person (i.e. natural person) or an organisation (i.e. legal entity, company) that has filed a patent application. There may be more than one applicant per application.
Computer-implemented inventions	The term "computer-implemented inventions" concerns patents with claims which involve computers, computer networks or other programmable apparatus, whereby at least one feature is realised by means of a program. The claims should define all the features which are essential for the technical effect of the process which the computer program is intended to carry out when it is run.
Espacenet	Free service from the EPO for searching patents and patent applications. Espacenet includes more than 130 million documents. The Global Patent Index (GPI) is a powerful tool that enables users to perform detailed searches in the EPO's worldwide bibliographic, legal event and full-text datasets.
International patent family	Each international patent family covers a single invention and includes patent applications filed and published at several patent offices. It is a reliable proxy for inventive activity because it provides a degree of control for patent quality by only representing inventions whose value the inventor considers to be sufficient to seek protection internationally.
Invention	Practical embodiment which involves, requires or produces a technical effect.
Inventor	A person designated as an inventor in a patent application. An inventor can also be an applicant. An inventor is always a natural person. There may be more than one inventor per application.
Jurisdiction	A country or countries (territory) for which a patent may be granted by the corresponding intellectual property office.
Patent application	Document summarising, describing and defining the scope of an invention for which patent protection is sought.
Patent family	A set of patents covering the same invention but filed at different patent offices. Counting patent families is a good proxy for counting inventions and removes possible bias introduced by the geographical coverage of the envisaged protection for the invention leading to an increased number of publications. The family size refers to the patents included in a patent family.
PATSTAT	The EPO's PATSTAT database has become a point of reference in the field of patent intelligence and statistics. It helps users perform sophisticated statistical analyses of bibliographical and legal event patent data.

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