

Decoding the Space Economy: Opportunities, Ecosystems and the Road Ahead

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Abstract

The global space economy is expanding rapidly, projected to grow from roughly USD 630 billion to USD 1.8 trillion by 2025, driven by advances that extend far beyond conventional satellite launches. Yet, the study remains fragmented across technology, economics, government policies and startups not just in India but across the globe. This study examines the space economy across its key commercial dimensions: satellite-based positioning, navigation and timing (PNT), communication, earth observation, manufacturing and space tourism. Across each of the segments, the paper evaluates the underlying technology and the business models.

To complement this technical review, a bibliometric analysis using Scopus data and VOSviewer is conducted to map publication trends, influential authors, leading journals and thematic clusters within the academic literature on the space economy. The findings indicate a multidisciplinary expansion of space-related research, reflecting the increasing integration of aerospace technologies with sectors such as logistics, agriculture, climate monitoring, defence, manufacturing and digital infrastructure.

The paper further examines India's emerging space ecosystem, profiling the government institutions and a growing cohort of private companies spanning launch vehicles, earth observation, satellite manufacturing, propulsion and data analytics. Together, these aspects provide a comprehensive view of the space economy's current opportunities, its ecosystem participants and the research foundations shaping its future direction.

Keywords

space economy, space sector, space industry, space technology, satellite communication, earth observation, India

1 Introduction

Space Economy today has moved from government controlled programs to an innovation-driven and economic area involving private players too. What is important is the creation of an ecosystem which supports the program. Companies have become smart in gauging the commercial potential for various sectors and thus it is seen as an essential aspect for any country which aspires to have a sustainable development. Estimates suggest that it could be a USD 1.8 trillion by 2035 (World Economic Forum, 2024).

At the backend, it is a complex interconnected ecosystem comprising satellite-based positioning, navigation and timing (PNT), communication services, Earth observation, manufacturing and logistics, defence, space tourism, space data analytics, in-orbit servicing, and an expanding network of downstream applications. Technological advancements are aiding the advancements of each of the aspects. It is worthwhile to mention out here that geo-political pressures are playing its way in governments' resolve to pursue their independent space agenda.

Parallel to this industrial transformation has been the emergence of the "New Space" movement, characterized by entrepreneurial ventures, venture capital financing, commercialization of government-developed technologies and public-private partnerships. Companies such as SpaceX, Blue Origin and Planet Labs have demonstrated that commercially viable business models can coexist with scientific exploration, encouraging similar developments across Europe, Asia and emerging economies. India has also entered this new phase through significant policy reforms initiated in 2020, the establishment of the Indian National Space Promotion and Authorisation Centre (IN-SPACe), the strengthening of NewSpace India Limited (NSIL) and the rapid growth of indigenous private space enterprises. These developments have positioned India as one of the most promising emerging participants in the global space economy (Yolusever, 2024).

Despite these developments, academic research remains fragmented across different streams like technology, space policies, government & statutory rules, defence studies, environmental science and strategic management. Besides, there is a dearth of bibliometric studies in this space. As a result researchers do not find good research works with a comprehensive approach of related literature, understanding the various nuances involved and dominant thematic clusters. This study firstly tries to combine the major components of space economy like PNT, satellite communication, defence applicability and futuristic aspects like manufacturing and space tourism. Secondly, it aims to have a scientific approach to the study by a bibliometric analysis (relying on Scopus database and using Vosviewer) identifying clearly the research trends, influential researchers, keywords analysis and thematic clusters. Finally, it does an India specific analysis on the developments by the country highlighting clearly the role of government (and its agencies) and the evolution of newer companies in the private space (Department of Science, GOI, 2026).

The findings are expected to assist researchers in identifying promising avenues for future inquiry while also informing policymakers, industry practitioners and investors seeking to understand the rapidly expanding economic frontier of space.

2 Domains of space economy

When we discuss space economy, it is important to evaluate the various aspects of it. The economic impact covers many dimensions beyond the conventional satellites. This study ventures into communication, navigation, tourism, manufacturing and earth observation. Each of the aspects are equally dynamic and evolving because of technology advancements acting as an enabler and affecting each of the aspects. The various dimensions as per the researchers are as follows

2.1 Satellite-Based PNT (Positioning, Navigation and Timing)

Executive Summary: PNT

Satellite-based Positioning, Navigation and Timing (PNT) systems operate by using a network of satellites that continuously broadcast precisely timed radio signals containing the satellite's location, orbital data and atomic-clock-based time information. These signals are transmitted through electromagnetic waves and received by devices such as smartphones, vehicles, aircraft, ships and navigation systems.

For positioning, a receiver measures the travel time of signals from multiple satellites to calculate the distance to each satellite. By comparing these distances using trilateration, the receiver determines its exact geographic coordinates (latitude, longitude and altitude).

For navigation, the calculated position is combined with mapping data or route information to determine movement paths and provide guidance. Devices such as cars, aircraft, drones and ships continuously update their position and adjust their routes based on real-time satellite data.

For timing, satellites use highly accurate atomic clocks to broadcast a global time reference. This allows devices and systems to synchronize their internal clocks, ensuring accurate coordination between communication networks, transportation systems, financial systems and other technologies (Moore, 2019).

Overall, satellites act as a global reference framework for location and time, enabling modern systems to accurately determine where something is, where it is going and when events occur.

Technical Discussion

PNT is a satellite provided framework of data used to pinpoint exact geographic coordinates, chart transit paths and synchronize clocks worldwide. Segment details are as follows:

Positioning

- Tools that pinpoint the location of a person or object.
- Ability to accurately and precisely determine one's location and orientation.
- For any device that uses GPS, satellites send signals containing their own location and precise time information. The device compares signals from multiple satellites (usually 4 or more) to calculate where it is (giving latitude, longitude and altitude). This allows it to determine its position and use it for things like navigation, tracking, or mapping.

Devices that use this:

- Smartphones: used for Google Maps, location sharing, ride-hailing apps and finding nearby places.
- Car navigation systems: used to track the vehicle's location and provide optimal routes.
- Aircraft navigation systems: used to help planes determine their position and follow flight paths.
- Ships and marine navigation systems: used to track location and plan sea routes.
- Smartwatches and fitness trackers: used to track running routes, cycling paths and movement.
- Emergency response systems: used to locate people during emergencies.
- Delivery and logistics trackers: used to monitor vehicles and shipments.
- Surveying and mapping equipment: used for creating accurate maps and measuring land.
- Agricultural equipment: used for precision farming and automated machinery.

Navigation

- It is the ability to determine current and desired position and apply corrections to attain a desired position.
- It charts how an object will reach its destination.

For any device that uses navigation, the process is generally:

- The device receives location information from satellites (GPS), sensors, or other positioning systems to determine its current position.
- The navigation system compares this position with stored maps or planned routes to decide where the device needs to go.
- The system continuously updates the position and provides guidance or adjustments to keep the device on the correct path.

Cars: GPS navigation systems guide drivers using maps and turn-by-turn directions.

Airplanes: Flight navigation systems help aircraft follow planned routes and stay on course.

Ships: Marine navigation systems help vessels determine their position and travel safely across oceans.

Drones: Navigation systems allow drones to fly along programmed paths and reach destinations.

Smartphones: Apps like Google Maps use navigation to guide people while walking, driving, or cycling.

Robots: Autonomous robots use navigation to move around environments and avoid obstacles.

Trains: navigation systems help monitor train locations and manage routes.

Spacecrafts: Navigation systems help determine position and adjust trajectories in space.

Military vehicles: navigation systems guide vehicles and equipment in different environments.

Agricultural machines: GPS navigation helps tractors follow precise paths across fields.

Timing:

- Determines the precise moment an event happened or is expected to happen.
- The ability to acquire and maintain accurate and precise time from a standard

For any device using PNT timing, the process is:

- Satellites send signals containing extremely accurate time information from their atomic clocks.
- The device uses these time signals to measure changes over time, such as movement, speed, or the order of events.
- The device combines accurate timing with location data to provide reliable tracking, navigation and coordination.

In simple terms:

Timing allows devices to know exactly when something happens, which helps them accurately determine position, movement and provide real-time updates.

Examples:

Cars and navigation systems: Use accurate timing to update location, calculate speed and provide real-time directions.

Airplanes: Use timing to synchronize navigation systems, track position and follow flight paths.

Ships: Use timing to coordinate location tracking and navigation across long distances.

Smartphones: Use GPS timing for location services, maps and communication networks.

Drones: Use timing to coordinate flight paths and maintain accurate movement.

Trains: Use timing for tracking, route management and coordination between systems.

Satellites and spacecraft: Use timing to determine position and control trajectories.

Emergency response vehicles (ambulances, fire trucks, police vehicles): Use timing for accurate tracking and coordination.

Delivery and logistics vehicles: Use timing to monitor vehicle locations and estimate arrival times.

Autonomous robots: Use timing to coordinate sensors, movement and navigation.

Agricultural machines (GPS-guided tractors): Use timing to follow precise paths in fields.

Communication systems (cell towers): Use timing to synchronize signals between towers and devices.

Devices that use both positioning and navigation include:

- Cars: GPS determines the vehicle's exact location (positioning) and helps plan routes and provide directions (navigation).
- Airplanes: GPS identifies the aircraft's position and helps it follow flight paths.
- Ships: GPS tracks the vessel's location and helps it travel along planned sea routes.
- Drones: GPS determines the drone's position and allows it to follow programmed flight paths.
- Smartphones: GPS identifies the user's location and apps use it for route guidance and directions.
- Robots: GPS or other positioning systems locate the robot, while navigation systems guide its movement.
- Trains: Positioning tracks train locations and navigation systems help manage routes.
- Spacecraft: Positioning systems determine the spacecraft's location and navigation systems adjust its trajectory.

- Military vehicles: Positioning provides location data and navigation guides movement.
- Agricultural machinery (e.g., autonomous tractors): Positioning tracks the machine's location and navigation allows it to follow precise paths.

The global space economy is projected to grow from USD Bn 630 to USD Tn 1.8 by 2025 with PNT being the core of this change (WEF, 2024)

2.2 Communication

Executive Summary

Communication satellites are advanced space-based relay systems that enable the transmission of voice, data, video and internet signals across vast distances, especially in regions where terrestrial infrastructure such as fiber-optic cables and cellular towers is unavailable or impractical. They operate by receiving signals from Earth through an uplink, processing and amplifying them using onboard transponders and transmitting them back through a downlink to ground stations, devices, or other satellites. This allows global connectivity without requiring direct physical connections between distant locations (Maral & Sun, 2020).

These satellites support a wide range of applications including global broadcasting, satellite internet, mobile and satellite communications, aviation, maritime connectivity, military communication, disaster response and remote-area networking. They are essential for connecting aircraft, ships, rural communities, research stations and isolated infrastructure where conventional communication networks cannot reach. Satellites also provide critical connectivity for the Internet of Things (IoT) by linking remote sensors used in agriculture, logistics, environmental monitoring and industrial systems.

Modern satellite systems, particularly Low Earth Orbit (LEO) constellations, have improved communication performance by reducing latency compared to traditional geostationary satellites. This has made satellite communication suitable for real-time applications such as video conferencing, online services and interactive internet use. Additionally, advances such as inter-satellite links allow satellites to transfer data directly between each other, reducing dependence on ground stations and improving global coverage (Handley, 2018).

Overall, communication satellites function as a global wireless infrastructure layer, bridging gaps between terrestrial networks and remote locations. By enabling reliable, long-range and resilient communication, they have become a fundamental component of modern telecommunications, emergency systems, transportation networks and digital connectivity worldwide.

Technical Discussion

Satellites relay voice, data, video and internet signals across vast distances, especially where terrestrial infrastructure (cables, cell towers) is impractical or absent. They enable global broadcasting (TV, radio), in-flight and maritime connectivity, rural and remote broadband, emergency communications during disasters when ground networks fail and backbone links for telecom operators. Newer LEO constellations (like Starlink) reduce latency compared to older geostationary systems, making satellite internet viable for real-time applications like video calls and gaming. They're also critical for connecting IoT devices in remote locations: agriculture

sensors, shipping containers, pipelines: and for direct-to-smartphone services that eliminate dead zones entirely (Anton, 2024).

Uplink: A ground station or device sends a radio signal up to the satellite, where it is received and amplified by the satellite's transponder.

Downlink: The satellite sends the processed signal back to Earth, where a receiving station or device converts it back into usable information.

Communication satellites receive and send voice, data, video and internet signals across large distances.

A sender transmits data to a satellite through an uplink, the satellite receives and amplifies the signal using a transponder, then sends it back to Earth through a downlink to a receiver.

This is an important way of communication when terrestrial infrastructure (fiber optic cables, telephone towers, underground networks) is impractical or absent.

But some places are difficult to connect. For example:

- oceans
- deserts
- mountains
- polar regions
- disaster affected places
- remote villages

Uses:

Communication satellites are used in many areas where long-distance or remote communication is needed. Examples include:

- **Satellite internet:** Provides broadband internet in remote areas where fiber cables or cell towers are unavailable.
- **Television and radio broadcasting:** Sends TV channels, radio signals and live broadcasts across countries or globally.
- **Mobile and satellite phones:** Enables communication in places without cellular networks, such as oceans, deserts and mountains.
- **Aircraft connectivity:** Provides in-flight Wi-Fi, communication and navigation data for airplanes.
- **Maritime communication:** Connects ships and offshore platforms for internet, calls, weather updates and operations.
- **Emergency and disaster communication:** Provides communication after earthquakes, floods, or storms when ground networks fail.
- **Military and defense communication:** Supports secure communication between military units and command centers.
- **Remote area connectivity:** Connects rural villages, research stations and isolated communities.

- Internet backbone connections: Helps telecom companies link distant regions and networks.
- Internet of Things (IoT): Connects remote sensors such as agricultural monitoring systems, pipeline sensors, weather stations and shipping container trackers
- Direct-to-device satellite services: Allows smartphones and devices to send messages or connect in areas without mobile coverage.
- Live events and news coverage: Transmits live video from locations where wired connections are unavailable.
- Space communication: Relays data between spacecraft, satellites and Earth stations.
- Weather and environmental monitoring systems: Transmits data from remote monitoring stations around the world.

The global satellite broadband receiver market is projected to grow from USD 2 billion per year today to USD 8 billion per year by 2035, driven primarily by the expansion of direct-to-device satellite communication (WEF, 2024).

2.3 Manufacturing

Executive Summary: Role of Satellites in Manufacturing and Supply Chain

Satellites support modern manufacturing and logistics systems by providing global positioning, communication and environmental monitoring capabilities that improve the efficiency, reliability and coordination of supply chains. GPS/GNSS satellites enable real-time tracking of vehicles, ships, aircraft and containers, allowing companies to monitor the movement of raw materials and finished products, predict delivery times, optimize transport routes and reduce delays. This helps manufacturers manage inventory levels and adjust production schedules based on the availability of materials.

Satellite-based communication systems allow factories, warehouses and transportation networks to remain connected across long distances, including remote locations where traditional communication infrastructure is unavailable. Through uplink and downlink transmission, companies can exchange operational data, monitor production processes, coordinate shipments and maintain communication with assets such as cargo ships and remote industrial facilities.

Together, satellite technologies create a connected global supply chain by linking suppliers, factories, transport networks, warehouses and customers. Industries such as automotive, shipping, aerospace, agriculture, energy and e-commerce use satellite-enabled systems to improve operational visibility, reduce downtime, increase efficiency and make faster data-driven decisions.

Technical discussion

The usefulness here works two ways. First, satellites themselves are a manufactured product: an entire industrial ecosystem exists around designing, building, testing and assembling satellite buses, payloads, solar arrays, propulsion systems and electronics, employing specialized aerospace supply chains. Second, satellites support manufacturing on the ground: precise GPS/navigation timing synchronizes automated factory systems and logistics networks; satellite communications connect remote industrial sites (mines, oil rigs, offshore platforms) to central operations; and Earth

observation data helps manufacturers track raw material supply chains, monitor facility construction and assess environmental compliance. Additionally, microgravity manufacturing (producing fiber optics, pharmaceuticals, or semiconductors in orbit) is an emerging niche enabled by satellite/space station platforms.

Satellites make manufacturing and supply chains more efficient, predictable and automated by helping companies track resources, communicate globally, predict disruptions and optimize transportation routes. This happens mainly through positioning, communication, monitoring and data collection.

Tracking shipments and vehicles (GPS / GNSS)

- Satellites provide positioning signals used by GPS devices in trucks, ships, aircraft and containers.
- Companies can track the real-time location of raw materials, products and vehicles. This helps with delivery time predictions, route optimization and preventing lost or delayed shipments

Monitoring raw material supply

- Satellites track the movement of raw materials (such as metals, fuel, or agricultural products) from suppliers to factories.
- Manufacturers can predict delays and adjust production schedules.

Optimizing factory operations

- Satellite communication allows factories in remote areas to stay connected.
- Satellite data can help monitor infrastructure, land conditions and nearby risks.

Improving inventory planning

- Knowing the location of materials and products helps companies maintain the right inventory levels. This reduces excess stock (wasted storage space) and shortages (production stoppages)

Real-time tracking of goods

- GPS satellites allow companies to track trucks, ships, aircraft and containers. Companies know where goods are, the estimated arrival times and whether or not the routes need changing

Reducing transport delays

- Satellite weather data helps companies avoid storms, floods and dangerous sea conditions

Improving global coordination

- Supply chains often involve many countries.
- Satellites allow communication between factories, warehouses, ships and delivery companies even when they are far apart.

Weather forecasting and risk management

- Weather satellites provide information about storms, floods, extreme temperatures and sea conditions.

- Logistics companies use this to avoid disruptions.

Possible future case studies across industries:

- Mining industry: A mining operation in a remote area can use satellites to communicate with headquarters, monitor machinery performance and track the transport of extracted materials.
- Oil and gas industry: Offshore oil platforms use satellites to send production data, receive instructions and maintain communication with engineers on land.
- Agriculture industry: Large farms use satellite data to monitor crop conditions, weather risks and irrigation needs, helping optimize production.
- Manufacturing industry: A factory in a rural location can transmit production data to managers, monitor equipment and coordinate supply deliveries.
- Energy industry: Remote solar farms or wind farms use satellite communication to monitor power generation and detect operational issues.
- Shipping industry: Cargo ships use satellites to communicate with ports, update locations and receive route instructions while at sea.

Manufacturing and Supply Chain

Optimizing Factory Operations Using Satellite Communication:

- Satellites allow factories located in remote or isolated areas to remain connected when traditional internet or communication networks are unavailable.
- Through satellite communication links, factories can send operational data (such as production status, equipment information and inventory levels) to company headquarters and receive instructions in return.
- Satellite data can also help companies monitor infrastructure, environmental conditions and potential risks around industrial sites, allowing them to plan maintenance and prevent disruptions.
- This improves decision-making, reduces downtime and allows companies to manage factories from anywhere in the world.

The global space economy is projected to grow to USD 1.8 trillion by 2035, with in-space manufacturing identified as a major emerging commercial sector (World Economic Forum, 2024).

2.4 Defense

Executive Summary: Role of Satellites in Defense

Satellites are a critical component of modern defense systems, providing global communication, navigation, surveillance, intelligence and threat detection capabilities. They operate as interconnected space-based platforms that collect, transmit and process information, allowing military forces to coordinate operations across large distances and respond rapidly to changing situations.

A major function of defense satellites is secure communication. Satellites act as relay nodes between geographically separated forces such as command centers, aircraft, ships and ground units. Data is transmitted from a ground or mobile station to a satellite through an uplink, where

onboard transponders receive, amplify and convert the signal before transmitting it back to Earth through a downlink. These communications are protected using encryption, frequency-hopping techniques and directional antennas to reduce interception and interference risks (Moltz, 2019).

Satellites also provide Positioning, Navigation and Timing (PNT) services, enabling accurate location tracking and synchronization. By receiving timing signals from multiple navigation satellites, military systems can calculate their precise position and movement. This supports troop coordination, aircraft navigation, vehicle tracking and precision-guided systems that rely on accurate positioning data.

Another major role is Intelligence, Surveillance and Reconnaissance (ISR). Satellites also provide early warning capabilities through advanced sensors, particularly infrared detectors. These sensors identify unusual heat signatures, such as those produced by missile launches and transmit alerts to command centers. This enables faster threat detection, tracking and decision-making.

Through Electronic Intelligence (ELINT), satellites can detect and analyze electromagnetic emissions from systems such as radar and communication networks. By studying signal characteristics including frequency, strength and location, ELINT provides insight into electronic activity and improves awareness of potential threats.

Finally, Space Domain Awareness (SDA) allows countries to monitor activities in orbit by tracking satellites, spacecraft and debris. SDA systems use radar, telescopes and space-based sensors to predict movements, prevent collisions, protect important satellites and identify unusual behavior in space.

Overall, defense satellites function as a space-based information network, combining communication systems, sensors, navigation technology and intelligence-gathering capabilities. They provide military organizations with persistent global awareness, secure connectivity and faster decision-making, making them essential infrastructure in modern defense operations.

Technical Discussion

Satellites form the backbone of modern military operations. They provide secure, jam-resistant communications for command and control across dispersed forces; GPS/navigation for precision-guided munitions and troop positioning; early warning systems that detect missile launches via infrared sensors; intelligence, surveillance and reconnaissance (ISR) through optical and radar imaging that can track troop movements, infrastructure and military assets even through cloud cover (via SAR); and space domain awareness to monitor adversary satellites and potential threats. They also support electronic intelligence gathering (intercepting communications) and increasingly serve as platforms for counter-space and missile defense systems (like the "Golden Dome" concept), making orbital assets both tools and potential targets in modern conflict (Johnson-Freeze, 2016).

Modern armies are spread across huge areas: soldiers, ships, aircraft, drones and command centers may be thousands of kilometres apart. Satellites enable global military communication by acting as relay stations between forces that may be separated by large distances. Communication devices on Earth transmit encrypted radio signals to a satellite through an uplink, where the satellite

receives, strengthens and processes the signal before sending it back to the intended receiver through a downlink. This allows military units, aircraft, ships and command centers to exchange real-time information without relying on nearby infrastructure. These communications are protected using technologies such as encryption, frequency hopping and directional antennas, making them more secure and resistant to interference or attempts to disrupt the signal.

Satellites provide a global connection layer that allows these forces to communicate, share intelligence, coordinate movements, navigate accurately and detect threats

Without satellites, a military would rely much more on radio towers, cables and aircraft relays which have limited range and can be disrupted.

Some defense satellites are equipped with infrared (IR) sensors that detect heat energy released from objects on Earth or in the atmosphere. These sensors are useful because missile launches create a strong heat signature due to the high-temperature exhaust produced by the missile's engines.

It can estimate important information such as:

- the approximate launch location
- the direction the object is moving in
- the time of launch
- whether or not the object may pose a threat

The satellite sends this information through communication links to ground-based command centers. These centers analyze the warning and can inform military forces, allowing them to prepare responses or take protective actions. The main advantage is that satellites provide wide-area, continuous monitoring, meaning they can detect threats much earlier than systems located only on the ground.

Generalized paragraph:

Defense satellites can act as early warning systems by using advanced sensors, such as infrared detectors, to monitor large areas of Earth for unusual activity. These sensors detect changes in radiation or heat patterns, which can indicate events such as missile launches. After detecting a potential threat, the satellite processes the information and transmits data to ground-based command centers through secure communication links. This allows military organizations to identify, track and respond to potential threats more quickly, improving situational awareness and defense readiness.

ISR satellites allow militaries to collect information, monitor activities and study specific targets from space. Optical imaging satellites capture detailed photographs using reflected sunlight, allowing observation of objects such as bases, ships and aircraft, but they are limited by darkness and clouds. Radar satellites using Synthetic Aperture Radar (SAR) overcome these limitations by sending radar waves to Earth and analyzing the reflected signals, allowing them to create images even at night or through clouds. Together, these systems provide continuous global surveillance and help military organizations understand changes, detect potential threats and make informed decisions.

Space Domain Awareness (SDA) allows countries to monitor and understand activity in space by tracking satellites, spacecraft and debris orbiting Earth. Using technologies such as radar, optical telescopes and space-based sensors, SDA systems collect information about the position, movement and behavior of objects in orbit. This helps prevent collisions, protect important satellites and identify unusual activity that could affect space operations. As satellites become essential for communication, navigation, intelligence and defense, SDA ensures that countries can maintain awareness and security in the space environment.

Electronic Intelligence (ELINT) uses satellites equipped with specialized sensors to detect and analyze electromagnetic signals produced by electronic systems on Earth. These satellites collect information such as signal frequency, strength, location and patterns of activity, allowing analysts to identify and understand sources such as radar, communication networks and other electronic equipment. By monitoring these signals over time, ELINT provides information about the operation and location of electronic systems, improving situational awareness and helping organizations make informed decisions. In modern defense, ELINT works alongside satellite imagery and other intelligence systems to create a more complete understanding of activities occurring on the ground.

2.5 Space Based Observation

Executive Summary

Space-based Earth observation involves the use of satellites equipped with advanced remote sensing technologies to collect, analyse and transmit information about Earth's land surfaces, atmosphere, oceans and human activity. These satellites operate by detecting electromagnetic signals from Earth using different sensor systems. Optical sensors capture reflected sunlight across visible and near-infrared wavelengths, allowing satellites to identify vegetation health, land cover, water bodies, urban development and environmental changes. Infrared sensors measure thermal radiation emitted by objects, enabling the detection of heat-based phenomena such as wildfires, volcanic activity, ocean temperature variations and atmospheric conditions. Synthetic Aperture Radar (SAR) sensors actively transmit microwave signals toward Earth and analyse the returning echoes to generate detailed surface images, allowing continuous monitoring regardless of sunlight, darkness, or cloud cover.

The data collected by these sensors is transmitted from satellites to ground stations through satellite communication links, where it is processed into usable information such as maps, environmental models and predictive datasets. Modern Earth observation systems combine satellite imagery with advanced computing, machine learning and artificial intelligence to automatically detect patterns and changes across extremely large areas. AI algorithms can compare current and historical satellite data to identify deforestation, urban expansion, damaged infrastructure, crop stress, wildfire activity and other environmental changes much faster than traditional manual analysis.

These capabilities have made Earth observation satellites essential across multiple industries and sectors. In weather forecasting and climate science, satellites provide continuous global measurements of clouds, atmospheric conditions, greenhouse gases, sea levels and ice coverage,

improving prediction accuracy and supporting climate change research. In disaster management, satellite data enables rapid mapping of floods, wildfires, earthquakes and storms, helping emergency organisations assess damage and coordinate responses when ground access is difficult. In agriculture, satellites support precision farming by monitoring crop health, predicting yields, analysing soil conditions and optimising irrigation. In environmental protection, they help track deforestation, illegal mining, pollution and ecosystem changes. In urban planning and infrastructure management, satellite imagery allows governments to monitor city growth, transportation networks, construction and land use. In resource exploration, satellites assist in identifying geological patterns linked to minerals, energy resources and water supplies.

Overall, space-based Earth observation transforms satellites into global monitoring platforms that provide continuous, large-scale and data-driven understanding of the planet. By combining advanced sensors, satellite communication, cloud computing and AI-based analysis, Earth observation systems convert raw measurements from space into actionable intelligence that supports scientific research, government decision-making, environmental conservation, economic planning and global security.

Technical Discussion

These satellites carry optical, infrared and radar (SAR) sensors to monitor the planet's surface, atmosphere and oceans. Practical applications include weather forecasting and climate monitoring, disaster response (mapping floods, wildfires, earthquake damage in near-real-time), agriculture (crop health monitoring, yield prediction, irrigation planning), environmental protection (deforestation tracking, illegal mining/fishing detection, pollution monitoring), urban planning and infrastructure monitoring and resource exploration (mineral and energy deposits). SAR is particularly valuable because it works day or night and through cloud cover, making it useful for both civilian disaster response and military surveillance. AI is increasingly used to automatically detect changes across large image datasets, turning raw imagery into actionable insights for governments, NGOs and businesses.

A. Optical, Infrared and SAR Sensors

Earth observation satellites use multiple sensor technologies, including optical, infrared and Synthetic Aperture Radar (SAR), to collect different types of information about Earth. Optical sensors capture reflected sunlight from Earth's surface to identify features such as vegetation, water, cities and land changes, while infrared sensors measure heat radiation emitted by objects to monitor temperature-related events such as wildfires, volcanic activity and ocean conditions. SAR sensors actively transmit microwave radar signals toward Earth and analyse the returning echoes to create images of the surface, allowing observation during both day and night and through clouds. Together, these sensors enable satellites to continuously monitor environmental conditions, natural resources, human activity and changes across the planet.

B. Monitoring Earth's Surface, Atmosphere and Oceans

Earth observation satellites provide continuous monitoring of the planet's surface, atmosphere and oceans by collecting data over large geographic areas and across long periods of time. They observe land features such as forests, farms, glaciers, deserts and cities to track changes in ecosystems, infrastructure and land use. Satellites also monitor the atmosphere by measuring clouds, temperature, moisture and gases, supporting weather prediction and climate research. Over oceans, satellites measure sea temperature, sea levels, currents, ice coverage and pollution patterns. By repeatedly collecting global data, satellites help scientists understand environmental changes, predict natural events and manage Earth's resources more effectively.

C. Weather Forecasting and Climate Monitoring

Satellites are essential for both weather forecasting and long-term climate monitoring because they provide real-time observations of Earth's atmosphere and environmental systems. Weather satellites collect information about cloud movement, storms, temperature, humidity and atmospheric conditions, which is transmitted to ground stations and processed by computer models to predict future weather events such as storms and cyclones. For climate monitoring, satellites track long-term changes including rising sea levels, melting glaciers, changing temperatures and greenhouse gas concentrations. This continuous global monitoring improves early warning systems, supports climate research and helps governments prepare for environmental changes.

D. Disaster Response and Emergency Management

Earth observation satellites support disaster response by providing rapid and large-scale information about natural disasters such as floods, wildfires, earthquakes and storms. Satellites use optical, infrared and SAR sensors to detect affected areas, measure damage and create maps that help emergency organisations make decisions. SAR technology is particularly useful because it can operate through clouds and darkness, allowing monitoring during severe weather conditions when traditional imaging may fail. Satellite data helps rescue teams identify damaged infrastructure, assess risks, plan evacuations and distribute resources more effectively during emergencies.

E. Agriculture and Food Production

Satellites support modern agriculture by monitoring crop health, predicting yields and improving resource management through remote sensing technologies. Sensors analyse how crops reflect different wavelengths of light to identify healthy and stressed vegetation, allowing farmers to detect problems such as drought, disease, or poor growth. Satellite data combined with weather and environmental information helps estimate future crop production, supporting food supply planning. Satellites also measure soil moisture and environmental conditions to improve irrigation planning, allowing water and agricultural resources to be used more efficiently.

F. Environmental Protection

Earth observation satellites play an important role in protecting the environment by continuously monitoring ecosystems, natural resources and human activities. Satellites track deforestation by comparing images over time to identify forest loss, detect illegal mining by observing changes in

land structure and monitor illegal fishing by analysing ship movements and ocean activity. They can also detect pollution, changes in ecosystems and environmental damage across large and remote areas. This information helps governments, researchers and conservation organisations enforce environmental regulations, protect natural habitats and manage resources sustainably.

G. Urban Planning and Infrastructure Monitoring

Satellite observation supports urban planning and infrastructure development by providing accurate information about how cities grow and change over time. Satellites monitor land use, construction, transportation networks, population expansion and changes to infrastructure, allowing planners to understand urban development patterns. This data helps governments make decisions about roads, buildings, public services and future expansion while considering environmental impacts. By providing a detailed view of cities from space, satellites improve planning efficiency and support the creation of sustainable urban environments.

H. Resource Exploration

Earth observation satellites assist in resource exploration by analysing Earth's surface to identify potential sources of minerals, energy resources and water. Different geological materials reflect and absorb electromagnetic radiation in unique ways, allowing satellite sensors to detect patterns linked to certain resources. Satellite imagery helps geologists study large and remote areas before conducting ground surveys, reducing exploration costs and improving efficiency. This technology supports industries involved in mining, energy and natural resource management by providing valuable information about Earth's composition (Melesse et al, 2007).

I. AI Analysis of Satellite Data

Artificial intelligence is increasingly used to process the enormous amounts of data produced by Earth observation satellites and convert raw satellite images into useful information. AI systems compare current satellite data with previous observations to automatically detect changes such as deforestation, new construction, wildfire locations, damaged infrastructure, or environmental changes. By rapidly analysing large datasets, AI allows governments, businesses, scientists and humanitarian organisations to extract insights faster than manual analysis. This combination of satellite technology and AI improves decision-making across environmental monitoring, disaster response, agriculture and resource management (Zhu, et al, 2017, Ma et al, 2019).

2.6 Tourism

Executive Summary

Satellites provide the essential communication, navigation and operational infrastructure that enables modern space tourism. Commercial spacecraft rely on satellite networks to maintain continuous links between passengers, onboard systems and mission control centres on Earth. Communication satellites facilitate the exchange of information through uplink and downlink processes, where signals containing commands, instructions and operational data are transmitted from ground stations to spacecraft, while telemetry data such as spacecraft position, speed, environmental conditions and system performance are sent back for monitoring. This allows

mission controllers to track spacecraft, manage operations and respond to potential issues in real time (Fortescue et al, 2011).

Beyond operational support, satellites enable the broader commercial ecosystem surrounding space tourism. High-bandwidth satellite communication will allow tourists and companies to transmit images, videos and live experiences back to Earth, while also supporting scientific experiments, technology testing and microgravity research conducted during flights. As a result, satellites will transform space tourism from a simple passenger experience into a multi-purpose platform combining exploration, entertainment, communication and research. Overall, satellites will act as the backbone of space tourism by providing the connectivity, control and data infrastructure required for safe and commercially viable access to space.

Technical Discussion

A. Communication and Data Relay

Satellites will act as communication bridges between space tourism vehicles and Earth-based mission control centres. A spacecraft carrying tourists will be equipped with communication systems such as radio transmitters, receivers and antennas that exchange information through electromagnetic radio waves. This communication infrastructure will be essential for passenger safety, operational control and maintaining contact throughout suborbital and orbital tourism flights.

B. Tracking, Navigation and Spacecraft Operations

Satellites will support space tourism by enabling accurate tracking and navigation of spacecraft throughout the mission. Navigation satellites will provide positioning information by transmitting precisely timed signals that will allow spacecraft systems and ground controllers to calculate their exact location and trajectory. This becomes especially important during launch, orbital travel and spacecraft re-entry, where small errors in position or speed can significantly affect the mission path. Ground stations can use satellite tracking data to monitor spacecraft movement, predict its future position and coordinate operations such as docking with commercial space stations or landing procedures. Satellite-based tracking systems can also help manage spaceport activities by monitoring launch vehicles, determining safe flight paths and guiding recovery teams to locate returning spacecraft.

C. Safety Monitoring and Mission Control

Satellites will provide the communication and monitoring capabilities required to keep space tourism missions safe. Throughout a flight, spacecraft sensors can collect large amounts of telemetry data about critical systems such as temperature, pressure, power supply, propulsion and structural conditions. This information will be transmitted through satellite communication networks back to mission control, where engineers will be able to analyse the data and identify potential issues. Continuous satellite connectivity allows controllers to send corrective instructions through uplink signals if adjustments are required. For commercial space tourism, where passengers may not have extensive astronaut training, reliable satellite-based monitoring is crucial

because it allows professionals on Earth to supervise the spacecraft and respond to changing conditions.

D. Research and Commercial Applications

Space tourism infrastructure supported by satellites will also enable additional scientific and commercial activities. During tourist flights, companies can use the microgravity environment to perform experiments, test materials and study how products behave in space conditions. Satellites will provide the communication link needed to transmit experiment results, monitor equipment and control research systems remotely. This will create a hybrid industry where tourism missions also function as platforms for scientific research, technology development and commercial testing. The same satellite systems that support passenger communication and spacecraft safety therefore can contribute to expanding access to space-based research.



Fig 1: Commercial dimensions of the Space Economy

Source: Authors

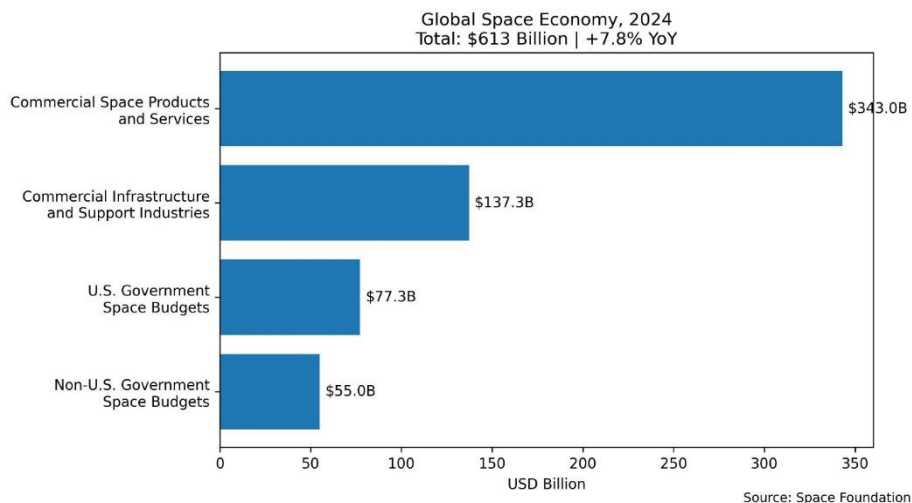


Fig 2: Global space economy (2024)

Source: Space Foundation

3 Bibliographic Analysis

Bibliometric analysis in this study uses Scopus as the primary data source and VOSviewer as the main visualisation tool, with carefully chosen keywords guiding the selection of relevant research topics.

Scopus, from the research base of Elsevier, is a large depository of abstract and citation database that offers coverage of journals, books, book chapters and conference proceedings, along with links to full-text content where available. It shows the future research areas and curates influential works and collaboration patterns across a wide range of academic disciplines (Donthu et al, 2021). VOSviewer is a specialised software application designed to construct and visualize bibliometric networks, including co-authorship, citation, co-citation and keyword co-occurrence relations.

By mapping these networks and highlighting clusters, it enables more nuanced detection of key authors, themes and country-level linkages than simple descriptive or manual methods.

Bibliometrics, originally associated with the idea of “statistical bibliography,” developed during the mid-twentieth century as scholars began systematically quantifying patterns in scholarly communication. The term “bibliometrics” was formally introduced by Alan Pritchard in 1969 and it now refers to the application of quantitative techniques to study, map and evaluate the dissemination and structure of scientific knowledge.

4 Need for the study

Given the multiple dimensions and the pace of changes coming up in the space economy space, it is essential to have the research works curated. This will not only help the present researchers in choosing their areas but also give some perspectives to future researchers. The present available literature is dispersed across many disciplines and time horizons and frequently relies on varied theoretical perspectives and measurement frameworks. This fragmentation curtails the comparability of results and complicates the identification of consistent determinants of sales performance. By systematically charting key authors, leading journals, thematic clusters and underlying intellectual foundations, the present study clarifies dominant antecedents, highlights emerging constructs and surfaces neglected linkages. In doing so, it supports more integrated theory development for scholars and provides practitioners with empirically grounded insights to inform sales performance enhancement strategies.

5 Data Set

For the work, Scopus data base was searched on 24-Jul 2026. The steps involved in choosing the set of articles for review are as follows

<i>Search Description(s)</i>	<i>Include</i>	<i>Exclude</i>	<i>Net</i>
------------------------------	----------------	----------------	------------

Scopus search using the following search transcript: "space technolog*" OR "space econom*" OR "space sector*" OR "space industr*" OR "space business" OR "space market*" OR "space commercialization" OR "space entrepreneur*" OR "economics of space" OR "space finance" OR "space investment*" in the Search criterion of "Abstract title, Abstract, Keywords"	18620		18620
Filter & limit to Publication years from 2015 to 2025	10085		10085
Filter & limit "Document type" to "Article", "Book" and "Book Chapter"	4357		4357
Filter & limit to "Final" in "Publication Stage"	4332		4332
Filter & limit to "English" in "Language"	3905		3905
Filter & limit "Subject area" to "Economics, Econometrics and Finance" and "Business, Management and Accounting"	643		643
Filter and remove research work without Authors		10	633
Filter and remove research work without Abstracts		8	625

Table 1: Scopus database search

Source: Authors

The Scopus query used was: (TITLE-ABS-KEY("space technolog*" OR "space econom*" OR "space sector*" OR "space industr*" OR "space business" OR "space market*" OR "space commercialization" OR "space entrepreneur*" OR "economics of space" or "space finance" OR "space investment*") AND (LIMIT-TO (DOCTYPE,"ar") OR LIMIT-TO (DOCTYPE,"ch") OR LIMIT-TO (DOCTYPE,"bk")) AND (LIMIT-TO (PUBSTAGE,"final")) AND (LIMIT-TO (LANGUAGE,"English")) AND (LIMIT-TO (SUBJAREA,"BUSI") OR LIMIT-TO (SUBJAREA,"ECON")) AND PUBYEAR > 2014 AND PUBYEAR < 2026)

All the analysis in the paper would be basis these 625 papers. A brief snap of the total research works collected are as follows

<i>Description</i>	<i>Data</i>	<i>Description</i>	<i>Data</i>
Total Research documents	625	Citations	6436
Articles	465	Citations / work	10.29

Authors	1382	# countries with publications	82
Index Keywords	1109	Author Keywords	1965

Table 2: Snapshot of the research works selected

Source: Authors basis details obtained from Scopus

6 Analysis and interpretation of results of Bibliometric Analysis

6.1 Publication trends

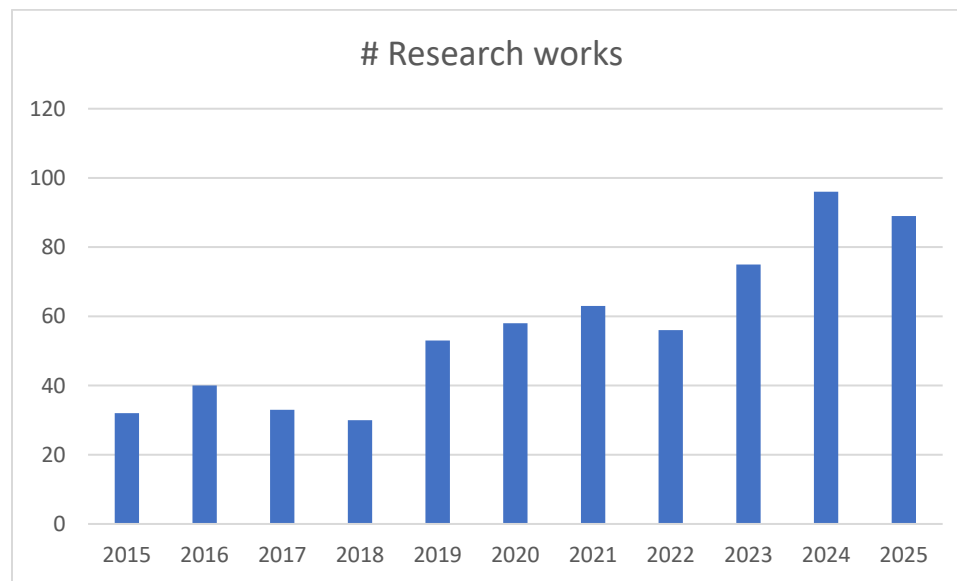


Fig 3: Annual publications of research works

Source: Authors basis details obtained from Scopus

This is a tabular representation of research works published through the past years. Though there has not been a definite trend, we see an explosion of research works post 2021

6.2 Basis article publications

The details of journals with the maximum published articles on space economy are as follows

<i>Journal Name</i>	<i># research works</i>	<i>ISSN</i>	<i>Publisher</i>
New Space	92	2168-0256	Mary Ann Liebert Inc.
Space Policy	86	0265-9646	Elsevier Ltd
Southern Space Studies	42	2523-3718	Springer International

Accounting, Auditing and Accountability Journal	7	0951-3574	Emerald Publishing
Science and Innovation	6	2409-9066	Publishing House Akademperiodyka
Cities	5	0264-2751	Elsevier Ltd
Eastern-European Journal of Enterprise Technologies	5	1729-3774	Technology Center
Environmental and Resource Economics	5	0924-6460	Springer International
Technological Forecasting and Social Change	4	0040-1625	Elsevier Ltd
Technovation	4	0166-4972	Elsevier Ltd

Table 3: Best journals in terms of articles published on space economy

Source: Authors basis data from Scopus

“New Space” and “Space Policy” come out to be the best journals with the highest number of articles published on this topic.

6.3 Publication basis countries

<i>Country</i>	<i># Research works</i>
United States	110
United Kingdom	80
Italy	58
France	44
India	40
South Africa	36
China	32
Germany	30
Australia	27
Brazil	25

Table 4: Countrywise research work details

Source: Authors basis data from Scopus

United States has the largest publications. None of the other countries have research work outnumbering 100.

6.4 Basis journal citations

<i>Journal Name</i>	<i># Citations</i>	<i>ISSN</i>	<i>Publisher</i>
Space Policy	1197	0265-9646	Elsevier Ltd
New Space	533	2168-0256	Mary Ann Liebert Inc.
Journal of Cleaner Production	418	0959-6526	Elsevier Ltd
Cities	274	0264-2751	Elsevier Ltd
Technological Forecasting and Social Change	252	0040-1625	Elsevier Ltd
Research Policy	198	0048-7333	Elsevier Ltd
Industrial Marketing Management	118	0019-8501	Elsevier Ltd
Technovation	110	0166-4972	Elsevier Ltd
China Economic Review	97	1043-951X	Elsevier Ltd
Futures	97	0016-3287	Elsevier Ltd

Table 5: Best journals in terms of citations on articles on space economy

Source: Authors basis data from Scopus

Besides the ones mentioned, we have 17 other journals with citations of atleast 50. Basis Table 3 and Table 5, it comes out that the following journals are good journals (basis large number of articles as well as citations) in the area of space economy.

Space Economy

New Space

Cities

Technological Forecasting and Social Change

Technovation

6.5 Basis Article Citations

<i>Paper title</i>	<i>Authors</i>	<i>Year</i>	<i>Journal Name</i>	<i>Citations</i>	<i>Publisher</i>	<i>ISSN</i>
--------------------	----------------	-------------	---------------------	------------------	------------------	-------------

Research on influencing factors of environmental pollution in China: A spatial econometric analysis	Liu K., Lin B.	2019	Journal of Cleaner Production	303	Elsevier Ltd	0959-6526
The evolution of mission-oriented policies: Exploring changing market creating policies in the US and European space sector	Robinson D.K.R., Mazzucato M.	2019	Research Policy	189	Elsevier B.V.	0048-7333
Co-creating and directing Innovation Ecosystems? NASA's changing approach to public-private partnerships in low-earth orbit	Mazzucato M., Robinson D.K.R.	2018	Technological Forecasting and Social Change	153	Elsevier Inc.	0040-1625
Exploring spatial patterns of urban brownfields regeneration: The case of Brno, Czech Republic	Frantál B., Greer-Wootten B., Klusáček P., Krejčí T., Kunc J., Martinát S.	2015	Cities	130	Elsevier Ltd	0264-2751

Industrial internet of things business models in the machine-to-machine context	Leminen S., Rajahonka M., Wendelin R., Westerlund M.	2020	Industrial Marketing Management	118	Elsevier Inc.	0019-8501
What Is New Space? the Changing Ecosystem of Global Space Activity	Paikowsky D.	2017	New Space	111	Mary Ann Liebert Inc.	2168-0256
Recent housing affordability in urban China: A comprehensive overview	Li K., Qin Y., Wu J.	2020	China Economic Review	97	Elsevier B.V.	1043-951X
Open data policies and satellite Earth observation	Harris R., Baumann I.	2015	Space Policy	82	Elsevier Ltd	0265-9646
Tales of a city: Sentiment analysis of urban green space in Dublin	Ghahramani M., Galle N.J., Ratti C., Pilla F.	2021	Cities	74	Elsevier Ltd	0264-2751
Blurring the Lines between Physical and Digital Spaces: Business Model Innovation in Retailing	Jocevski M.	2020	California Management Review	73	SAGE Publications Ltd	0008-1256

Table 6: Best articles in terms of citations on articles on space economy

Source: Authors basis data from Scopus

The articles have been sorted in terms of number of citations. Besides the ones mentioned, we do have 18 other articles with an individual citation of atleast 50.

6.6 Basis Productive Co-Authors

The details with respect to the best productive co-authors are as follows

<i>Co-authors</i>	<i># of research works</i>
Tucker B.P.; Alewine H.C.	5
Paravano A.; Locatelli G.; Trucco P.	3
Vecchi A.; Brennan L.	3
Adilov N.; Alexander P.J.; Cunningham B.M.	2
Berthet M.; Corrado R.	2
Cohen E.; Spector S.	2
Harris W.L.; Wonglimpiyarat J.	2
Mani S.; Dadhwal V.K.; Shaijumon C.S.	2
Sciortino G.P.; Bergamini E.	2
Vecchi A.; Ricci F.	2

Table 7: Productive co-authors basis number of articles on space economy

Source: Authors basis data from Scopus

6.7 Basis Productive Authors

The details with respect to the best productive co-authors are as follows

<i>Authors</i>	<i># of research works</i>
Vidmar M.	4
Janikowski A.	3
Okwechime E.	3
Siebrits A.	3
Zhou Y.	3
Cooke P.	2
Dominoni A.	2
James T.	2
Jide-Omole A.A.	2
Lele A.	2

Lucas-Rhimbassen M.	2
Manov B.S.	2
Martens B.	2
Martin A.-S.	2
Modell S.	2
Nie M.	2
Nowak K.	2
Pratistha B.	2
Rementeria S.	2
Rogerson C.M.	2
Rouillon S.	2
Ruel S.	2
Verspieren Q.	2

Table 8: Productive authors' basis number of articles on space economy

Source: Authors basis data from Scopus

Vidmar M from United Kingdom, Janikowski A. from United States, Okwechime E. from United Kingdom, Siebrits A. from South Africa and Zhou Y. from China have the largest single publications in this space.

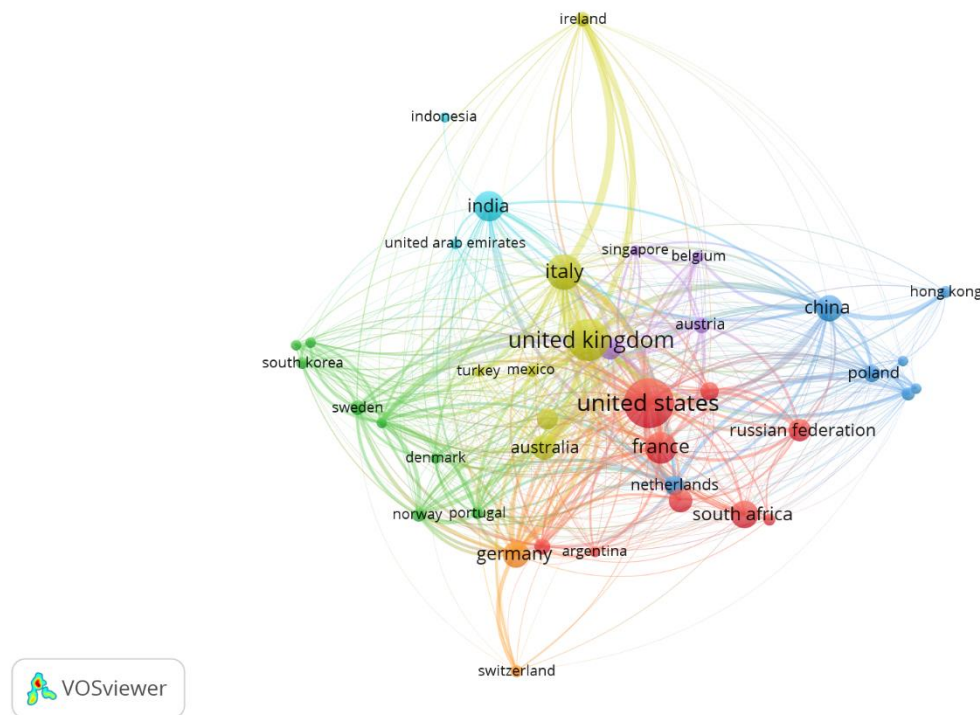
6.8 Country coupled bibliometric analysis

We used the minimum number of documents for a country as 5 and arrived at 40 countries out of 82. The screenshot of Vosviewer result is appended below.

<i>Countries</i>	<i>Documents</i>	<i>Citations</i>	<i>Total link strength</i>	<i>Citations per document</i>
United Kingdom	79	1273	7487	16.11
Italy	57	526	5360	9.23
United States	109	942	4076	8.64
France	44	784	2892	17.82
Australia	27	369	2456	13.67
Germany	30	355	2198	11.83
China	32	779	1880	24.34
Canada	23	530	1579	23.04
Finland	6	228	1558	38.00
Netherlands	18	129	1478	7.17

*Table 9: Bibliographic coupled data for countries basis total link strength**Source: Vosviewer results basis data from Scopus*

United Kingdom has the largest number of articles. However, when it comes to quality (referred by citations / research work), Finland, China and Canada rate higher.

*Fig 4: Bibliographic coupled data for countries basis total link strength**Source: Vosviewer basis data from Scopus*

6.9 Co-occurrence of author keywords

We used the minimum number of co-occurrence of author keywords as 10 and we arrived at 13 keywords out of 1965, which meet the threshold. The screenshot of Vosviewer result is appended below.

<i>Keyword</i>	<i>Occurrences</i>	<i>Total link strength</i>
commercial space	15	15
space industry	29	14
innovation	23	13
new space	21	13

entrepreneurship	10	7
newspace	10	7
space	16	7
space economy	29	7
india	10	6
space policy	25	6

Table 10: Author keywords basis total strength

Source: Vosviewer results basis data from Scopus

While we have taken note of the Top 10 authors keywords, the other ones in terms of total link strengths are: “space tourism” and “space technology”. These seem to be related to the theme “space economy” but the other important word which comes is “sustainability”. This indicates that researchers working on space economy are also working on sustainability.

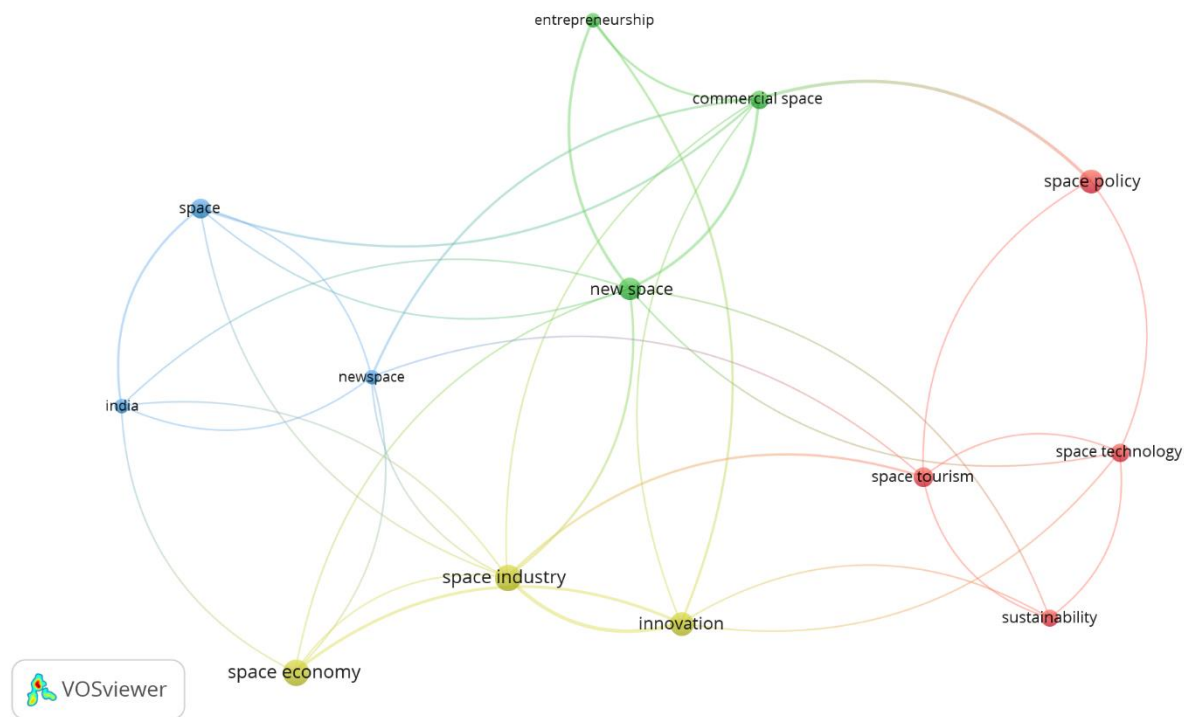
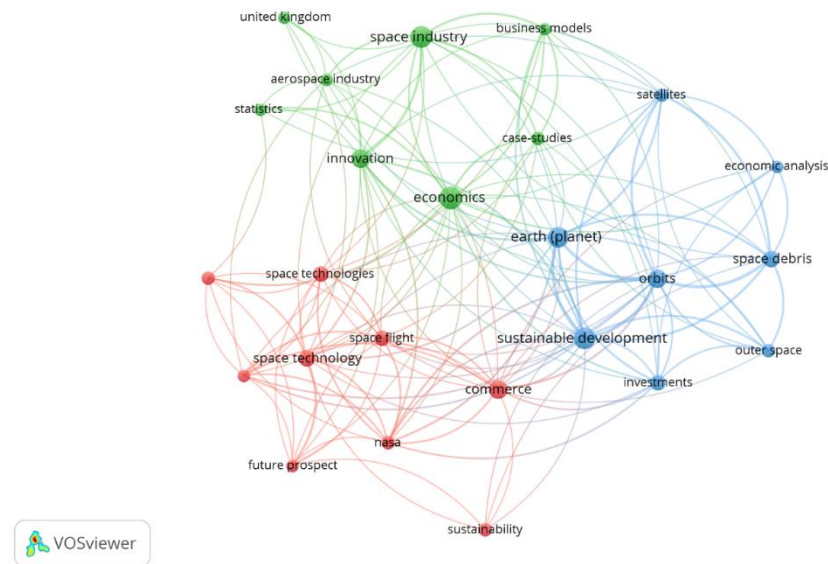


Fig 5: Author keywords basis total strength

Source: Vosviewer basis data from Scopus

6.10 Co-occurrence of index keywords

We used the minimum number of co-occurrence of index keywords as 10 and we arrived at 25 keywords out of 1109, which meet the threshold. The screenshot of Vosviewer result is appended below.



<i>Keyword</i>	<i>Occurrences</i>	<i>Total link strength</i>
orbits	11	47
sustainable development	14	43
earth (planet)	13	40
economics	15	28
space debris	8	28
innovation	11	25
nasa	6	25
satellites	6	23
space industry	14	23
space technology	8	23

Table 11: Index keywords basis total strength

Source: Vosviewer results basis data from Scopus

Like the case of author keywords, here also we observe that research is happening around sustainable development. Besides these, we also see “investments”, “space flight”, aerospace industry” and “future prospects” as the top keywords with high link strengths.

This clearly strengthen our theoretical proposition of areas which are being covered in space economy.

Fig 6: Index keywords basis total strength

Source: Vosviewer basis data from Scopus

Clearly, there are 3 distinct clusters. The description of each are as follows

Cluster	# keywords	Top 5 keywords
I	9	commerce, economic and social effects, economic developments
II	8	aerospace industries, business models, case-studies
III	8	earth (planet), economic analysis, investments

Table 12: Cluster details of Index keywords

Source: Vosviewer results basis data from Scopus

6.11 Co-authorship Countries Analysis

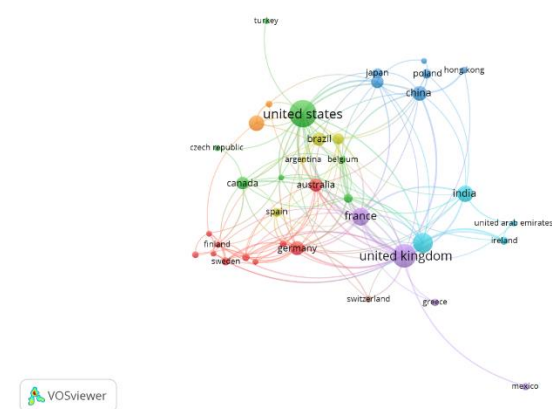
With a minimum criterion of 5 documents per country, we arrive at 40 countries out of a total of 82 countries.

Countries	Documents	Citations	Total link strength
United Kingdom	79	1273	70
United States	109	942	42
France	44	784	33
Germany	30	355	31
Italy	57	526	30
China	32	779	21
Netherlands	18	129	21
Australia	27	369	19
Austria	12	171	18
Canada	12	530	15

Table 13: Country wise co-authorship analysis

Source: Vosviewer results basis data from Scopus

The countries have been arranged in terms of total strength.



VOSviewer

Fig 7: Co-authorship-countries analysis

Source: Vosviewer basis data from Scopus

6.12 Funding

166 research works have been funded. The large funding Institutions are as follows:

<i>Funding Institutions</i>	<i># Research works</i>
European Space Agency, ESA	2
National Aeronautics and Space Administration, NASA	2

Table 14: Funding Institution details

Source: Authors basis data from Scopus

The bibliometric analysis mentioned indicates increased academic interest in the area of space economy after 2021. Themes that are in focus are commercialization, innovation, sustainability, business models and policy, with the United States and the United Kingdom emerging as leading contributors. The analysis also highlights sustainability as an increasingly interconnected research theme, indicating that future space activities are likely to be evaluated not merely on technological capability but also on their environmental and societal impact.

7 India's tryst with Space economy

The global space sector has undergone significant transformation, moving from a model dominated by government agencies toward one driven by private-sector innovation and commercial activity. Traditionally, space exploration and satellite development were controlled by governments because of the high costs, technological complexity, and strategic importance involved. Countries such as the United States, Europe, China and Russia introduced policies encouraging commercialization, public-private partnerships and competition to strengthen their space industries.

India's space sector, historically led by ISRO and the Department of Space (DOS), followed a primarily government-driven approach. Private companies mainly served as contractors or suppliers rather than independent space companies capable of developing their own launch vehicles, satellites and services. While this model helped India achieve major scientific and technological milestones, it limited private investment and innovation. The rapid expansion of private space industries globally highlighted the need for India to reform its space ecosystem and create opportunities for commercial growth.

To address these challenges, the Government of India introduced major reforms on June 26, 2020, allowing private enterprises to participate across all stages of space activities. These reforms opened areas such as satellite manufacturing, launch vehicle development and space-based services to private companies/NGEs. A central part of this transformation was the creation of the Indian National Space Promotion and Authorisation Centre (IN-SPACe), an autonomous agency under the Department of Space. IN-SPACe acts as a single-window organisation that enables, authorises and regulates private space activities while allowing companies to access ISRO

facilities and infrastructure. This helped shift private firms from being dependent suppliers to independent participants in India's space economy.

Further strengthening private participation, the Indian Space Association (ISpA) was launched in October 2021. ISpA supports collaboration between the government, NGEs, and academic institutions. It provides policy recommendations, encourages innovation, and promotes India's goals of self-reliance through initiatives such as "Atmanirbhar Bharat" and "Make in India". Additionally, the government promoted the commercialisation of ISRO-developed technologies through a partnership between the Department of Space and NewSpace India Limited (NSIL). This initiative enabled the transfer of hundreds of ISRO technologies to private and public organisations, helping accelerate innovation and industrial growth.

Overall, these reforms represent a major shift in India's space strategy (from a primarily government-controlled sector toward a more open, competitive and commercially driven ecosystem). They aim to increase private investment, encourage innovation, create new space businesses, and strengthen India's position in the global space economy.

<i>Categories of satellites</i>	<i># (till April 2025)</i>
Communication Satellites	43
Earth Observation	50
Navigation Satellites	11
Space Science Missions	7
Technology Demonstration Missions	24

Table 15: Satellite launches by India

Source: ISRO

7.1 Government Organisations

<i>Entity</i>	<i>Role and responsibility</i>
DoS	Policy formulation, inter-ministerial coordination, international representation
ISRO	R&D, mission planning, capacity building, and technology and data sharing
NSIL	Commercial deployment and operation of space assets
IN-SPACe	Authorize, regulate, promote, and facilitate all space activities; issue guidelines; manage infrastructure and data access.

Table 16: Government institutions of India involved with Space Economy

Source: Authors

7.2 Private Organisations

Some of the key companies involved in Space Economy and its components are appended below.

7.2.1 Companies involved in Launch Vehicle Design/Manufacturing

Skyroot Aerospace is an Indian space-tech unicorn and commercial launch service provider headquartered in Hyderabad. Founded in 2018 by former ISRO scientists, it is the first private company in India to successfully design and launch a rocket into space. In 2022, they successfully launched the Vikram-S rocket through Mission Prarambh. This was the first private Indian vehicle to reach space, completing a suborbital flight. The company recently launched its first orbital flight with Vikram-1, designed to carry up to 480 kg to low Earth orbit.

Agnikul Cosmos started as a company in Chennai, India, and began its operations from the National Center for Combustion R&D at Indian Institute of Technology, Madras (IIT-M). In 2020, the company became the first space-tech company to sign an agreement with the Indian Space Research Organisation (ISRO), under the then newly announced space initiatives. They created the world's first single-piece 3D-printed rocket engine called Agnilet in 2021 and successfully fired it. In 2022 the company established India's first private launchpad, Agnikul Launchpad-01, at SDSC SHAR, and in 2024, they launched the rocket, Agnibaan SOrTeD, from Agnikul.

7.2.2 Companies in Earth observation

Pixxel was founded on February 27th, 2019 with the aim to monitor Earth and expand humanity's reach into space. It launches Shankuntala in April 2022 on a SpaceX Falcon-9. This was a microsatellite that served as India's first private Earth - imaging hyperspectral satellite. On February 27th, 2023, Pixxel revealed the first hyperspectral images from their demo satellites publicly, and in the same year they received a grant to build a minituarised multi-payload satellite for the Indian Air Force.

GalaxEye was founded in 2020 out of IIT Madras and is building satellites that fuse radar and optical sensors in real time. Before GalaxEye, satellites used optical imagery to explore space, however this was inefficient since optical imagery can be blocked by clouds, darkness, and weather. An initial alternative was SAR (synthetic aperture radar), however SAR is hard to interpret. Thus, GalaxEye is building the world's first multi-sensor imaging satellite, The Drishti Mission. These indigenously built satellites will enable governments, defense, and industries to perform advanced state-of-the-art geospatial analyses. GalaxEye's Drishti mission has a unique multi-sensor capability that brings intuitive all-time, all-weather imagery from space, even during night time and cloud cover. Mission Drishti is India's largest privately built satellite, delivering the highest-resolution imagery among private players.

Digantara was created in 2018 with the aim to build a space-based traffic management platform that tracks satellites and tiny orbital debris with extreme precision. This helps global operators prevent space collisions, counter emerging threats and ensure long-term security and sustainability in space. They have created a software platform called Space - MAP. The platform provides a foundational infrastructure layer for managing orbital operations, analyzing threats, and ensuring the sustainability of the near-Earth environment. Additionally, they launched India's first private

debris-tracking satellite, Pushan-Alpha, which is a pioneering CubeSat. Launched aboard a SpaceX rocket, it operates in a Sun-Synchronous Orbit (SSO) as a dedicated space weather test bed.

7.2.3 Companies in Satellites & manufacturing

Dhruva Space was established in 2012 in Hyderabad, India. It is a full-stack Space Engineering solutions provider. Dhruva operates across satellite manufacturing, launch services, and ground station networks simultaneously. The company developed the P-30 nanosatellite and P-90 microsatellite platforms — designed for Low Earth Orbit (LEO), they offer pre-configured, scalable spacecraft buses that help commercial, defense, and scientific missions reduce deployment timelines and launch costs — and has successfully launched eight payloads to date, including the Thybolt technology demonstration satellites in November 2022 and the LEAP-TD mission aboard ISRO's PSLV-C58 in January 2024. In 2024, IN-SPACe authorised Dhruva to offer ground stations as a service, allowing satellite operators globally to use its Indian ground infrastructure.

Kawa Space is a Mumbai-based earth observation company founded in 2019 by Bala Menon and Kris Nair. The company is developing a constellation of small satellites focused on a specific technical problem: making satellite data faster and cheaper to use by processing imagery directly onboard the satellite in orbit rather than downlinking vast amounts of raw data to the ground. Kawa was among the first Indian companies to demonstrate edge computing on an orbiting satellite, capturing high-resolution images and computing results in real time before transmitting only the processed output. This approach dramatically reduces the bandwidth and ground infrastructure needed to extract useful intelligence from satellite data, making earth observation more accessible to a wider range of organisations.

7.2.4 Companies in Propulsion

Bellatrix Aerospace is a Bengaluru-based propulsion company founded in 2015. It was initially developed as a launch vehicle startup before pivoting in 2022 to focus exclusively on in-space propulsion systems. The company now manufactures a range of satellite thrusters, including Hall-effect electric thrusters, green-propellant chemical thrusters that replace the toxic and carcinogenic hydrazine traditionally used in satellites, and a uniquely innovative atmospheric-breathing electric thruster that collects residual air particles from the upper atmosphere and uses them as propellant — eliminating the need to carry fuel onboard for very low Earth orbit satellites. Bellatrix has also developed the Pushpak Orbital Transfer Vehicle, which it has contracted with NewSpace India Limited to integrate into ISRO commercial launch missions, enabling precise multi-orbit satellite deployment from a single rocket.

Manastu Space is a Mumbai-based propulsion startup founded in 2018 with a mission to make space safer and more sustainable. The company's primary product is the iBooster — a green propulsion system that replaces the toxic hydrazine fuel used in most satellite thrusters with hydrogen peroxide, which is significantly safer to handle, store, and transport. The company is also developing in-orbit refuelling and life-extension services that would allow satellite operators

to replenish propellant in space rather than decommissioning satellites once their fuel runs out — extending operational lifetimes and reducing orbital debris. In December 2024, the company delivered its iBooster system to DRDO, marking India's first domestically developed green satellite propulsion system entering defence use.

7.2.5 Companies in Data & analytics

SatSure is a Bengaluru-based earth observation and analytics company founded in 2017. The company uses satellite imagery and AI to help banks and insurance companies assess risk for farmers across India producing crop health reports, yield estimates, and land productivity scores without needing anyone to physically visit the farm. This makes it significantly faster and cheaper for financial institutions to offer loans and insurance to India's farming communities. It has also expanded internationally, partnering with Kenya's agricultural research body to bring the same model to African markets.

MapmyIndia (CE Info Systems) is India's only publicly listed digital maps and location intelligence company, founded in 1995. Over three decades, it has built India's most detailed homegrown map database covering roads, addresses and terrain across the country at a high level of accuracy. MapmyIndia combines satellite imagery from ISRO and commercial providers with its own ground-surveyed data to power car navigation systems, logistics platforms, and government mapping programmes. It converts raw satellite data into everyday navigation and mapping products used by many.

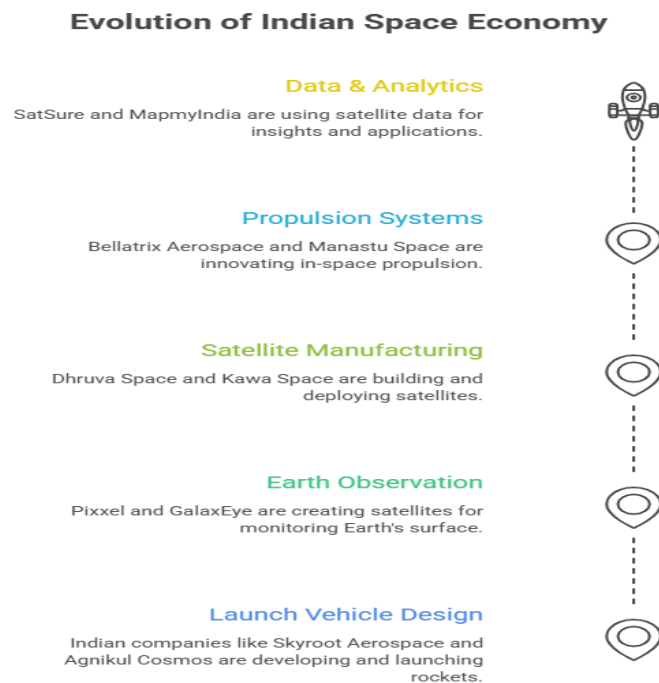


Fig 8: Private Indian companies in the Space Economy domain

Source: Authors

7.3 Some industry aspects and statistics

India's space economy was valued at USD 8.4 billion in 2023 and is targeted to reach USD 44 billion by 2033, with every USD 1 invested generating an estimated USD 2.54 in GDP (Press Information Bureau, Government of India, 2025).

7.3.1 PNT

India's push for sovereign PNT significantly intensified after it was denied vital GPS data during the Kargil conflict, driving ISRO to build out its NavIC (Navigation with Indian Constellation) system. Through NavIC and GAGAN, India now provides sovereign positioning, navigation and timing solutions supporting logistics, telecom, financial systems and strategic military operations. India's assured PNT market is forecast to grow at a 35.3% CAGR, driven by NavIC adoption and 5G timing infrastructure (Future Market Insights, 2025; Mordor Intelligence, 2025).

7.3.2 Communication

India's satellite communication (SATCOM) market is projected to grow from USD 3.2 billion in 2025 to USD 6.3 billion by 2034 at a 7.39% CAGR (IMARC Group, 2025).

7.3.3 Defence

India is expected to invest USD 3 billion over the coming years in defence-related space contracts for satellite surveillance, space situational awareness (SSA), and cyber defence (Indian Aerospace & Defence Bulletin, 2025).

India's annual space budget increased by 123% between 2014 and 2024, with 75% of the 2024–25 budget allocated to technological projects, while 70 domestically built satellites have been launched since 2014 (Army Recognition, 2025).

7.3.4 Space based earth observation

The satellite remote sensing services market in India was valued at USD 338 million in 2022 and was expected to grow to about USD 400 million by 2025, driven by applications such as digital mapping, topography analysis, weather forecasting, and agricultural monitoring. The broader India satellite-based EO market is estimated to reach USD 1,829 million by 2032 at a CAGR of 9.85% from 2026 to 2032.

7.4 The Road ahead for India

The recently concluded policy reforms and the strong forays being made in the private (read other than government) indicate the Nation's increased focus on the same. The change is a big transition actually as the Nation has just moved from government-controlled to private participation. Continued investment in satellite manufacturing, launch services, Earth observation, downstream applications and space-based analytics will determine India's ability to achieve its stated ambitions in the global space economy.

8 Limitations of the study

As of any research, this research has few limitations too a The database of searches has been taken from Scopus. There could be good research works which are present in other databases like Web

of Science and Dimensions. There could be papers which are published in journals or books beyond the domains of the databases.

b The selected papers and research works are all English articles. There could be good articles in the non-English group.

c The keywords have been chosen carefully and the researchers have tried to be comprehensive and encompass several expressions relating to “Space Economy”. However, there could be some omissions which might result in missing out of important and relevant studies. Some other researchers may have used terminologies other than the ones used by the researchers of this paper.

d While bibliometric analysis is valuable for assessing research output and academic influence, it does not fully capture the qualitative or real-world impact of research. Citation counts reflect scholarly recognition but may not indicate how effectively research informs practice, policy or problem-solving.

9 Future research and scope

Future research may extend the present research by focusing on as many individual segments of the space economy. Sector-specific models can be designed on the commercial front, business-wise as well as integrating performance parameters. The enablers of the developments like AI, digital twins and sustainable developments can also be mapped to each of these sectors.

10 Contributions of the authors

Dr Sukhamaya Swain: Scopus searches and VosViewer analysis, writing: original draft

Ms Aditi Nayak: Conceptualization, writing: original draft

Dr Asmita Mahapatra: Conceptualization, review & editing

Dr Charu Bansal: Final draft checking

Conclusion

The domain of “space economy” globally has changed from being government-backed programs to a commercially driven eco-system. Our study shows that today’s space economy extends far beyond satellite launches and space exploration, encompassing positioning, navigation and timing (PNT), satellite communications, Earth observation, manufacturing, defence, space tourism and a rapidly expanding range of downstream applications.

The bibliometric analysis reveals a significant acceleration in scholarly interest in the space economy, particularly after 2021. It is being seen as a multidisciplinary research domain. The intellectual landscape is increasingly characterised by themes relating to commercialisation, innovation, sustainability, entrepreneurship and policy. While countries such as the United States and the United Kingdom continue to dominate academic output, growing contributions from emerging economies indicate the widening global participation in both research and commercial space activities. The analysis also highlights sustainability as an emerging cross-cutting theme, suggesting that future space development will increasingly be evaluated not only by technological advancement but also by its environmental, economic and societal contributions.

The study further shows that India has entered a transformative phase in its space journey. Policy reforms initiated since 2020, the establishment of IN-SPACE and the expanding role of NewSpace

India Limited have fundamentally altered the country's space ecosystem by encouraging private participation and innovation. The emergence of indigenous enterprises across launch vehicles, satellite manufacturing, Earth observation, propulsion systems and space analytics demonstrates India's growing capability to become a significant contributor to the global space economy. Green shoots are visible though sparingly across the ecosystem. Sustained investments in research, human capital, regulatory facilitation and public-private collaboration will be essential to realise the full potential. Needless to say, continued pursuance by government will also be key to the development.

We are in an exciting phase of this aspect of science and management. There will be probably be no area linked to humankind which would not be affected by the developments in the space economy. All we have to have is clarity in vision and faith on the planners and the developers of the same.

While writing the paper, we missed out on the opportunities of investment for the common man. The flowing areas might provide a framework for the same: satellite operators & services, spacecrafts & launch systems, components & sub-systems, propulsion & fuels, electronics & semiconductors, specialty materials and alloys and raw materials & mining; not written in any suggestive order of priority.

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