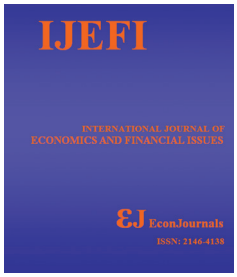


International Journal of Economics and Financial Issues

ISSN: 2146-4138

available at http: www.econjournals.com

International Journal of Economics and Financial Issues, 2025, 15(5), 447-453.

Unveiling the Space Economy from an Economical and Environmental Perspective with Special Reference to India

Pooja Choudhary[1], Neeraj Kumar[1], Alam Ahmad[2]*, Samreen Akhtar[2]

[1]Department of Economics, ICFAI School of Social Sciences, ICFAI Foundation for Higher Education, Hyderabad, Telangana, India, [2]Department of Finance, College of Administrative and Financial Sciences, Saudi Electronic University, Riyadh, Saudi Arabia. *Email: a.ahmad@seu.edu.sa

Received: 25 February 2025 **Accepted:** 12 August 2025 **DOI:** https://doi.org/10.32479/ijefi.15924

ABSTRACT

Space Economy includes any activity that involves exploring, researching, understanding, managing and utilizing space. The present article includes the development, significant actors, country-specific spending, environmental effects, and economic significance of the space economy with particular reference to India. The budgets of the major spacefaring countries and highlights of national spending on space programs are also discussed. It emphasizes that while developing and less developed nations find it difficult to afford space programs, those with high GDPs can often invest in space research. The connection between the space economy and the environment is also examined, along with the advantages of satellite-based Earth monitoring for the environment and studies on climate change, as well as the production of space trash and efforts to mitigate its effects. Finally, the economic contribution of the space economy is studied, highlighting its significance in raising global GDP through various enterprises and endeavors.

Keywords: Space Economy, Spending, Environmental, Economic development, Tourism
JEL Classifications: Q5, Z39, O53

1. INTRODUCTION

The space economy refers to the economic activities and industries related to space exploration, satellite communications, and the utilization of space resources. It encompasses various sectors and activities that contribute to developing, utilizing, and commercializing space technologies, services, and applications (OECD, 2020). The space economy includes government-funded space programs and private-sector companies involved in space-related activities (Ronci et al. 2020; Ricard et al. 2015). The space economy includes a wide range of sectors and activities (Hegadekatti 2017), such as: Satellite Industry which involves the design, manufacturing, launching, and operation of satellites for various purposes, including communication, navigation, Earth observation, and scientific research, Space Launch Services which focuses on developing and operating launch vehicles and services to deliver payloads into space, including satellites and spacecraft, Space Tourism which allows individuals to travel to space for leisure, adventure, or research, Space Research and Development which includes scientific research conducted in space, such as experiments on the International Space Station (ISS) and the development of new technologies for space exploration, Earth Observation and Remote Sensing which uses satellites to gather data and images of the Earth's surface for applications such as weather forecasting, environmental monitoring, agriculture, and urban planning, Satellite Communication and Broadcasting that focuses on providing communication services, including voice, data, and video transmission, via satellites (Binci, et al., 2022). It also includes satellite broadcasting for television and radio, Space Mining and Resource Utilization, which involves the exploration and extraction of valuable resources from celestial bodies, such as the Moon and asteroids, for commercial purposes, Space-based Navigation and Positioning Systems that include developing and operating satellite-based navigation systems like GPS (Global

Positioning System) and other positioning technologies for navigation, mapping, and timing applications.

There is much room for technological innovation, scientific discovery, and economic growth in the space economy, a subject that is expanding quickly. It supports many different industries and sectors on Earth, including telecommunications, weather forecasting, navigation, agriculture, disaster management, and national security (Iliopoulos and Esteban 2020). Increased investment and competition in the space economy have resulted from commercializing space operations fueled by establishing private space enterprises and alliances between public and private institutions (Space Safety Magazine, 2020). As a result, new technologies have been created, space access costs have decreased, and new prospects for commercial space endeavours have emerged.

2. EVOLUTION OF THE SPACE ECONOMY

The space race between the United States and the Soviet Union in the middle of the 20th century was a turning point in space exploration and technology (Launius et al., 2012). The development of the space economy over time is a shift from a government-driven space exploration model to a more varied and dynamic ecosystem comprising both public and private sector organizations. Here are some significant turning points in the development of the space economy:

2.1. Initial Space Exploration

The first artificial satellite, Sputnik 1, was launched by the Soviet Union in 1957, marking the beginning of the space economy. This occurrence ushered in the Space Age and set off a race to set new records between the United States and the Soviet Union.

2.2. Apollo Moon Missions

The Apollo program by NASA in the 1960s and 1970s aimed to land humans on the Moon. The successful Apollo 11 mission in 1969, which saw Neil Armstrong and Buzz Aldrin become the first humans to set foot on the Moon, demonstrated the potential for human space exploration and captured the public imagination.

2.3. Satellite Communications

The development of satellite communications systems in the 1960s and 1970s revolutionized global telecommunications. Satellites enabled long-distance telephone calls, television broadcasts, and data transmission, transforming global communication.

2.4. Space Shuttle Program

The launch of the Space Shuttle program in 1981 by NASA introduced reusable spacecraft, allowing for more cost-effective access to space. The Space Shuttle facilitated the deployment of satellites, conducted scientific research in space, and supported the construction of the International Space Station (ISS).

2.5. International Space Station

The collaboration between multiple countries led to the establishment of the ISS in 1998. The ISS serves as a research laboratory and a platform for international cooperation in space exploration involving government agencies and commercial entities.

2.6. Commercial Space Industry

In recent decades, the space economy has significantly shifted towards commercialization. Private companies like SpaceX, Blue Origin, and Virgin Galactic have emerged as key players in space exploration, satellite launches, and space tourism. These companies have developed reusable rockets, reduced launch costs, and opened up new opportunities for commercial space ventures.

2.7. Small Satellites and Cubesats

The miniaturization of satellites and the development of CubeSats (small standardized satellites) have lowered the barrier to entry for space-related activities, as a result in a proliferation of small satellite constellations for various purposes, such as Earth observation, communication, and scientific research.

2.8. Space Resource Utilization

There is increasing interest in the potential utilization of space resources, such as water ice on the Moon and asteroids, which can enable in-space manufacturing, refuelling of spacecraft, and resource extraction for commercial purposes.

3. KEY PLAYERS IN THE SPACE ECONOMY

The space economy is a global initiative encompassing numerous nations and areas. While traditionally, some countries have had a more significant influence on space exploration and the space industry, and the situation is changing due to the entry of new players and rising commercialization (Weinzierl and Sarang 2021).

The rise of commercial space companies, particularly in the United States, has significantly impacted the space economy. Companies like SpaceX, Blue Origin, and Virgin Galactic are driving innovation, lowering launch costs, and expanding commercial space capabilities (Table 1). These companies are involved in satellite launches, cargo resupply missions, and developing new space technologies. It is crucial to remember that the space economy is a worldwide endeavour and that many other nations, such as Canada, Australia, Brazil, and South Korea, are actively engaged in space-related activities. International partnerships, like those with the International Space Station, further highlight the cooperative character of space exploration and the international scope of the space industry.

4. COUNTRY-SPECIFIC SPENDING ON THE SPACE ECONOMY

Space economy spending varies from nation to nation and consists of only governmental investments. The space economy budgets can change annually, and specific details may vary. Table 2 exhibits the significant countries' space expenditures. It is evident that countries with high GDPs typically have the funds available to invest in space exploration. According to the list of spacefaring countries, the number of countries capable of sending rockets into space is only about 8 or 9.

As a result, it is challenging for most countries to invest in space research. Additionally, space programmes require very high

Table 1: Countries with a sizable presence in the space economy

Country	Description
United States	The United States has been a leader in the space economy for decades. NASA, the National Aeronautics and Space Administration, has been at the forefront of space exploration, scientific research, and the development of space technologies. The country also has numerous private space companies, including SpaceX, Blue Origin, and Boeing, which drive commercial space activities and innovation.
European Union	The European Union has significantly contributed to the space economy through the European Space Agency (ESA). The ESA collaborates with member states to undertake space missions, satellite launches, and scientific research. The EU also has its satellite navigation system called Galileo, providing positioning and timing services.
Russia	Russia has a long history in space exploration and remains a crucial player in the space economy. The country's space agency, Roscosmos, operates the Soyuz spacecraft and Proton rockets, conducts space research, and collaborates with other nations on space missions. Russia's expertise in human spaceflight has made it a crucial partner in crewed missions to the International Space Station.
China	China has rapidly developed its space program and has made significant strides in recent years. The China National Space Administration (CNSA) has conducted crewed missions, lunar exploration, and satellite launches and is actively involved in space research and development. China's space capabilities continue to expand, with plans for space station construction and long-term exploration goals.
Japan	The Japan Aerospace Exploration Agency (JAXA) has been engaged in space exploration, satellite launches, and space research. Japan has developed technologies for Earth observation, lunar missions, and scientific research, including the Hayabusa missions to asteroids.
India	The Indian Space Research Organisation (ISRO) has made notable advancements in the space economy. India has successfully launched satellites for communication, Earth observation, and scientific research, including missions to the Moon and Mars. ISRO's cost-effective approach to space technology has garnered attention globally.

Source: Authors' compilation

Table 2: Expenditure on space programs

Country	2009-2010		2021-2022	
	GDP, PPP (constant 2017 international) ($ trillion)	Spending on Space Program[1] ($ billion)	GDP, PPP (constant 2017 international) ($ trillion)	Spending on Space Program[2] ($ billion)
United States	16.86	17.80	21.13	62.00
Russia	3.42	5.60	4.08	3.42
Japan	4.88	2.46	5.13	4.90
France	2.74	2.17	3.05	4.20
Germany	3.84	2.00	4.42	2.53
Italy	2.53	1.80	2.48	1.74
China	11.88	1.30	24.86	11.94
India	5.23	1.40	9.28	1.93
Canada	1.53	0.48	1.83	0.32
United Kingdom	2.65	0.41	3.03	1.15
Europe	17.22	20.74	19.74	2.60
Global	96.66	42.00	134.08	103.00

Source: [1]Hegadekatti, (2017), [2]Statista (2023)

technical knowledge and skill. As a result, the entire cost of a space programme increases. As a result, only countries with sufficient financial, material, and human resources and political will can support space programmes. Therefore, these countries also gain the most from such initiatives. However, developing and less developed countries need help to afford the cost of the space programme or its associated benefits (Hegadekatti 2017). Global government spending on space initiatives reached a record high of over 103 billion dollars in 2022. In 2022, the United States government invested about 62 billion dollars in its space programmes, giving it the nation with the most significant space spending globally. China came in second, spending about 12 billion dollars on space programmes behind the United States (Figure 1).

Several Asian countries have actively participated in the space economy and have made significant strides in space exploration, satellite launches, and space-related technologies. China has emerged as a significant player in the space economy. In 2021-22, china spent around $11.9 million. The China National Space Administration (CNSA) has achieved significant milestones, including crewed missions, lunar exploration, and developing its satellite navigation system called BeiDou. China has also established a strong presence in commercial satellite launches, providing launch services to domestic and international customers. India has been increasing its investments in space activities in recent years (CNSA 2022).

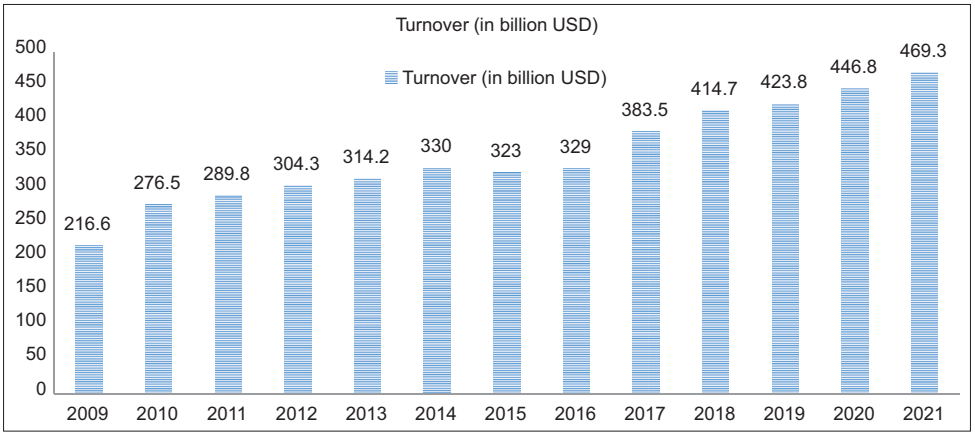
5. SPACE ECONOMY AND ENVIRONMENT

The environment and the space economy are intertwined, and the effects of the space industry's operations on the environment can be both positive and detrimental. As it relates to the environment and the space economy, the following are some essential factors to consider:

5.1. Environmental Benefits

Satellites used for Earth observation provide valuable data on climate change, weather patterns, deforestation, and other

Figure 1: Global turnover of the space economy over the years



Source: https://www.statista.com/statistics/946341/space-economy-global-turnover

environmental factors. This information supports environmental monitoring, disaster management, and sustainable resource management. Space-based instruments are crucial in monitoring greenhouse gas emissions, studying climate patterns, and understanding the Earth's climate system. This data contributes to climate change research, modelling, and mitigation efforts. Satellites can detect and monitor environmental hazards such as oil spills, wildfires, and pollution. This information helps in early detection, response planning, and implementing measures to protect ecosystems and human health.

5.2. Space Debris and Environmental Impact

Space activities contribute to generating space debris, including defunct satellites, spent rocket stages, and fragments. Space debris poses a risk of collisions, which can generate more debris and damage operational satellites. Space agencies and organizations are actively working on space debris mitigation strategies, including designing satellites and rockets for safe disposal after their operational life. Additionally, efforts are being made to develop technologies for active debris removal to clean up existing debris.

5.3. Sustainable Practices

Satellite manufacturers are increasingly adopting sustainable design practices, including environmentally friendly materials and components. Satellite operators are also implementing measures to improve operational efficiency and reduce energy consumption. Ensuring responsible end-of-life disposal of satellites is essential to minimize the creation of space debris. Satellites are designed with deorbiting mechanisms to bring them back into the Earth's atmosphere for controlled re-entry and burn-up.

5.4. Renewable Energy from Space

There have been proposals for space-based solar power satellites that capture solar energy in space and transmit it back to Earth for clean energy generation. This concept could provide a sustainable and renewable energy source without relying on fossil fuels. It is significant to emphasize that the space sector understands the value of sustainability and environmental stewardship. The environmental impact of space activities is being reduced through various efforts. For instance, both public and commercial organizations in the space industry are looking into environmentally friendly propellant alternatives, enhancing the performance of launch vehicles, introducing rocket recycling and reusability, and implementing sustainable practices throughout the lifecycle of space systems.

Even though the space economy contributes to GHG emissions, its overall impact is minimal compared to other industries and sectors, including transportation, energy, and manufacturing. However, ongoing initiatives to cut emissions, adopt sustainable habits, and encourage environmental responsibility are still crucial to ensuring the long-term viability of space activities.

6. ECONOMIC CONTRIBUTION OF SPACE ECONOMY

The space economy significantly boosts global GDP through various industries and ventures. The space economy has a bright future, full of innovative possibilities. The space economy's economic contribution in the form of Satellites provides a wide range of services contributing to economic growth. These include communication services, such as satellite TV, internet connectivity, and long-distance calls. Satellite-based navigation systems like GPS also support transportation, logistics, and location-based services, enhancing efficiency and productivity in various industries.

Earth observation satellites generate valuable data for various applications. Industries such as agriculture, forestry, urban planning, disaster management, and natural resource exploration utilize satellite data for informed decision-making. This data contributes to increased productivity, risk management, and resource optimization. The space sector drives technological advancements that have ripple effects across various industries. Innovations in materials, manufacturing processes, miniaturization, and data analysis from space-related research and development find applications in sectors like aerospace, automotive, healthcare, telecommunications, and more. The transfer of space technology to terrestrial industries fosters economic growth and competitiveness.

The launch industry is crucial in the space economy. Companies and organizations that provide launch services for satellites, spacecraft, and payloads generate revenue and employment opportunities. The increasing demand for satellite launches, including small satellite constellations, drives the launch industry's growth globally. The emergence of commercial space tourism presents a new avenue for economic contribution. Companies offering space tourism experiences create jobs, stimulate tourism, and generate revenue. Additionally, space-related entertainment, including documentaries, films, and media coverage of space missions, attracts audiences and contributes to the entertainment industry's economic value.

The space economy creates employment opportunities across various sectors, including engineering, manufacturing, research and development, operations, and support services. The demand for skilled professionals in aerospace engineering, satellite technology, data analysis, and space sciences drives workforce development and contributes to economic prosperity. The space industry has a record of generating spin-off technologies and intellectual property with commercial applications beyond the space sector. Examples include advancements in robotics, telecommunications, medical devices, software, and environmental monitoring tools. These spin-off technologies contribute to innovation, entrepreneurship, and economic diversification.

The space economy's growth has a multiplier effect on other industries and the overall economy. Investments in space research and development, infrastructure, and commercial ventures create demand for goods and services, generating economic activity and stimulating related sectors. Recalling that the space economy has economic benefits beyond just generating money is crucial. Technological developments, research collaboration, educational opportunities, and multinational alliances are indirect economic advantages promoting innovation, knowledge transfer, and long-term economic development.

7. SPACE ECONOMY AND INDIA

The nation runs a sizable fleet of earth observation and satellite communications satellites for civil purposes, including disaster management, tele-education, and telehealth (Misty, 1998). It launches its satellites from the Satish Dhawan Space Centre in Sriharikota. The Department of Space's Indian Space Research Organisation (ISRO), which includes facilities and labs throughout the nation, oversees R&D, operations, and production (OECD, 2019). India is one of the few spacefaring countries in the world, although it only makes up 2% of the global space industry, now estimated to be worth roughly USD 360 billion. Private sector firms like SpaceX, Blue Origin, Virgin Gigantic, and Arianspace have changed the space industry by slashing prices and turnaround times while leveraging innovation and cutting-edge technology. In India's case, the private sector's involvement has been circumscribed to that of providers or vendors to its government space programme (Government of India 2022).

The government expenditure on space economy in India was 804 billion rupees in FY2017 which rose to 913.06 billion rupees in 2018 and to 1119.27 billion rupees in 2019 and in 2020 it was estimated to be around 1313.93 billion rupees. In 2021-22, the Indian Space Research Organisation (ISRO) had an approximately $1.9 billion budget. This budget supports missions such as satellite launches, lunar exploration, and communication satellite programs (Krishnamurthy, 2022). The total budgetary allocation for FY 2023-2024 towards the department of space is INR 12543.91 crores. One of the many reforms implemented to advance the space economy is the newly created Indian National Space Promotion and Authorization Centre (IN-SPACe), which will be encouraging Non-Governmental Entities (NGE) to conduct independent space activities, opening up ISRO infrastructure and facilities, using a demand-driven approach to develop space assets, and providing startup businesses with essential supplies. Bellatrix, Aerospace, Dhruva Space, ISRO, Agnikul Cosmos, Skyroot Aerospace, ABL Space Systems, Astrosale, Rocket Lab, GHGSAT, and Pixxel are the top 10 Indian space firms that have been setting the bar for space innovation. Other Asian countries such as South Korea, Iran, Israel, and Malaysia, among others, are also actively involved in space-related activities. The positions of these countries in the space economy continue to evolve as they advance technology, increase international collaborations, and participate in commercial space ventures.

Additionally, the demand for goods and services from the space industry will only expand significantly with the development of the digital sectors (Mani et al., 2023). Through satellite surveillance, intelligence, and communications, India's space capabilities are now sufficiently developed to be employed for power projection and force multiplication. According to research created by Ernst & Young (EY) and the Indian Space Association (ISpA), India is expected to reach USD 13 B by 2025. The commercial space sector could advance up the value chain thanks to ISRO-created launch pads and laboratories with facilities for testing, monitoring, and telemetry.

The conventional satellite communication and remote sensing industries have been liberalized due to the government's most recent updates to the SpaceCom and SpaceRS laws. New drone regulations, as well as instructions for gathering and creating geospatial data, were also made public by the government. Under different space technology programs, the IN-SPACe, an interim autonomous nodal agency under the Department of Space, has received nearly 40 applications from major corporations, startups, MSMEs (micro, small and medium-sized companies), and academic institutions. These suggestions span upstream (manufacturing of launch vehicles and satellites) and downstream (earth observation applications, communications) operations.

Five satellites have been registered as part of implementing the national space object registration mechanism: Six memorandums of agreement for exchanging technological know-how and resources have been inked with business or academic organizations. According to the PM Gati Shakti National Master Plan, the government wants to increase logistics efficiency by providing multimodal connections to various economic zones and integrating infrastructural links for the movement of people, products, and services. Additionally, it will make substantial use

of technology, such as the spatial planning tools made possible by the Bhaskaracharya National Institute for Space Applications and Geoinformatics using ISRO images. Due to its end-to-end domestic space capability, cost-effectiveness, skilled human resources, well-developed space ecosystem for entrepreneurship, well-structured institutional setup and management, along with space applications and a potential space business market, India has the potential to become a space economy power (Shaijumon 2022). The government's most recent changes to the SpaceCom and SpaceRS rules have resulted in the liberalization of the traditional satellite communication and remote sensing businesses. The government has made available new drone laws as well as guidelines for collecting and producing geospatial data.

8. CHALLENGES OF THE SPACE ECONOMY

The space economy has positive outcomes, including employment, revenues, and technological and scientific innovation (OECD, 2020). Although there are many opportunities in the space economy, several difficulties must be overcome to expand and explore sustainably. The issues facing the space economy are distinctive. They are primarily connected to the enormous distances between celestial bodies, their gravitational forces, which are responsible for the high cost of lifting payloads from various planetoids, and the unfavourable climate, which increases the scarcity of resources for human survival (Jora et al. 2023). Some significant issues facing the space economy are the high cost of space exploration and access to space remains a significant challenge. Launching payloads into space, developing spacecraft, and maintaining space infrastructure requires substantial financial resources. Lowering the cost of space access through technological advancements, reusable rockets, and increased competition is crucial to expanding the space economy.

Space debris, including defunct satellites, spent rocket stages, and fragments, poses a growing threat to space activities. It increases the risk of collisions and can damage operational satellites. Therefore, Managing and mitigating space debris through international cooperation, responsible satellite design, and end-of-life disposal strategies are necessary to ensure the long-term sustainability of the space environment. The space economy involves numerous countries and entities operating in space. Establishing clear regulations, international standards, and frameworks for space activities is challenging. Cooperation among nations is essential to address issues such as traffic management, resource utilization, intellectual property rights, and preventing conflicts in space. Space weather events like solar flares and geomagnetic storms can impact space-based systems, including satellites and communication networks. The effects of space weather and radiation challenge the reliability and durability of space infrastructure. Developing technologies to mitigate the impacts of space weather and protect sensitive space assets is crucial.

The space economy requires a skilled and diverse workforce, including scientists, engineers, technicians, and professionals from various disciplines. Attracting and retaining talent in the space industry is essential for innovation and continued growth. Encouraging STEM education, promoting diversity and inclusion, and fostering collaboration between academia and industry are essential in addressing this challenge. The public perception of space activities and their importance can impact funding and support for space programs. Advocating for the societal and economic benefits of space exploration, scientific discoveries, and the development of space technologies is essential for garnering public and political support, which drives funding for space initiatives.

Advancing space technologies and fostering innovation are crucial for the space economy. Research and development efforts are needed to improve launch technologies, propulsion systems, communication networks, robotics, and resource utilization capabilities. Encouraging private sector innovation and partnerships with academia can drive technological advancements in the space industry. Due to the influence of objective and subjective elements, the process of social development is dynamic, necessitating the introduction of the PPP concept (Karpenko et al. 2023). International cooperation, regulatory reforms, technical improvements, and environmentally friendly practices are necessary to address these issues. By overcoming these obstacles, the space economy can develop further, promote academic research, spur economic progress, and open the door for more space exploration and use.

9. CONCLUDING REMARKS

The use of space resources, satellite communications, and other associated companies and activities are all included in the space economy, a sector that is quickly growing. It has changed from being a model pushed by the government to one that is more varied and includes both public and private sector organizations. The first artificial satellite's launch, the Apollo Moon missions, the advancement of satellite communications, and the construction of the International Space Station are all notable turning points in the history of the space industry. The United States, the European Union, Russia, China, India, and Japan are significant actors in the space industry and private sector firms like SpaceX, Blue Origin, and Virgin Galactic. These organizations support satellite launches, space exploration, space science research, and the creation of new technology. The United States is the biggest spender on space programmes, followed by China. However, other nations also contribute to space programmes. Nevertheless, given the high degree of technical expertise, finances, and political will needed, the cost of space programmes creates difficulties for many nations, particularly developing ones. The space economy has both positive and negative effects on the environment. On the positive side, satellites used for Earth observation contribute to environmental monitoring, climate change research, and the protection of ecosystems. However, space debris generated by space activities poses risks, and efforts are being made to mitigate and remove debris. Sustainable practices like responsible end-of-life disposal of satellites and exploring renewable energy sources from space are also being pursued. The economic contribution of the space economy is significant, boosting global

GDP through various industries and ventures. It supports sectors such as telecommunications, weather forecasting, navigation, agriculture, disaster management, and national security. The space economy fosters technological innovation, scientific discovery, and economic growth, with increased investment and competition driven by the commercialization of space operations. In conclusion, the space economy is a rapidly expanding sector with many industries and activities. It has evolved from a government-driven model to a more diverse ecosystem involving public and private sector entities.

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