Acta Astronautica 222 (2024) 162–173

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

The impact of the new space economy on sustainability: an overview

Alessandro Paravano [a,*], Matteo Patrizi [a], Elena Razzano [b], Giorgio Locatelli [a], Francesco Feliciani [c], Paolo Trucco [a]

[a] Politecnico di Milano, School of Management, Via Lambruschini 4/B, 20156, Milano, Italy
[b] Formerly European Space Agency, European Centre for Space Applications and Telecommunications, Fermi Avenue, Harwell Science & Innovation Campus, Didcot, Oxfordshire, OX11 0FD, United Kingdom
[c] European Space Agency, European Space Research and Technology Centre., Postbus 299, 2200, AG Noordwijk, the Netherlands

A R T I C L E I N F O

Keywords:
Value
Environmental social and governance (ESG)
Corporate social responsibility (CSR)
Complex projects
Economics
Internet satellite

A B S T R A C T

The first overarching objective of the Space Agenda 2030 is to strengthen the role of the space sector as a major driver of sustainable development. To achieve this objective, the European Space Agency launched already 10+ years ago the ESA Business Applications Programme to foster the adoption of space technologies in non-space sectors, promoting the development of commercial satellite-based projects (i.e., projects developing business applications based on Earth Observation, Satcom and Navigation satellite technologies and data) and contributing to achieving Sustainable Development Goals (SDGs).

While space technologies undeniably offer substantial societal benefits, there exists an opportunity to provide professionals and academics with a comprehensive perspective on the ongoing progress of commercial satellite-based projects in their vital role in advancing the achievement of Sustainable Development Goals (SDGs) and tackling Grand Challenges. Our research aims to clarify commercial satellite-based applications' direct and indirect impacts on SDGs and their features contributing to achieving them.

We develop a taxonomy of the ESA Business Applications programme portfolio, analysing 603 commercial satellite-based applications developed between 2014 and 2022 across 34 variables (including SDGs directly or indirectly impacted), sourced from the program's web pages. We perform descriptive statistics and exploratory data analysis to present commercial satellite-based applications' direct or indirect impact on the 169 SDG targets. Finally, we describe the features of commercial satellite-based projects (e.g., geographical scope, satellite technology adopted, non-space domains of application) contributing to the SDGs' achievement.

Our results show that 603 commercial satellite-based applications impact at least one SDG. Overall, SGD3 is the most impacted (136, 22 %), followed by SDG11 (105, 17 %) and SDG2 (78, 12 %). 257 Earth Observation-based applications mostly impact SDG2 (58, 23 %), SDG15 (38, 15 %) and SDG11 (34, 13 %). 230 Satellite Navigation-based applications mostly impact SDG3 (68, 30 %), SDG11 (52, 23 %) and SDG6 (22, 10 %). 116 Satellite communication-based applications mostly impact SDG3 (33, 28 %), SDG11 (16, 14 %) and SDG4 (15, 13 %). Moreover, we identify 14 application domains, and for each of them, we investigate their impact on SDGs. The application domains that mainly impact SDGs are Health (91, 16 %), Food and Agriculture (85,15 %), and Energy (51, 9 %).

Our research demonstrates and strengthens the space sector's role as a major driver of sustainable development. Researchers may adopt the methodology in other contexts, overcoming the geographical and data accessibility limitations of our research.

1. Introduction

The States Members of the United Nations acknowledge the relevance of the peaceful uses of outer space in enriching humankind's knowledge and life on Earth [1]. Two main reasons explain this consensus. First, space technologies nowadays permeate our daily lives [2]. Every day, we bring with us, literally wear, at least one technology that is linked or derived from outer space. Just think of the satellite

* Corresponding author.
E-mail addresses: alessandro.paravano@polimi.it (A. Paravano), matteo.patrizi@mail.polimi.it (M. Patrizi), ele.razzano@gmail.com (E. Razzano), giorgio.locatelli@polimi.it (G. Locatelli), francesco.feliciani@esa.int (F. Feliciani), paolo.trucco@polimi.it (P. Trucco).

https://doi.org/10.1016/j.actaastro.2024.05.046
Received 12 January 2024; Received in revised form 10 April 2024; Accepted 31 May 2024
Available online 6 June 2024
0094-5765/© 2024 The Authors. Published by Elsevier Ltd on behalf of IAA. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

navigation devices installed on the smartphone in your pocket. Second, space technologies create unique value for their users [3]. For example, the advent of satellite navigation has revolutionised transportation and mobility, enabling companies such as UBER, Deliveroo, and Amazon, to deliver new services and build new business models. Over the past decade, the Copernicus Emergency Management Service has provided more than 1000 products (e.g., maps, analyses based on satellite imagery) before, during or after a crisis (e.g., floods, tsunamis, earthquakes) and early warning services), for more than 50 countries, saving millions of lives [4].

Space technologies are key in advancing global development, particularly concerning the United Nations 2030 Agenda for Sustainable Development, its goals and targets [5]. On the one hand, space technologies directly serve as catalysts for sustainable development [6] by, for example, fostering clean energy adoption. On the other hand, space technologies indirectly support the monitoring and assessment of sustainable agenda achievement [7]. For example, earth observation data are used to monitor rising sea levels, assess the biosphere evolution, and understand climate change [8,9].

Various applications and target markets are associated with the downstream stream. We define downstream as companies offering digital innovation solutions and services (e.g., IT provider, system integrator, consulting firm) and specialised research centres that deal with research, development and implementation of the most advanced digital technologies leveraging space technologies and data [3,10].

Satellite communication is a prime example of space technology utilised for commercial purposes. Nevertheless, innovative services increasingly rely on satellite navigation and Earth observation technologies as enabling factors [9]. As satellite image resolution improves with advancements in computational power, Earth observation (EO) imagery becomes increasingly appealing. Numerous business applications leverage Earth Observation [11], especially in services that contribute to the achievement of Sustainable Development Goals (SDGs) [12].

Similarly, other user sectors leverage the Global Navigation Satellite System (GNSS) for various purposes. Consequently, services often employ EO and GNSS in synergy, complementing the data generated by the former [1]. Some of these services directly address SDG-related issues such as climate action, good health and well-being, or life on land [13].

The practitioner and scientific communities acknowledge the impact of space technologies and infrastructures [14], specifically Earth observation and satellite navigation, on attaining specific SDG targets. In this regard, the first overarching objective of the Space Agenda 2030 is to strengthen the role of the space sector as a major driver of sustainable development, calling for a holistic and comprehensive view of the current development of commercial satellite-based projects in supporting the achievement of the SDGs.

To this end, our research aims to clarify commercial satellite-based applications' direct and indirect impacts on SDGs, and their features contributing to achieving them.

In doing so, we investigate the ESA Business Applications (ESA BASS) programme portfolio. The European Space Agency developed the programme to promote developing, testing, and validating products, services, and businesses enabled by space technologies. We develop a taxonomy of the ESA BASS programme portfolio, analysing 603 commercial satellite-based applications developed between 2014 and 2022 across 34 variables (including SDGs directly or indirectly positively impacted), from the program's web pages. We perform descriptive statistics and exploratory data analysis to present commercial satellite-based applications' direct or indirect impact on the 169 SDG targets. Finally, we describe and discuss the features of commercial satellite-based projects (e.g., geographical scope, satellite technology adopted, non-space domains of application) contributing to the SDGs' achievement (See Table A in Appendix for the list of SDGs).

2. Background

2.1. Space economy and sustainability

The plethora of opportunities enabled by space technologies for sustainability, the decrease in costs to access space [15], the new regulations and liberalisation of the market [16], as well as the new technological development [17] is fostering the growth of the so-called "Space Economy" [8], bringing in new stakeholders in the space industry [18], and fostering the development of commercial space applications that may create value for space technologies and applications users [19].

Space Economy and sustainability are strictly connected. The progress in these endeavors can be gauged through the Sustainable Development Goals (SDGs) lens. The United Nations (UN) General Assembly endorsed "Transforming Our World: the 2030 Plan for Sustainable Development" in September 2015 [1], which serves as a global development roadmap that governments and various stakeholders can use as a blueprint for advancing economic, social, and environmental sustainability. The UN 2030 Agenda encompasses seventeen Sustainable Development Goals (SDGs) along with their associated targets and indicators, explicitly calling for collecting new data and utilising diverse data sources to facilitate implementation [20]. Within this context, a plethora of important and valuable initiatives were born. For example, the Group on Earth Observation, through its initiative, EO for Sustainable Development, supports realising the 2030 Agenda. One of the primary objectives of this initiative is to showcase how Earth observation data, when combined with geospatial information, socio-economic data, and other sources, can make a meaningful impact on achieving the SDGs [12]. In the same vein, UNOOSA underscores the principal SDGs and their related targets that stand to benefit from the application of Earth observation technologies [21]. UNOOSA also highlights the influence of GNSS on the SDGs. UNOOSA acknowledges the combined impact of employing Earth observation technologies and GNSS on the SDGs. Among the 17 SDGs, UNOOSA designates 13 of them as being in the "significant contribution tier." [1] These SDGs reap the most substantial benefits from the utilisation of space technologies. The European Space Agency (ESA) strongly emphasises harnessing space technologies to achieve SDGs and attain the objectives outlined in the European Green Deal and Digital Agenda [22].

2.2. The 2030 Space Agenda

The United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) has decided to develop a "Space2030" agenda and its implementation plan. The agenda aims to capitalise on the growing commercialisation of space by promoting innovation, competitiveness, and sustainability. It emphasises the importance of partnerships with industry, academia, and international organisations to develop new space technologies and services for sustainability [23]. Additionally, it highlights the need to address societal challenges such as climate change, global health, and sustainable development by leveraging space-based data and technologies. The 2030 Space Agenda represents a significant step forward in shaping the future of space activities and ensuring the value enactment for people and our planet [1].

2.3. The ESA Business Applications Programme

Following the Space Agenda guidelines, the European Space Agency launched already 10+ years ago the ESA Business Applications Programme to foster the adoption of space technologies in non-space sectors, promoting the development of commercial satellite-based projects. It provides financial and managerial support to projects that exploit, in a short-term range, space data and technologies in non-space domains such as insurance, energy, and healthcare. These applications have the potential to contribute to societal challenges such as climate change and zero hunger by monitoring and analysing data from space, helping make informed decisions. A practical example is represented by Earth observation satellites. If equipped with optical/thermal or radar sensors, it can measure the concentration of various atmospheric pollutants, such as nitrogen dioxide, sulfur dioxide, and particulate matter. The data collected are then analysed to identify areas where air quality is poor and determine the causes of the pollution. Governments and other authorities can use this information to develop targeted interventions to improve air quality, such as adjusting traffic flow patterns, imposing emissions restrictions on industrial facilities, or promoting public transportation.

The ESA Business Applications initiative actively promotes the establishment of space-based services. This programme offers entrepreneurs valuable guidance and three distinct financing options: Kick-Start Activity, Feasibility Study, and Demonstration Project. The Kick-Start Activity is a financing programme that accommodates various industries and encompasses themed initiatives. This streamlines the development of innovative commercial services and applications that rely on space assets and data. Feasibility studies form the cornerstone for identifying, analysing, and defining potential new applications and services. According to ESA's guidelines, these studies should be driven by user and customer needs since they must address specific problems and have market viability. This is confirmed by gauging interest from potential clients in adopting and investing in the proposed service. A successful Feasibility Study paves the way for progression to a Demonstration Project, ultimately aimed at launching a commercial service. Demonstration Projects are dedicated to providing pre-operational demonstration services. Much like Feasibility Studies, these projects are user-centred and leverage the integrated use of one or more space assets.

Companies eligible for these programmes receive funding that covers a percentage of their incurred costs. There are two avenues for entering the programme. In the first scenario, the company acts as the prime contractor and can apply through a competitive tender process initiated by ESA to find and develop solutions to specific problems. In the second scenario, referred to as "direct negotiation," the prime contractor submits a proposal that undergoes evaluation and approval by an evaluation panel instead of a competitive bidding process.

The ESA Business Applications programme has proven instrumental in fostering the adoption of downstream applications within the space industry. By providing companies with professional guidance and financial support through various funding options, such as Kick-Start Activities, Feasibility Studies, and Demonstration Projects, the programme empowers innovators to turn their space-related ideas into practical, marketable solutions. This approach stimulates creativity and innovation and accelerates the development and deployment of commercial services that rely on space assets and data. In doing so, the ESA Business Applications programme plays a vital role in advancing the adoption of downstream applications, contributing to the growth and sustainability of the Space Economy while addressing real-world sustainability challenges and opportunities.

3. Methodology

3.1. Dataset development and data collection

We build an original database of 603 projects developed between 2014 and 2022. The research focused on extracting relevant information from the Business Application webpage, where these projects are publicly presented. Each project contains details regarding the specific needs it aims to address, the target users, and the space technologies being utilised.

The decision to investigate the ESA Business Application programme for our study was grounded in four main considerations that underscore its representativeness of the satellite-business applications landscape. Firstly, the ESA database offers a comprehensive repository of projects developed within the realm of space technology applications, encompassing a diverse array of initiatives across various sectors and domains. As a leading authority in space exploration and technology, the ESA BASS portfolio reflects a broad spectrum of industry endeavours, ranging from products and services in fields such as energy, environmental monitoring, biodiversity, healthcare, education and disaster management. Secondly, ESA's stringent project selection and evaluation processes ensure a high standard of quality and innovation, making the projects featured in their database inherently significant and impactful within the industry and SDGs. Third, the ESA database serves as a reliable source of publicly available information, providing transparency and accessibility to stakeholders, researchers, and industry professionals alike. By leveraging this authoritative database, our study gains credibility and relevance, as it draws insights from a representative sample of industry initiatives endorsed by a globally recognised institution. Fourth, the ESA BASS database stands as a robust resource for our study, distinguished by its comprehensive collection of over 10 years' worth of projects consistently gathered and catalogued. This extensive temporal coverage ensures a rich and diverse dataset, capturing the evolution and trends within the realm of satellite-based applications over a significant timeframe. The consistency in data collection and inclusion protocols further enhances the reliability and integrity of the database, facilitating rigorous analyses and meaningful insights into the industry landscape. As such, the ESA BASS database emerges as a fitting choice for our study, providing a solid foundation for our research of European satellite-based applications impacting SDGs.

The availability of reliable data primarily drove the temporal range selection. 2014 is the year in which the commencement of publicly accessible information pertaining univocally to projects is documented on the ESA BASS website. This year serves as a starting point for systematically tracking and analysing the evolution of projects. We conducted the data collection and analysis in 2023. Here, it is necessary to specify that the ESA BASS projects' duration ranges from six-month to multi-year duration and that information regarding projects may not be updated immediately after their completion, presenting a challenge in terms of temporal standardisation. To mitigate possible inconsistency regarding project information, we decided to include only projects concluded within the calendar year 2022. This approach ensures a cohesive dataset and ensures the integrity and reliability of our analyses, thereby contributing meaningfully to the understanding of satellite-based applications' impact on SDGs dynamics and outcomes.

The collected data is then organised and recorded in a dataset. 34 variables are created, some directly available on the website (https://business.esa.int/), while others are ad hoc engineered and validated with ESA experts [24]. See Table B in the Appendix describing our data structure.

For the sake of clarity, here we briefly describe the data structure that includes the satellite-based application name, its link to the ESA BASS webpage, the start and end dates, the kind of activity (i.e., kick-start, feasibility, demonstration) as presented in the background. The status of the project is denoted as "Completed" or "Ongoing". The thematic areas of the project, such as "Food & Agriculture" and "Healthcare", specify the project's thematic focus from the ESA perspective. The objective of the satellite business application is taken by the project website outlining the project's primary goal. System architecture, space-added value, satellite-business application features, and value proposition provide insights into the technical and strategic aspects of the project. The dataset specifies the prime contractor name and nationality, as well as sponsors, partners, and clients retrieved from the satellite-business application webpage. We also specify the client(s) needs and nationality/region to investigate the geographical scope of these projects. The dataset also includes data regarding the technology behind the applications, such as the Satellite infrastructure, Satellite sensor used, the complementary data and technologies (such as drones, cloud computing, and artificial intelligence). Finally, we reported the direct and indirect impacts on SDGs, SDGs targets, and Grand challenges.

We thoroughly examined our data to ensure database consistency, prioritising completeness over granularity in our dataset [17]. The rationale behind this choice is that many attributes exhibiting inconsistent completeness levels across projects would hinder the feasibility of conducting detailed and reliable analyses. Following this, we have determined the specific sets of values that each attribute can assume, employing two primary methodologies [18]. We have directly extracted values from the project webpages when they occur frequently across projects. Alternatively, we have defined attribute values based on public documents available online. We call "value" a piece of specific information that a variable can assume, including numbers, strings of characters, boolean values (true or false) [25] (e.g., variable = "SDG impacted", values = "SDG1" or "SDG2" etc.) (See Table B in the Appendix)

To guarantee the accuracy and completeness of our data, we triangulated them with secondary data. For example, suppose a project mentions partners or clients. In that case, we searched for further information on the project on the partners' and clients' websites, and performed a search online for news, reports and video interviews confirming or disconfirming our data. Furthermore, we performed open interviews with experts to validate our data. Expert interviews were chosen as a suitable method to validate our data because of the exploratory nature of our research [24,26]. The interviewees were selected through purposive sampling [27,28] according to their job content and direct involvement in the satellite-based applications for sustainability. The sampling stopped when we reached theoretical saturation [29]. Table C in the Appendix synthesises the profiles of the experts interviewed. We conducted 5 interviews of, on average, 1 h with experts in commercial satellite-based applications and their impacts on SDGs, with an average of 20 years of experience in the industry. All the conversations took place online via MSTeams, and all the interviewees and organisations were granted anonymity. The data analysis was concurrent with the data collection. We started the interviews by showing the expert the database and preliminary results, asking to comment, agree and disagree with the data structure and content. The discussion was an open interview to access the respondent's point of view. We followed the data structure as guidance (going line by line of Table B in Appendix [30]. During the interview, we took note of possible improvements in the data structure according to their feedback [31]. For example, interviewee 4 suggested including the "sponsors" variable to keep track of financial flows. We concluded the interview when the senior expert had no more suggestions. In the following interview, we show the expert (e.g., interviewee 5) the data structure validated and revised by the previous expert (e.g., interviewee 4). Finally, we asked via email for further feedback and to validate the final version of our data [32].

Our study focused on investigating the positive impacts of satellite-based technologies on Sustainable Development Goals (SDGs). Three key considerations guided this decision. Firstly, research focus. By concentrating solely on positive impacts, we were able to analyse the beneficial outcomes associated with satellite-based applications thoroughly. This focused approach allowed for an in-depth examination of success stories and best practices within the ESA BASS programme, providing valuable insights into the ways in which satellite-based applications can effectively advance sustainable development objectives. Secondly, data availability. The ESA BASS database predominantly features projects that highlight positive outcomes and achievements resulting from the application of satellite-based technologies. Consequently, our dataset primarily comprised initiatives that showcase the beneficial impacts of satellite-based applications. Third, results comparability. By focusing on positive impacts, we were able to identify common characteristics of the satellite-based applications and their direct and indirect impact on SDG targets. Nevertheless, as also discussed in the Results and Discussion section, future research could complement our research by investigating the possible negative impacts of satellite-based applications on SDGs.

We adopted the framework provided by UNOOSA [9] to delineate the Sustainable Development Goals (SDGs) impacted by the service. Specifically, we identify the SDGs classified as the "Significant contribution tier," most profoundly influenced by EO and GNSS technologies. This approach results in an attribute structure that enables us to analyse various dimensions of each project, including technological, economic, and sustainability aspects [33]. Subsequently, we populate each attribute with a value only when explicit references or substantial evidence about it are found on the project's webpage, including its textual content and any integrated media such as images or graphs [34]. To ensure the accuracy and completeness of our dataset, we have further validated it through interviews conducted with subject matter experts [24].

3.2. Data analysis

We perform descriptive statistics and exploratory data analysis to analyse the features of commercial satellite-based projects that directly or indirectly impact SDGs [35]. Our analytical process begins with an individual assessment of each attribute to ascertain the frequency of occurrence for each value it can take. If an attribute allows for multiple values, we explore how these values relate to one another within the same attribute, uncovering potential correlations [31]. Additionally, we introduce a temporal dimension to uncover trends and spikes attributed to external factors. Moving forward, we examine values across thematic areas and countries within each attribute, emphasising significant disparities. This analysis focuses on the most densely populated thematic areas and countries, offering significance to the data. We highlight the satellite infrastructure that are exploit by projects [25].

In the subsequent stages of our analysis, we focus on evaluating the influence of Sustainable Development Goals (SDGs) and Grand Challenges and their associated targets within each segment, offering insights into the extent of their significant and minimal impact [36]. Furthermore, for projects within the subset that exhibit the most substantial short-term impact, our research aims to determine the proportion of commercial satellite-based applications contributing positively to addressing Climate Change.

4. Results and Discussion

4.1. ESA business applications key figures

The research provides several key figures regarding different aspects of the ESA Business Application programme projects. For once, the analysis shows the programme's success in attracting and developing innovative services within the European space economy.

Regarding satellite infrastructure exploited by business applications, satellite navigation services and Earth observation are gaining increasing traction, while satellite communication services, traditionally the dominant commercial force in space assets, are witnessing a shift in market dynamics. EO and GNSS-based applications demonstrate their value across diverse sectors and are progressively becoming central to end-users. A noticeable trend is a gradual transition towards adopting satellite navigation (SatNav) technologies in projects within the Business Application until 2018. However, since then, Earth observation (EO) data has experienced exponential growth, further facilitated by the widespread availability of FFO (Free and Open Data) and the initiatives developed by ESA. As a result, Earth observation has emerged as the most prominent and widely leveraged satellite infrastructure [37]. This signifies the increasing recognition and value of Earth observation within the industry. Fig. 1 illustrates the trends of business applications according to the satellite infrastructure exploited (a satellite-based application may exploit more than one technology).

EO data-driven services find fertile ground in sectors such as Agriculture, Forestry & Fishing, Energy & Utilities, Construction & Infrastructure, Finance, Insurance & Legal, and Environment & Wildlife (Fig. 2). This technology enables operators in these fields to utilise data

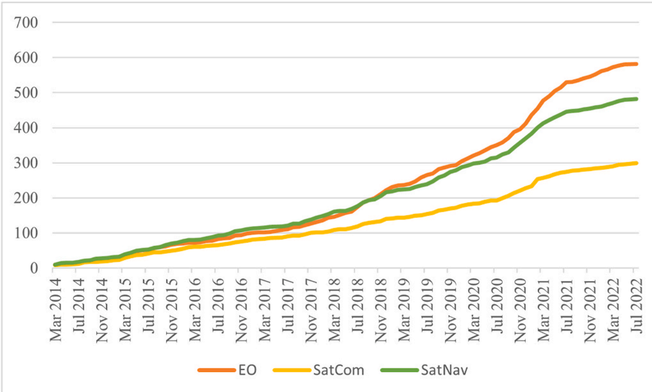

Fig. 1. Cumulated time series of satellite infrastructure exploited.

for, among others, weather forecasting, solar irradiance prediction, ground deviation analysis, vegetation monitoring, damage assessment after severe events, pollution monitoring, and construction site evaluation [5,38]. Satellite navigation technologies find valuable applications in sectors like Transport & Logistics and Health & Social Care, where real-time geolocation and positioning play a critical role in operational efficiency [39]. Lastly, satellite communications have found great implementation in the Education Information & Communication sectors, providing stable and fast internet connections in remote areas where terrestrial telecommunications technologies are limited.

Regarding the geographical distribution of the prime contractors participating in the programme, the most participatory countries in applying projects to the Business Application programme are the United Kingdom, Italy, and Germany, accounting for 46,2 % of the total number of projects (Fig. 3). France and Spain, despite being major contributors to ESA's budget, demonstrated limited participation. Here, we have to clarify that the budget allocation of a single member state influences business project development. To incentivise applications in specific areas or themes, the ESA releases calls for proposals, effectively encouraging companies to utilise space technologies. They have proven highly effective, leading to spikes in applications during the opening periods in almost all areas and crucial during periods of significant impact, stimulating a quicker recovery.

4.2. *The impact of ESA business application projects on SDGs and grand challenges*

Our results show that the ESA Business Application project is key in enabling companies to develop projects that directly or indirectly impact SDGs. Fig. 4 illustrates the SDG's direct and indirect impact.

Our results show that 603 commercial satellite-based applications impact at least one SDG. Tables 1–4 present the three most impacted SDGs, showing the overall picture, and a detailed view of Earth Observation, Satellite navigation, and Satellite communication. Overall, SGD3 is the most impacted, followed by SDG11, and SDG2. 257 Earth Observation-based applications mostly impact SDG2, SDG15, and SDG11. 230 Satellite Navigation-based applications mostly impact SDG3, SDG11, and SDG6. 116 Satellite communication-based applications mostly impact SDG3, SDG11, and SDG4.

Tables 1–4. Mostly impacted SDGs.

Moreover, we identify 14 application domains, and for each of them, we investigate their impact on SDGs. The application domains that mainly impact SDGs are Health (91, 16 %), Food and Agriculture (85,15 %), and Energy (51, 9 %).

Their contribution varies depending on the country and socio-economic context in which they are developed, thereby influencing different SDGs [14,40]. Overall, only considering a direct tangible impact, SDG 3 (Good Health and Well-being) is the most significantly impacted (114 cases, 23 %), followed by SDG 11 (Sustainable Cities and Communities) (91 cases, 18 %) and SDG 2 (Zero Hunger) (74 cases, 15 %) (Fig. 5). Italy's response to the COVID-19 pandemic has led to numerous business cases directly impacting SDG 3, with 89 % of these cases developed after 2020 in the "Health" thematic area. France's projects directly impact SDG 2 and 14, aligning with the country's environmental and marine protection policies. Germany has made notable progress in promoting sustainable infrastructure and clean energy, making the greatest contributions to SDGs 7 and 11.

The selection of technology plays a pivotal role in shaping its influence on Sustainable Development Goals (SDGs). Earth Observation-based applications have emerged as a significant contributor among the various technological domains, with 257 cases demonstrating impact on SDGs. These applications have had a particularly notable

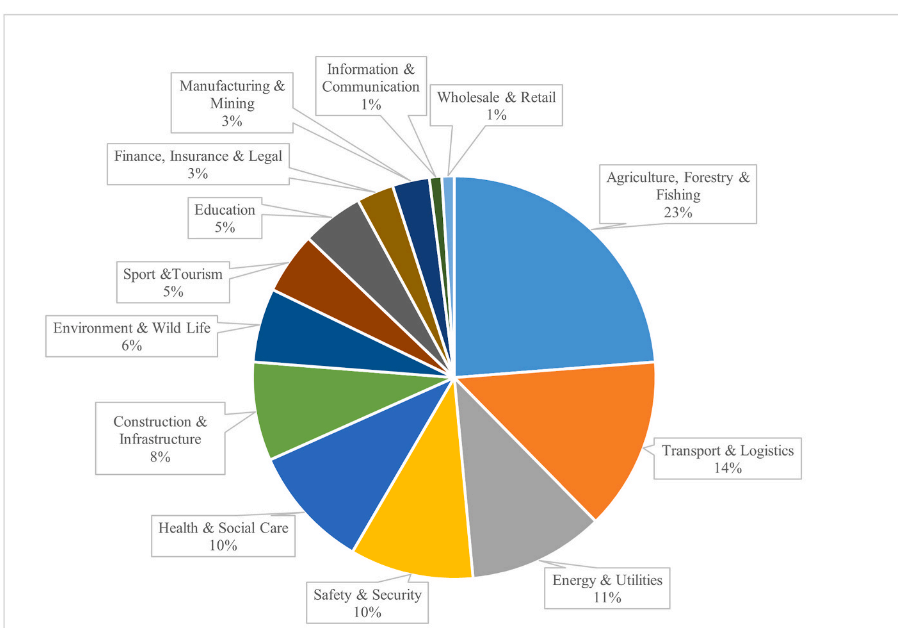

Fig. 2. Distribution of projects in the thematic areas.

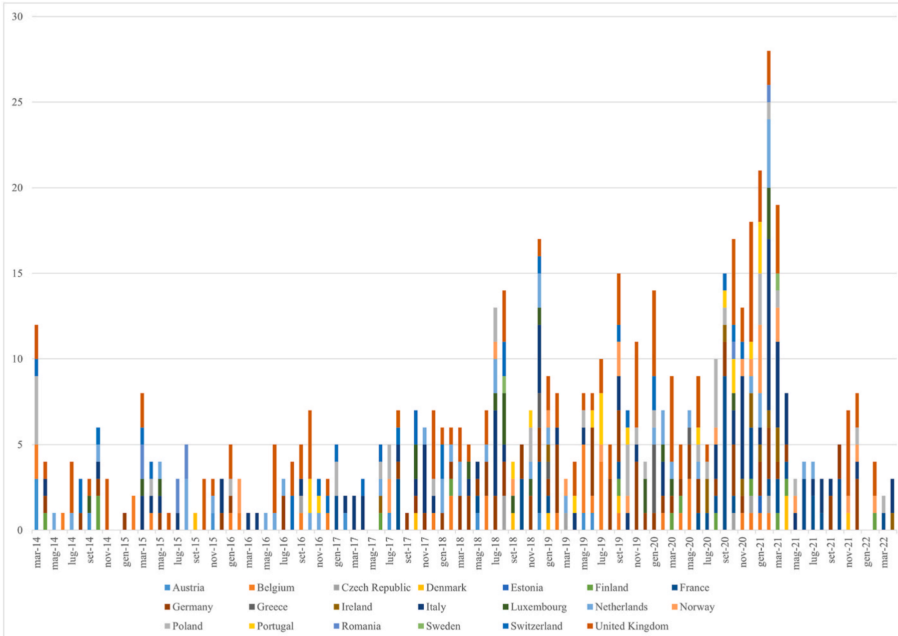

Fig. 3. Time-series of projects according to prime contractor nationality.

Fig. 4. ESA BASS projects impact on SDGs.

Table 1
Mostly impacted SDGs by commercial satellite-based applications.

Overall 603 commercial satellite-based applications		
SDG	**# of projects**	**% projects**
SDG3	136	22 %
SDG11	105	17 %
SDG2	78	12 %

Table 2
Mostly impacted SDGs by Earth Observation commercial satellite-based applications.

Earth Observation 257 commercial satellite-based applications		
SDG	**# of projects**	**% projects**
SDG2	58	23 %
SDG15	38	15 %
SDG11	34	13 %

Table 3
Mostly impacted SDGs by Satellite Navigation commercial satellite-based applications.

Satellite Navigation 230 commercial satellite-based applications		
SDG	**# of projects**	**% projects**
SDG3	68	30 %
SDG11	52	23 %
SDG6	22	10 %

Table 4
Mostly impacted SDGs by Satellite Communication commercial satellite-based applications.

Satellite Communication 116 commercial satellite-based applications		
SDG	**# of projects**	**% projects**
SDG3	33	28 %
SDG11	16	14 %
SDG4	15	13 %

influence on SDG 2, with 58 cases (constituting 23 % of the total) primarily targeting this goal. Additionally, SDG 15 and SDG 11 have been positively affected by Earth Observation-based applications, with 38 cases (accounting for 15 %) and 34 cases (comprising 13 %), respectively.

On the other hand, satellite navigation-based applications have garnered substantial attention, boasting 230 cases in total. They have been particularly instrumental in advancing SDG 3, with 68 cases (constituting 30 % of the total) focusing on this critical health-related goal. Furthermore, SDG 11 and 6 have also benefited significantly, with 52 cases (23 %) and 22 cases (10 %), respectively, showcasing the potential of Satellite Navigation-based technologies in addressing urban and water-related challenges.

Satellite communication-based applications, although fewer in number compared to the previous two categories, still wield a noteworthy impact, comprising 116 cases. These applications have predominantly contributed to SDG 3, with 33 cases (constituting 28 %) aiming to enhance healthcare and well-being. SDG 11 and SDG 4 have also seen substantial progress due to satellite communication technologies, with 16 cases (14 %) and 15 cases (13 %) addressing urban development and quality education, respectively.

The end-users of these projects also play a role in shaping their impact on SDGs. B2B end-users, such as farmers, NGOs, and insurance companies, are the most prevalent, while B2G end-users primarily consist of governmental and environmental organisations, as well as municipalities benefiting from public services and resource management. Projects targeting B2C end-users, such as patients, students, and seniors, positively impact education and healthcare-related SDGs. However, most cases involving B2B end-users do not significantly affect SDGs, indicating that specific user categories prioritise economic growth and profitability over social and environmental sustainability.

As shown in Fig. 6, of the whole set of projects inside the Business Application, 32 % of them successfully contribute to at least one grand challenge. Projects employing earth observation technology significantly impact challenges of Climate Change (30 %), Biodiversity Loss (21 %) and Net Zero & Carbon Neutrality (19 %).

The ability to obtain spatial data on air quality, greenhouse gas emissions, solar irradiation prediction, and habitat health monitoring plays a vital role in addressing these challenges [41]. Satellite navigation applications also significantly impact the protection of older populations (41 %) and biodiversity preservation (18 %). The ability to remotely monitor individuals' health status through these technologies [42], along with geolocation capabilities for tracking animals,

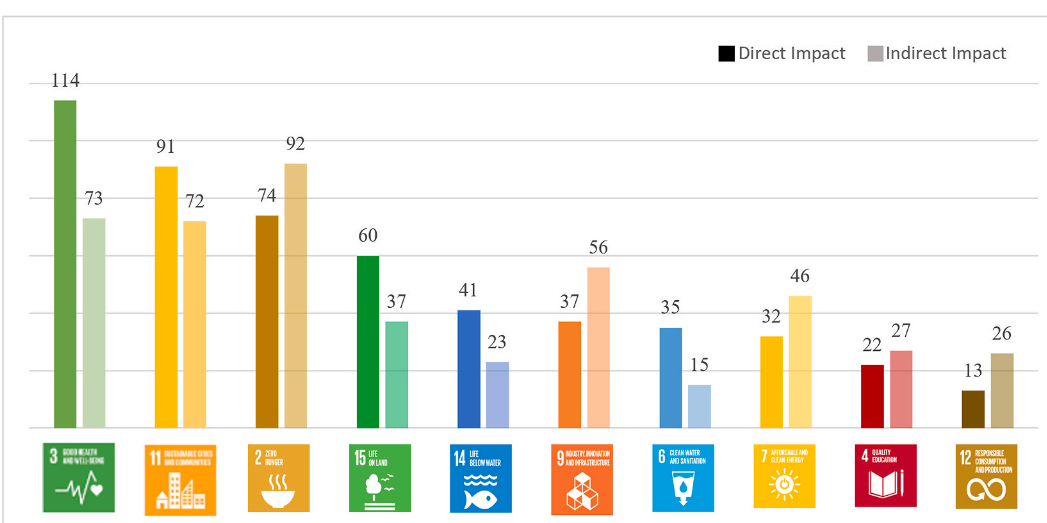

Fig. 5. Top 10 SDGs mostly impacted within the ESA Business Application Database.

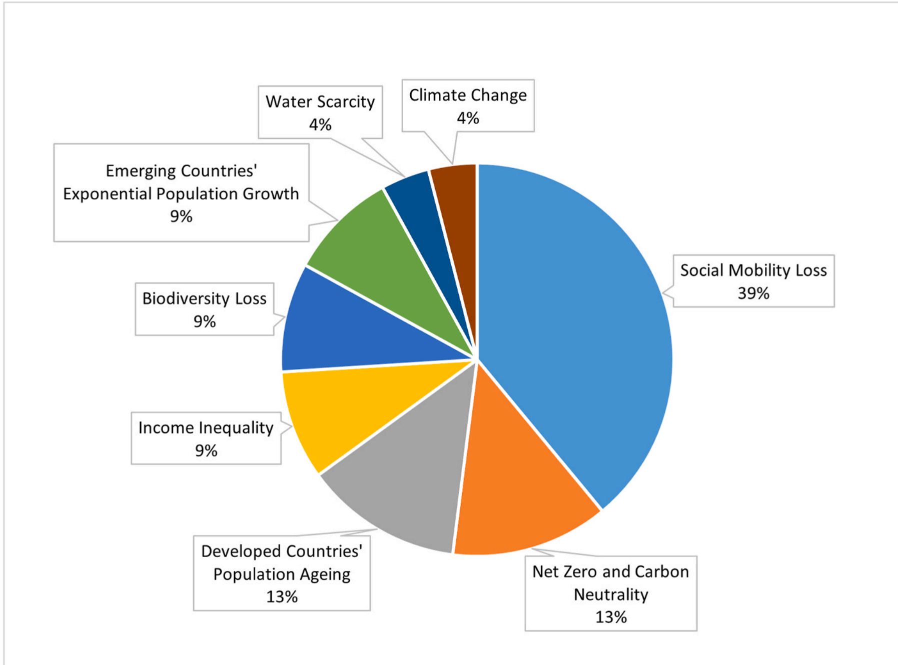

Fig. 6. Grand challenges tackled by ESA Business Application projects.

contributes positively to these challenges [43]. Satellite communications are crucial in addressing humanitarian and social disparity challenges (48 %). By offering stable and high-speed connectivity in remote regions or areas with limited telecommunications infrastructure, satellite communications enable marginalised populations to access the full range of services available on the Internet and educational content [15, 44]. This capability bridges the digital divide, ensuring that even the most underserved communities have equal opportunities to benefit from online resources [45]. Satellite communications catalyse social inclusion, empowering individuals and communities to overcome barriers and participate in the digital world, regardless of their geographic location or socioeconomic status [37].

We argue that readers must interpret the findings within the context of this inherent temporal constraint 2014–2022. Indeed, in 2023 and 2024, several initiatives have been launched to foster the positive impact of satellite-based applications on several SDGs that nowadays result in less impact (e.g., SDG5 and SDG16). For example, the ESA BASS call for "commercial applications of space robotics" [46] may favour the development of new technology impacting SDG5, providing new technologies and solutions in health and safety to achieve gender equality. Future research should explore these relevant and urgent SDGs, further investigating the impact of satellite-based applications.

We acknowledge that satellite-based applications may have negative impacts on SDGs [1]. For example, satellite-based applications may exacerbate existing inequalities and contribute to the widening of the digital divide between countries, especially emerging countries that lack the resources and infrastructure to exploit these applications and depend on developed countries to leverage these assets, or lack the resources to foster their industrial development, progressing, therefore, at a slower pace than developed countries (having therefore a negative impact on SDG10) [47]. This disparity in access to satellite-based services and technologies can further perpetuate socio-economic disparities and indirectly hinder progress towards poverty eradication (SDG 1), as marginalised communities are left behind in the digital age [48]. Additionally, the deployment and operation of satellite systems can inadvertently contribute to environmental degradation, including land, atmospheric, and outer space pollution (SDGs 14, 15). The disposal of space debris poses risks to both terrestrial and extraterrestrial ecosystems, potentially undermining efforts to conserve and sustainably manage terrestrial and marine environments. Moreover, satellite-based applications may drive the consumption of critical materials (SDG 12), such as rare earth elements and precious metals, leading to resource depletion and environmental degradation [49]. By acknowledging these potential negative impacts, we aim to provide a more comprehensive perspective on the broader implications of satellite-based applications. It is imperative that future research delves deeper into these complex issues to understand better the trade-offs associated with the exploitation of satellite-based applications, thereby informing more sustainable and equitable approaches to their implementation.

SDGs are often used as a global development goal-setting instrument for both policy and research impact assessment [5]. Our data show that satellite-based applications developed by the ESA BASS have an impact in other regions. For example, satellite-based solutions for agriculture monitoring have a positive impact on reducing food scarcity in emerging countries. It is, therefore, fundamental to acknowledge the relevance of fostering global policy synergies that favour the cross-regional adoption of satellite-based applications and incentivise companies in developed countries to develop products and services for emerging countries [7], aware of the possible limitations (e.g., digital divide) explained above.

By systematically analysing 603 commercial satellite-based applications, we provide policymakers with empirical evidence of the direct and indirect impacts of satellite-based applications on SDGs at the European level. This insight enables policymakers to make informed decisions regarding resource allocation, investment prioritisation, and policy formulation to maximise the positive impact of satellite-based applications on sustainable development objectives [50]. The identification of the most impacted SDGs and application domains provides policymakers with targeted information to tailor policies and initiatives that align with specific regional and industrial development priorities. For example, we show that SDG3 is significantly impacted by satellite-based solutions, which are developed by European prime contractors but developed in other regions, and underscores the importance of designing policy enabling cross-industry fertilisation. Future research may adopt the same methodology in other geographical regions, leveraging the SDGs standards to explore possible complementarities to assess the impact of commercial satellite-based projects within their jurisdictions, thereby facilitating evidence-based decision-making and policy development at the local level and fostering a global harmonisation of the regulation regarding the adoption of satellite-based solutions for sustainability.

5. Conclusions

The Business Application Programme initiative positively develops satellite-based projects to impact SDGs and grand challenges. The findings indicate a consistent increase in project subscriptions, with occasional historical fluctuations. This growth can be attributed to ESA's support for downstream sector business ideas and advancements in satellite technologies, particularly in earth observation and satellite navigation, enabling their application beyond the traditional space sector. Adopting the Copernicus earth observation program's Free, Full, and Open data policy has further improved data accessibility. Satellite navigation systems have become ubiquitous, primarily benefiting industries such as transportation, logistics, and healthcare, where real-time geolocation and positioning are crucial.

SDGs 3, 11, 12, and 15 emerge as the most frequently impacted Sustainable Development Goals. Businesses tend to invest in these SDGs because they align with commercial interests and revenue generation opportunities. However, other SDGs, particularly those related to human development and good governance, are currently underrepresented in the initiatives.

The analysis reveals that 30 % of initiatives impact at least one Grand Challenge, with climate change, biodiversity loss, and achieving Net Zero and Carbon Neutrality being the most affected areas. These programmes are primarily focused in Europe, so environmental issues are often prioritised due to their urgency on the continent. Various factors embedded within projects demonstrate positive and negative influences on attaining Grand Challenges.

In summary, this study has emphasised the effectiveness of the Business Application Programme in promoting the commercialisation of services offered by space assets. It sheds light on important technological and business trends that have shaped the space industry's past, present, and future. Furthermore, it demonstrates how the services enrolled in the programme can significantly contribute to the achievement of "Grand Challenges." In conclusion, it demonstrates and strengthens the space sector's role as a major driver of sustainable development. Researchers and practitioners may adopt the methodology in other contexts, overcoming the geographical and data accessibility limitations of our research.

CRediT authorship contribution statement

Alessandro Paravano: Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. **Matteo Patrizi:** Data curation, Formal analysis, Writing – original draft. **Elena Razzano:** Data curation, Formal analysis, Validation, Writing – review & editing. **Giorgio Locatelli:** Investigation, Supervision, Validation, Writing – review & editing. **Francesco Feliciani:** Data curation, Project administration, Validation. **Paolo Trucco:** Conceptualization, Investigation, Methodology, Project administration, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This paper is the first cornerstone of broader collaboration research between the European Space Agency and Politecnico di Milano under the Memorandum "Business Analysis and Support on Advanced Air Mobility, the New Space Economy Evolution and Impact". It aims to promote space-based applications and services in different domains and coordinate in-depth studies on new service development and business model innovation in the New Space Economy.

The dataset utilised in the study is not available upon request. However, researchers interested in exploring satellite-based applications within the European Space Agency Business Applications programme can access public information regarding these projects through the ESA website and adopt the data structure presented in Table B in the Appendix.

Appendix

Table A
UN Sustainable Development Goals (SDGs) - https://sdgs.un.org/goals

SDG #	SDG Title	SDG short description
SDG1	No Poverty	End poverty in all its forms.
SDG2	Zero Hunger	End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
SDG3	Good Health and Well-being	Ensure healthy lives and promote well-being for all at all ages
SDG4	Quality Education	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
SDG5	Gender Equality	Achieve gender equality and empower all women and girls
SDG6	Clean Water and Sanitation	Ensure availability and sustainable management of water and sanitation for all.
SDG7	Affordable and Clean Energy	Ensure access to affordable, reliable, sustainable and modern energy for all.
SDG8	Decent Work and Economic Growth	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.
SDG9	Industry, Innovation, and Infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation.
SDG10	Reduced Inequalities	Reduce inequality within and among countries.
SDG11	Sustainable Cities and Communities	Make cities and human settlements inclusive, safe, resilient and sustainable.
SDG12	Responsible Consumption and Production	Ensure sustainable consumption and production patterns.
SDG13	Climate Action	Take urgent action to combat climate change and its impacts.
SDG14	Life Below Water	Conserve and sustainably use the oceans, seas and marine resources for sustainable development.

(*continued on next page*)

Table A (*continued*)

SDG #	SDG Title	SDG short description
SDG15	Life on Land	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and biodiversity loss.
SDG16	Peace, Justice and Strong Institutions	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.
SDG17	Partnerships for the Goals	Strengthen the means of implementation and revitalise the Global Partnership for Sustainable Development.

Table B
Data structure

Attribute	Value	Format	Example
ID	001–603	Number	“152”
Link	Webpage link	Text	“https:// …”
Project name	“Project name”	Text	Confidential
Start date	“month/year”	Date	“Mar-15”
End date	“month/year”	Date	“Apr-16”
Activity	Kick-start, Feasibility, Demonstration	Category – Single choice	“Demonstration”
Thematic call	Yes, No	Boolean	“No”
Status	Completed, Ongoing	Boolean	“Completed”
Thematic Area	Environment, Wildlife and Natural Resources; Safety & Security; Infrastructure & Smart Cities; Transport & Logistics; Food & Agriculture; Maritime and Aquatic; Energy; Health; Finance, Investment & Insurance; Aviation; Tourism; Education & Training; Media, Culture and Sport; Water; Forestry	Category – Multiple choice	“Food & Agriculture”
The objective of the satellite business application	“Description from the webpage”	Text	“The project aims to reduce water consumption by leveraging the Earth Observation satellite.”
System architecture	"Description from the webpage"	Text	"The application consists of a web app that farmers can use to monitor the water consumption in their fields."
Space added value	"Description from the webpage"	Text	"The application leverages the unique EO satellite sensors to monitor water consumption in the fields.”
Satellite-business application features	"Description from the webpage"	Text	“Satellite data integration”, “cloud storage”, “cloud computing”, “web app platform”
Value proposition	"Description from the webpage"	Text	"Offering farmers a reliable and user-friendly service to reduce water consumption."
Prime contractor	"Name from the webpage"	Text	"Company XXX ″
Prime contractor nationality	"Country"	Text	"France"
Sponsor(s)	"Name from the webpage"	Text	"Company YYY"
Partner(s)	"Name from the webpage"	Text	"Company ZZZ"
Client(s)	"Name from the webpage"	Text	"Farmer AAA", "Farmer BBB"
Client(s)needs	“Description from the webpage”	Text	“Farmers seeking to reduce water consumption”
Client(s) nationality/region	"Name of the country"	Text	"Uganda"
Client sector	Environment, Wildlife and Natural Resources; Safety & Security; Infrastructure & Smart Cities; Transport & Logistics; Food & Agriculture; Maritime and Aquatic; Energy; Health; Finance, Investment & Insurance; Aviation; Tourism; Education & Training; Media, Culture and Sport; Water; Forestry	Category – Multiple choice	"Agriculture"
Client type	B2B, B2C, B2G	Category – Multiple choice	"B2C″
Satellite infrastructure	EO, Satcom, satnav	Category – Multiple choice	"EO"
Satellite used	"Name of the satellite"	Text	"Copernicus Sentinel 2"
Satellite sensor used	Optical, SAR, Multispectral, Lidar	Category – Multiple choice	"Multispectral"
Complementary data source	Drones, in-situ sensors, Aerial imageries, client data	Category – Multiple choice	"Drones"
Complementary technology	Machine learning, cloud computing, cloud storage, artificial intelligence, 5G	Category – Multiple choice	"Cloud computing"
SDG directly Impacted	SDG1-SDG17	Category – Multiple choice	“SDG6”
SDG Target directly impacted	Target1-Target 169	Category – Multiple choice	“Target 6.4”
SDG indirectly impacted	SDG1-SDG17	Category – Multiple choice	“SDG2”, “SDG6”
SDG Target indirectly impacted	Target1-Target 16	Category – Multiple choice	“Target 2.1”, “Target 6.1”;
Grand challenge impacted	Climate change, Biodiversity loss, Income inequality, Housing shortages, Social mobility loss, Polarised politics, Emerging countries’ exponential population growth, Developed countries’ population ageing, Water scarcity, Zero hunger, Net zero and carbon neutral	Category – Multiple choice	"Water scarcity"
Additional notes	"Notes from researchers"	Text	"Comment"

Table C
Experts profiles

Senior Expert	Role	Organisation	Expertise	Years of experience	Interview Duration
Interviewee #1	Senior Officer	Space Agency	Managing and supporting commercial satellite-based application projects	25	1.05 h
Interviewee #2	CEO	Private company	Managing several satellite-based application projects	21	1.02 h
Interviewee #3	CTIO	Private company	Managing several satellite-based application projects	19	1.00 h
Interviewee #4	Officer	Space Agency	Managing and supporting commercial satellite-based projects	13	1.04 h
Interviewee #5	Professor	University	Assessing direct and indirect impact on SDGs of emerging technologies	23	1.06 h

References

[1] United Nations Office for Outer Space Affairs, The “Space2030” Agenda: space as a driver of sustainable development (2021). https://www.unoosa.org/oosa/oosadoc/data/resolutions/2021/general_assembly_76th_session/ares763.html. (Accessed 1 June 2023).
[2] Members of the International Space Station (ISS) Program Science Forum (PSF), International Benefits for Humanity, 2022. https://www.nasa.gov/sites/default/files/atoms/files/iss_benefits_for_humanity_2022_book.pdf.
[3] A. Paravano, G. Locatelli, P. Trucco, What is value in the New Space Economy? The end-users' perspective on satellite data and solutions, Acta Astronaut. (2023), https://doi.org/10.1016/j.actaastro.2023.05.001. S0094576523002242.
[4] OBSERVER: The Copernicus Emergency Management Service (CEMS) Risk and Recovery Mapping component celebrates its 10th anniversary | Copernicus, (n.d.). https://www.copernicus.eu/en/news/news/observer-copernicus-emergency-management-service-cems-risk-and-recovery-mapping-component (accessed March 22, 2024).
[5] S. Paladini, K. Saha, X. Pierron, Sustainable space for a sustainable Earth? Circular economy insights from the space sector, J. Environ. Manag. 289 (2021) 112511, https://doi.org/10.1016/j.jenvman.2021.112511.
[6] A. Baumgart, E.I. Vlachopoulou, J. Del Rio Vera, S. Di Pippo, Space for the sustainable development goals (Space4SDGs): mapping the contributions of space to the 2030 agenda for sustainable development. Proceedings of the International Astronautical Congress, IAC 2020-Octob, 2020.
[7] N. Pulsiri, V. Dos Santos Paulino, The green path to space sustainability: twenty years of research, Int. J. Technol. Manag. Sustain. Dev. 22 (2024) 299–318, https://doi.org/10.1386/tmsd_00079_1.
[8] OECD, OECD Handbook on Measuring the Space Economy, second ed., OECD, 2022 https://doi.org/10.1787/8bfef437-en.
[9] United Nations Office for Outer Space Affairs, European Global Navigation Satellite System and Copernicus: Supporting the Sustainable Development Goals, 2018, p. 118.
[10] K. Davidian, Operationalising the definition of “commercial space,”, Acta Astronaut. 198 (2022) 541–549, https://doi.org/10.1016/j.actaastro.2022.06.040.
[11] D. Donaldson, A. Storeygard, The view from above: applications of satellite data in economics, J. Econ. Perspect. 30 (2016) 171–198, https://doi.org/10.1257/jep.30.4.171.
[12] K. Anderson, B. Ryan, W. Sonntag, A. Kavvada, L. Friedl, Earth observation in service of the 2030 agenda for sustainable development, Geo Spatial Inf. Sci. 20 (2017) 77–96, https://doi.org/10.1080/10095020.2017.1333230.
[13] United Nations Office for Outer Space Affairs, Space and Global Health, 2022. https://www.unoosa.org/res/oosadoc/data/resolutions/2022/general_assembly_77th_session/ares77120_html/N2274743.pdf. (Accessed 1 June 2023).
[14] S. Paladini, K. Saha, The quest for sustainability in lower orbit: conceptual models for space tourism, Int. J. Tourism Res. 25 (2023) 333–349, https://doi.org/10.1002/jtr.2568.
[15] L. Budd, S. Paladini, Space exploration as a propulsive industry in levelling up, Contemporary Social Science 18 (2023) 357–380, https://doi.org/10.1080/21582041.2023.2280703.
[16] D. Martin-Lawson, S. Paladini, K. Saha, E. Yerushalmi, The cost of (Un)regulation: shrinking Earth's orbits and the need for sustainable space governance, J. Environ. Manag. 349 (2024), https://doi.org/10.1016/j.jenvman.2023.119382.
[17] M. Weinzierl, Space, the final economic frontier, J. Econ. Perspect. 32 (2018) 173–192, https://doi.org/10.1257/jep.32.2.173.
[18] A. Paravano, G. Locatelli, P. Trucco, End-users engagement for enacting value of complex projects: an ecological perspective, J. Manage. Eng. 40 (2024), https://doi.org/10.1061/JMENEA.MEENG-5724.
[19] A. Paravano, G. Locatelli, P. Trucco, What is value in the New Space Economy? The end-users perspective. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85167604442&partnerID=40&md5=fd3860a90e7f41acf56633a5994abaec, 2022.
[20] ESPI, ESPI Yearbook 2019, Space Policies, Issues and Trends, European Space Policy Institute, Vienna, Austria, 2020. www.espi.or.at.
[21] PricewaterhouseCoopers (PwC), Copernicus ex-ante benefits assessment Final report. www.pwc.fr/space, 2017.
[22] ESA, Final Report on the Space Economy 2016, 2016. ESA.
[23] UNCC, United Nation Climate Change - Net Zero Financing Roadmaps, 2021.
[24] H. Aguinis, A.M. Solarino, Transparency and replicability in qualitative research: the case of interviews with elite informants, Strat. Manag. J. 40 (2019) 1291–1315.
[25] O. Pesämaa, O. Zwikael, J.F. Hair, M. Huemann, Publishing quantitative papers with rigor and transparency, Int. J. Proj. Manag. 39 (2021) 217–222, https://doi.org/10.1016/J.IJPROMAN.2021.03.001.
[26] M. Saunders, P. Lewis, A. Thornhill, Research Methods for Business Students, Pearson education, 2009.
[27] L.A. Palinkas, Qualitative and mixed methods in mental health services and implementation research, Journal of Clinical Child \& Adolescent Psychology 43 (2014) 851–861.
[28] M.Q. Patton, Qualitative Research \& Evaluation Methods: Integrating Theory and Practice, Sage publications, 2014.
[29] B. Saunders, J. Kitzinger, C. Kitzinger, Anonymising interview data: challenges and compromise in practice, Qualitative Research 15 (2015) 616–632.
[30] P.R. Easterby-Smith, Mark, Richard Thorpe, Jackson, Management and Business Research, SAGE Publications Ltd, 2015.
[31] A. Bryman, Integrating quantitative and qualitative research: how is it done? Qualitative Research 6 (2006) 97–113, https://doi.org/10.1177/1468794106058877.
[32] S. Spall, Peer debriefing in qualitative research: emerging operational models, Qualitative Inquiry 4 (1998) 280–292.
[33] S.K. Arora, Y. Li, J. Youtie, P. Shapira, Using the wayback machine to mine websites in the social sciences: a methodological resource, J Assn Inf Sci Tec 67 (2016) 1904–1915, https://doi.org/10.1002/asi.23503.
[34] H.J. Oh, S. Chang, B. Ashuri, Patterns of skill sets for multiskilled laborers based on construction job advertisements using web scraping and text analytics, J. Manage. Eng. 39 (2023) 04023009, https://doi.org/10.1061/JMENEA.MEENG-5243.
[35] M. Héroux-Vaillancourt, C. Beaudry, C. Rietsch, Using web content analysis to create innovation indicators—what do we really measure? Quantitative Science Studies 1 (2020) 1601–1637, https://doi.org/10.1162/qss_a_00086.
[36] S.K. Shah, K.G. Corley, Building better theory by bridging the quantitative-qualitative divide, Journal of Management Studies 43 (2006) 1821–1835, https://doi.org/10.1111/j.1467-6486.2006.00662.x.
[37] S. Atek, C. Pesaresi, M. Eugeni, C. De Vito, V. Cardinale, M. Mecella, A. Rescio, L. Petronzio, A. Vincenzi, P. Pistillo, F. Bianchini, G. Giusto, G. Pasquali, P. Gaudenzi, A Geospatial Artificial Intelligence and satellite-based earth observation cognitive system in response to COVID-19, Acta Astronautica 197 (2022) 323–335, https://doi.org/10.1016/j.actaastro.2022.05.013.
[38] M. Argentiero, P.M. Falcone, The role of earth observation satellites in maximising renewable energy production: case studies analysis for renewable power plants, Sustainability (Switzerland) 12 (2020), https://doi.org/10.3390/su12052062.
[39] EUSPA, EUSPA EO and GNSS market report. https://doi.org/10.2878/94903, 2022.
[40] A. Bahadorestani, N. Naderpajouh, R. Sadiq, Planning for sustainable stakeholder engagement based on the assessment of conflicting interests in projects, Journal of Cleaner Production 242 (2020) 118402, https://doi.org/10.1016/j.jclepro.2019.118402.
[41] A. Paravano, G. Locatelli, P. Trucco, Assessing the value of the next generation space projects: state-of-the-art and new perspectives. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85167605753&partnerID=40&md5=d4d4e01fb404e62edd5f374f6d15d619, 2022.
[42] S.K. Borowski, S.W. Ryan, D.R. McCurdy, B.G. Sauls, Key technologies, systems, and infrastructure enabling the commercialisation and human settlement of low earth orbit, the moon, and cislunar space, New Space 9 (2021) 104–122, https://doi.org/10.1089/space.2020.0029.
[43] G. Denis, H. de Boissezon, S. Hosford, X. Pasco, B. Montfort, F. Ranera, The evolution of Earth Observation satellites in Europe and its impact on the performance of emergency response services, Acta Astronautica 127 (2016) 619–633, https://doi.org/10.1016/j.actaastro.2016.06.012.
[44] European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs., PWC., ECORYS., Satellite Communication to Support EU Security Policies and Infrastructures: High Level SATCOM User Requirements, Publications Office, LU, 2014. https://data.europa.eu/doi/10.2873/48575. (Accessed 20 November 2022).
[45] M. Guerster, E. Crawley, S. Aliaga, B. Cameron, So many beams, so little time: revenue Management in the next generation of flexible communication satellites, Acta Astronautica 191 (2022) 479–490, https://doi.org/10.1016/j.actaastro.2021.08.001.
[46] Commercial Applications of Space-Enabled Robotics, (n.d.). https://business.esa.int/funding/call-for-proposals-non-competitive/commercial-applications-space-enabled-robotics (accessed March 22, 2024).

[47] V. Almonacid, L. Franck, Extending the coverage of the Internet of things with low-cost nanosatellite networks, Acta Astronautica 138 (2017) 95–101, https://doi.org/10.1016/j.actaastro.2017.05.030.

[48] Y.K. Dwivedi, L. Hughes, A.K. Kar, A.M. Baabdullah, P. Grover, R. Abbas, D. Andreini, I. Abumoghli, Y. Barlette, D. Bunker, L. Chandra Kruse, I. Constantiou, R.M. Davison, R. De, R. Dubey, H. Fenby-Taylor, B. Gupta, W. He, M. Kodama, M. Mäntymäki, B. Metri, K. Michael, J. Olaisen, N. Panteli, S. Pekkola, R. Nishant, R. Raman, N.P. Rana, F. Rowe, S. Sarker, B. Scholtz, M. Sein, J.D. Shah, T.S.H. Teo, M.K. Tiwari, M.T. Vendelø, M. Wade, Climate change and COP26: are digital technologies and information management part of the problem or the solution? An editorial reflection and call to action, International Journal of Information Management 63 (2022), https://doi.org/10.1016/j.ijinfomgt.2021.102456.

[49] T.A. Tsalis, K.E. Malamateniou, D. Koulouriotis, I.E. Nikolaou, New challenges for corporate sustainability reporting: United Nations' 2030 Agenda for sustainable development and the sustainable development goals, Corporate Social Responsibility and Environmental Management 27 (2020) 1617–1629, https://doi.org/10.1002/csr.1910.

[50] A. Froehlich, N. Ringas, J. Wilson, How space can support African civil societies: security, peace, and development through Efficient Governance Supported by space applications, Acta Astronautica 195 (2022) 532–539, https://doi.org/10.1016/j.actaastro.2021.06.006.