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ANALYSIS OF SPACEFLIGHT ACTIVITIES' IMPACT ON SUSTAINABLE DEVELOPMENT IN THE GLOBAL SOUTH

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ABSTRACT: Sustainable development is the current paradigm for development in the global south. Since 1976 nations of the global south have conducted space missions. This work investigates which impact on sustainable development in the global south spaceflight has. The majority of Sustainable Development Goals can be addressed with space activities, e.g. by setting up satellite infrastructures for communication, creating businesses or supporting protection of ecosystems. Short-term effects such as build-up of own industry for own satellites and infrastructure can be seen when analysing satellite numbers and mission types. The reduction in launch costs and miniaturization of satellites in the 2010s have increased satellite numbers, by improving accessibility to space technology. This led to a thriving space industry in global south nations e.g. Argentina. The continuity of the effects cannot yet be determined fully, due to the recency of most activities, even though for some nations, e.g. Brazil or Indonesia, activities have been continuous. Strategic integration of space activities into planned sustainable development could not be detected. Potential benefits were realized mostly via services and there is unused potential for technology application on Earth.

KEY WORDS: Sustainable development, spaceflight, satellites, space infrastructure, spin-off technologies

NOMENCLATURE

APSCO	Asia-Pacific Space Cooperation Organization
ARMS	African Resources and Environmental Management Satellite Constellation
ASI	Agenzia Spaziale Italia
CEOS	Committee of Earth Observation Satellites
CNES	Centre national d'études spatiales (National Center for Space Studies)
CONAE	Comisión Nacional de Actividades Espaciales (Argentina space agency)
CSA	Canadian Space Agency
DAC	Development Assistance Committee
DART	Double Asteroid Redirection Test
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Center)
ESA	European Space Agency
GDP	Gross domestic product
LEO	Low Earth Orbit
IAF	International Astronautical Federation
ISS	International Space Station
JAXA	Japanese Aerospace Exploration Agency
NASA	National Aeronautical and Space Administration
ODA	Official Development Assistance
OECD	Organisation for Economic Co-operation and Development
SDG	Sustainable Development Goal(s)
SGAC	Space Generation Advisory Council
SUPARCO	Space & Upper Atmosphere Research Commission
UN	United Nations
UN COPUS	United Nations Committee on the Peaceful Uses of Outer Space
VNR	Voluntary National Review

1. INTRODUCTION

Since the beginning of the space age with Sputnik's launch in 1959, space activities have supported the development of the world, e.g. by introducing new technologies, processes and services, either by direct application, such as communication satellites, or by spin-off application, such as e.g. solar cells, which by now are a relevant, sustainable electrical power source terrestrialy applied and formerly developed for space (Maiwald, et al., 2021). Especially their efficiency, which is typically required to be high for space application, make spaceflight technologies promising means to enhance sustainable development on Earth.

In the past decades emerging and developing nations, summarized in the following as global south, conducted space misisons with a varying degree of success and sophistication. Examples for space activities are e.g. China's ambitious space program comprising of interplanetary space probes to Moon and Mars and human spaceflight missions in Low Earth Orbit (LEO), India's launcher program, which also aims for human spaceflight activities, or the Congolese Troposphere launcher development, which is privately driven with some national support. The International Space Station (ISS) has also been part of space activities from the global south with crew and visitors from countries like Brazil, Kazakhstan, Malaysia, South Africa and the United Arab Emirates[1].

Costs for space missions are typically high, e.g. NASA's recent Double Asteroid Redirection Test (DART) mission cost 324 million US$ (The Planetary Society, no date) and for industrialized space nations, studies show a significant economic gain from funding in space missions, e.g. the European Space Agency (ESA) has created a return of 80% of investment within the ISS program for instance in the form of patents (pwc, 2016).

It is however, unclear how spaceflight activities contribute to the sustainable development of nations in the global south, therefore

[1] https://www.nasa.gov/feature/visitors-to-the-station-by-country/

this work investigated their impact in the global south. The goal is to evaluate space activities, understand the continuity of their possible contribution and analyse how far potential utility is actually exploited.

For this work global south nations are considered, if they are listed by the Organisation for Economic Co-operation and Development's (OECD) Development Assistance Committee (DAC) as having received official development assistance (ODA) in 2021[2].

1.1. Sustainable Development

Per definition, sustainable development is "*the development that meets the need of the present without compromising the ability of future generations to meet their own needs*" (United Nations General Assembly, 1987).

Typically, e.g. by Hilser (2013), it is described by three dimensions, equally relevant. These dimensions are economy, ecology and social and are, i.e. usually a measure affecting one dimensions is also affecting others (positively or negatively), making sustainable development complex a complex challenge. (Hilser, 2013)

For instance, building a factory, can improve the economic situation in a region, e.g. due to new job opportunities. These new jobs enable financing better education for the workers families, i.e. there is a potential positive impact in the social dimension. However, pollution can negatively affect the health of the people living in the area and also the ecosystem, i.e. both the social and ecological dimensions.

As a human activity spaceflight also has a relation to sustainable development, e.g. either as an activity to be conducted sustainably or in support of sustainable development on Earth, e.g. by technologies, or resources transferred from space to Earth.

The relation of spaceflight and sustainable development can have four perspectives, defined by the origin and the target of the direction of sustainable development (Maiwald, 2022). These perspectives are (Maiwald, 2022):

- Earth-to-Earth
- Earth-to-Space
- Space-to-Earth
- Space-to-Space

These perspectives describe the borders of the system to be developed sustainably. The first perspective means that via Earth's space programs Earth can be supported in its sustainable development, e.g. by terrestrial application of technologies or scientific results (Maiwald, 2022). A perspective originating from Earth to space describes situations where space missions are supported form Earth to remain sustainble, e.g. like ISS is operated with the help of resupply from Earth (Maiwald, 2022). Similarly, space can support Earth's sustainable development, e.g. by resources or Earth observation data (Maiwald, 2022). Last, space missions can be developed sustainably in space itself, e.g. by using renewable resources, such as solar energy, to make a mission independent of resupply from Earth (Maiwald, 2022).

1.1.1. Sustainable development as paradigm for spaceflight

Sustainable development and sustainability have implicitly and explicity. Yet, the understanding of these concepts is lacking in most instances, especially in the dimensions not regarding economy (Maiwald, 2022). The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (United Nations Office of Outer Space Affairs, 2017, p. 3 ff) from 1967, regulates e.g. top-level cooperation between nations via the United Nations and e.g. prescribes that everyone should benefit from space activities and prohibits one-sided gain from resource exploitation. It further mandates environmental protection on the lunar surface (United Nations Office of Outer Space Affairs, 2017, p. 3 ff). This means it implicitly affects the ecological and social dimensions of sustainable development.

An explicit concept is the concept of Planetary Sustainability as defined by NASA (2014). It focuses on Earth and incorporates space in the sense that space can serve as source for (unspecified) resources to be used for living on Earth. This concept does not include any social considerations about just distribution of resources or environmental protection ideas for the space environment (Maiwald, 2022). Newman (2015) and Hofman et al. (2010) consider the environmental dimension more than institutional or governmental concepts and aim for more conservation and protection of non-terrestrial environments (Maiwald, 2022). The Secure World Foundation (2013) relates sustainability mostly to Earth's space environment and addresses the generation of space debris, i.e. remnants of old, non-operational satellites or spent rocket stages.

In general, it can be said that sustainability is often regarded from an economical point of view for future space missions, e.g. reducing costs and effort for mission resupply by using resources on site (Maiwald, 2022). Concepts often lack a discussion or even acknowledgement of social aspects (Maiwald, 2022). Especially, the threat of exploiting of resources is not discussed by organizations, only individuals, although the repercussions on Earth could be manifold. Exploiting the lunar surface for resources and thus changing its appearance could have cultural effects for people on Earth, especially e.g. isolated groups of people, who might not even be aware of spaceflight (Maiwald, 2022). A thorough, formal understanding of the dimensions of sustainable development is not apparent in the concepts found in the spaceflight community (Maiwald, 2022). If space is to be accessed in a sustainable manner, this must change.

1.1.2. Spaceflight activities for sustainable development and sustainable development goals

Two of the previously explained perspectives relate to Earth's sustainable development by space activities, either directly, e.g. by resources used from space, or indirectly, e.g. by technology spin-offs.

Space missions in general, but especially also human spaceflight missions, have to be resource efficient to limit the costs, e.g. by limiting launch mass, and enable long-term missions. For long-term human missions, life-support systems are developed which operate circular (Maiwald, et al., 2021b), i.e. resources are regenerated, e.g. by using plant growth for oxygen generation out of crew produced carbon dioxide. This is the so-called

[2] https://www.oecd.org/dac/financing-sustainable-development/development-finance-standards/DAC-List-ODA-Recipients-for-reporting-2021-flows.pdf

closed-loop approach and is essentially a similar challenge to sustainable living on Earth. Here Earth's ecosystems provides the same "services" to its human population as an artificial life-support system does for its crew (Maiwald, et al., 2021). The space environment further poses high demands on reliability on space systems, e.g. due to radiation exposure. The costs and adverse environmental conditions in space typically require redundancy concepts for space systems. These and other challenges, e.g. miniaturization, make space actors so-called "lead users", i.e. they are leading technological development (Maiwald, et al., 2021). Spaceflight is essentially acting as a furnace for technologies, which are required for a space mission because of unique abilities necessary for a given mission. Once developed the development costs have been spent within the frame of space programs, the technology is however available for further applications, including on Earth. One such example are solar cells.

They originally have been too expensive for terrestrial application, but have been the only option at the time for recharging satellite batteries, resp. powering spacecraft. Solar cells were thus adopted as major power generation technology for space (Perlin, 1999). This implementation reduced the costs for solar cells over time and eventually enabled their terrestrial application (Perlin, 1999). Today they are a relevant technology for humanity's sustainable development by supplying climate friendly energy (Maiwald, et al., 2021). Further possible technology adaptations could occur e.g. for agricultural technologies, e.g. aeroponic systems used for human spaceflight (Maiwald, et al., 2021), which can reduce water demand to 2% and reduce fertilizer need to 60%, removing pesticides from agriculture and improving harvest yield by 75% (Oluwafemi, 2021). Generally, space activities can support all dimensions of sustainable development. Manufacturing, operating spacecraft and their technologies influences the economic dimension, see Figure 1.

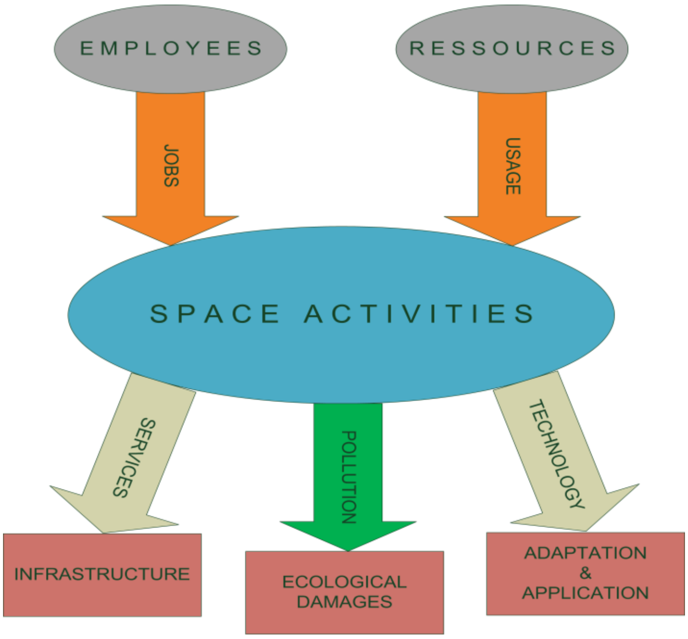

Figure 1. Possible influence and interdependence of space activities concerning sustainable development.

Fields of application for technical knowhow fosters interest in education of relevant fields, e.g. engineering or physics and technology development allows economic growth (Wood & Weigel, 2012). Applying satellites for communication with remote areas influences the social dimension, e.g. by enabling education like realized in India since the 1980s (Bhatia & Rangarajan, 1999). This way space activities can e.g. support SDG 4, prescribing access to education or SDG 9 with reference to building of infrastructure, here infrastructure for communication applying services of space activities. Similarly, space infrastructure can provide services affecting the ecological dimension, e.g. by monitoring deforestation or greenhouse gas emissions (SDGs 15 and 13). Further examples for space related services and affecting SDGs are given in Figure 2.

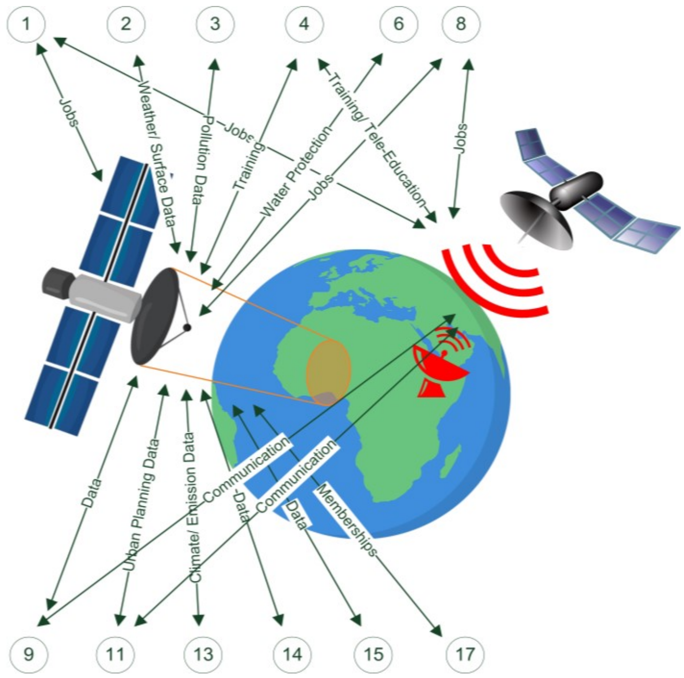

Figure 2. Relation space missions (left: Earth observation, right Communication) on the SDGs.

Negative effects, e.g. due to pollution or resource exploitation can occur as well. Launch vehicles failures can threaten human lives and infrastructure (e.g. as occurred during the launch of Intelsat 708 by China) (Lan, 2013) (Zak, 2013). If the bulk of work is conducted abroad and e.g. a spacecraft is only obtained in a foreign country this can lead to money drain or draining other resources.

An overview about the SDGs and further influences on them by space activities is given in the appendix for reference, along with a list of the SDGs for easier reference.

A summary of how which SDG can be addressed by which kind of space activity, i.e. a service or a technology along with how the SDGs relate to which dimension for space activities is given in Figure 3.

1.2. Paper outline

Section 2 of this paper describes the method that has been used to obtain the data and information for the presented work. This work happened in two layers, first on a scale including the overall global south and second two case studies, Argentina and Pakistan (selection reasons are given in Section 2 as well).

The next section presents and explains the results for the global analysis, pointing out specific numbers and trends, e.g. in launch numbers, launch mass and space budgets. It also discusses the overview information.

In Section 4 a similar report is given about the data collected for Argentina and Pakistan, in more detail. More emphasis is also given on e.g. education program and technology development in both nations.

Afterwards, in Section **Eroare! Fără sursă de referință.** overall i ssues of the analysis are discussed and the last section concludes the paper.

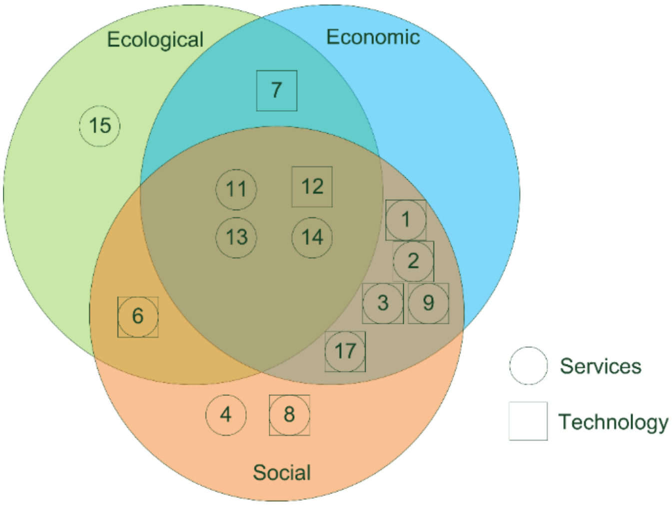

Figure 3. The SDGs in relation to the dimensions of sustainable development as addressed with spaceflight activities derived from services (marked by a circle) or technology (square) or both.

2. METHOD

The elements listed before, where spaceflight activities can support sustainable development are summarized in Table 1. Several elements affect more than one SDG, e.g. Element 1 can support achieving SDG 1 and SDG 8. These elements are the basis for evaluation and research within this work. The work is based on a literature review, a set-up satellite database, analysis of the found data and questionnaires for space actors in Argentina and Pakistan, of which however only one replied.

2.1. Literature review

The literature review has been conducted from by searching actor and literature databases. For the actor side, ESA and NASA (as space actors) have been selected. ESA is an international organization representing several nations and NASA is the most important space agency in the fiel. Other actors are not included, as they are e.g. involved in ESA (e.g. the German Aerospace Center (DLR), French National Centre for Space Studies (CNES)), too small contributors or provide little information (e.g. Roscosmos), which is easily accessible. The European Space Policy Institute has also been considered on the space actor side. It is an entity governed by several members among them also ESA, DLR, CNES and companies, e.g. ARIANESPACE, OHB, Thales. These actors' databases, publications and websites were searched for projects concerning *sustainable development*, *developing countries cooperation* and *development cooperation*.

The United Nations and World Bank were considered as actors in development cooperation and their databases were searched with *space missions sustainable development* and *space cooperation global south*, but also *space negative impact on sustainable development* and *pollution space industry*.

Web of Science, Science Direct and Scopus were used for searching scientific journals with the terms: *space missions sustainable development*, *spaceflight contributing to sustainable development*, *space missions impact sustainable development*, *space missions in the global south*, *developing countries space missions*, *developing countries space co-operations*, *space missions resource drain*, *space missions negative impact*, *space missions pollution*. Results were filtered for fit with this work, especially concerning the previously defined elements.

As a second layer of review, the same sources are searched for information concerning the two case studies.

Table 1. Summary of elements, which can support sustainable development and can be driven by spaceflight activities.

No.	Description	Affected Aspect/ SDG
1	Create qualified jobs	Poverty/ SDG 1, Economic Growth/ SDG 8
2	Disaster relief support (observation and communication)	Poverty/ SDG 1, Food Security/ SDG 2
3	Supporting agriculture via technology	Less pollution via pesticides, Food Security/ SDG 2, Water security/ SDG 6
4	Basic research in human physiology (for human spaceflight)	Health/ SDG 3
5	Promoting STEM and offering training positions and advancing domestic education in high-tech fields	Education/ SDG 4
6	Support water usage efficiency with technologies and processes	Water security/ SDG 6
7	Provide relevant data with Earth observation missions	Water security/ SDG 6, urban planning/ SDG 11, Fight climate change/ SDG 13, Conserve oceans/ SDG 14, Protect ecosystems/ SDG 15
8	Support electrical energy generation with improved solar cells, energy harvesting and battery technology	Provide modern energy/ SDG 7
9	Set-up satellite communication	Built infrastructure/ SDG 9
10	Promote technology development	Foster innovation/ SDG 9
11	Support development of closed economy technologies and processes	Sustainable cities/ SDG 11, Sustainable consumption/ SDG 12
12	Realize cooperation and exchange of know-how	Global partnership/ SDG 17

2.2. Satellite database

After the literature search, a satellite database has been established, documenting space missions of nations in the global south. Data collected were name, country, year (of launch), mission type (public or private), mission purpose (e.g. science, education or communication), size (launch mass), orbit (e.g. geostationary or low Earth orbit), who built the satellite (internal, external or a mixture), and the official ID as well as the sources of the information along with relevant key words. The database is available as supplement.

Finding information for the database has been challenging. Databases exist with different purposes, e.g. containing orbit properties, and often these databases do not contain all information and thus several databases or other sources, e.g.

news articles or press releases, have to be used to complement and complete the information.

One major source for establishing the database has been the satellite database of the Union of Concerned Scientists (UCS), which can be downloaded from their website (UCS, 2005).

This database was used to create a list of missions, information concerning especially the type of cooperation (if any) and other data was typically searched for in other sources as described before. The entries in the UCS database are only covering still operating satellites, with few exceptions (UCS, 2005), i.e. it is incomplete for the intended purpose. A secondary list of satellite missions was found at the Skyrocket database for satellites (Krebs, no date), which limits itself not to operating satellites. Again, here, mission names were used for the to-be-build database, whereas further sources were used to compile and supplement information (as noted in the database in the last column). Supplementary sources have been:

- The NASA Space Science Data Coordinated Archive (NASA, no date, e)
- N2Yo-database, a database used for satellite viewing on Earth, (N2Yo, 2008)
- Satbeams-database, used for determining satellite coverage on Earth, (Satbeams, 2007)
- ESA's Earth Observation database, used for Earth observation satellites, (ESA, 2018)
- The Nanosats database, (Kulu, 2014)

These mentioned databases were used to find original sources, subsequently used for the to-be-build database. Where possible, SCOPUS and Science Direct were searched for peer-reviewed publications on a given mission. If no other source was available, news articles or press releases about a mission were used.

Two limitations have been imposed for the own database: First, only missions launched up to 2021 (from 1976, where the first developing country launched a satellite) were used for the evaluation, to ensure that the numbers are complete. Later launches, even if only planned, were include, but to only use complete numbers, the limit for evaluation was 2021.

Second, missions from Russia, China and India have not been considered for the database. All three nations have advanced space programs, including human spaceflight programs (although India's first astronaut has yet to launch) and launch vehicles. Russia is considered "a world leader in space" (Mathieu, 2010). China operates its own, modular space station Tiangong (not to be mixed up with its prototype predecessors Tiangong-1 and Tiangong-2) (Wilkins, 2022). India is currently making huge progress in its own human spaceflight program (Kunhikrishnan, 2019), nearing its first flight. Furthermore, all three nations have a large number of satellites, which would likely dilute the information about the remaining global south. For instance, Russia had 169 satellites in operation from 1994 to 2021 (UCS, 2005), China had 317 satellites for 1999 to 2021 (ibidem) and India had 50 for the time interval from 2003 to 2021 (ibidem). This number does not include the total timeframe from 1976 to 2021, i.e. more missions would be added.

2.3. Case studies selection and questionnaire

During evaluation of the results of the built database, Argentina stuck out due to the number of satellites launched and planned (several hundred). To analyse the situation in Argentina further, it was selected as one case study. As a nation, which has had satellites since the 1990s just like Argentina, but has seemingly not developed a strong industry or program, Pakistan is selected as second case study.

The following questions have been sent to contact points of the Argentina and Pakistan space agencies, as well as of both countries' contact points of the Space Generation Advisory Council (SGAC)3. The SGAC is a non-governmental organization that is a forum for young professionals (up to 35 years of age) and students, which is working on space projects and also links its members to e.g. UN or space organizations such as IAF. Due to its network nature, the respective, domestic representatives have been selected as additional contact points.

The main goal of the questionnaire has been to understand if and how sustainable development is an active goal of space activities and which links to other governmental departments exist. It was to be investigated, if space activities are a conscious contribution for sustainable development in Argentina and Pakistan. For this purpose, the following questions have been asked:

1. Is there an official plan/ strategy to incorporate space activities into a national sustainable development strategy (e.g. concerning jobs, education, ecology)? If so, please provide some relevant details, how sustainable development is planned to be supported by space activities.
2. Which concepts exist to enhance or support education with space activities (e.g. curricula, internships, school events)?
3. Which concepts exist to actively support sustainable development in the general public with spin-off technologies from space activities?
4. How are space missions directly used for supporting sustainable development? Is this support happening locally or nationally (e.g. using Earth observation data for urban planning, environmental protection)?
5. What are the processes and channels through which officials tasked with space activities interact and coordinate with officials tasked with sustainable development?

3. IMPACT IN THE OVERALL GLOBAL SOUTH

A summary of the results collected in the satellite database, see Section 2.2, is given in Figure 4. In shades of blue the number of satellites for various global south nations are given for the timeframe of 1976 to 2021, ranging from 1 to the maximum of 35 satellites (for Argentina). In total 257 missions have been identified for this time frame in the global south without Russia, China, and India. Violet markings show which nations are planning missions, which currently have no satellite missions, plan some for the future and in pink, which nations neither have satellites or any plans at the moment. From this figure it can be seen that the majority of African nations have no satellites and also do not plan to change that, which is in contrast to e.g. south America, where several nations possess satellites.

3.1. Numbers and trends

In the initial years, i.e. from 1976 to 1992, mission in developing countries are sporadic, i.e. there are sometimes gaps of several

[3] https://spacegeneration.org/

years before another mission in a developing country is launched. From 1992 onwards, there are missions every year and there is a clear upwards trend in the general numbers of space missions. This is shown in Figure 6 to Figure 9.

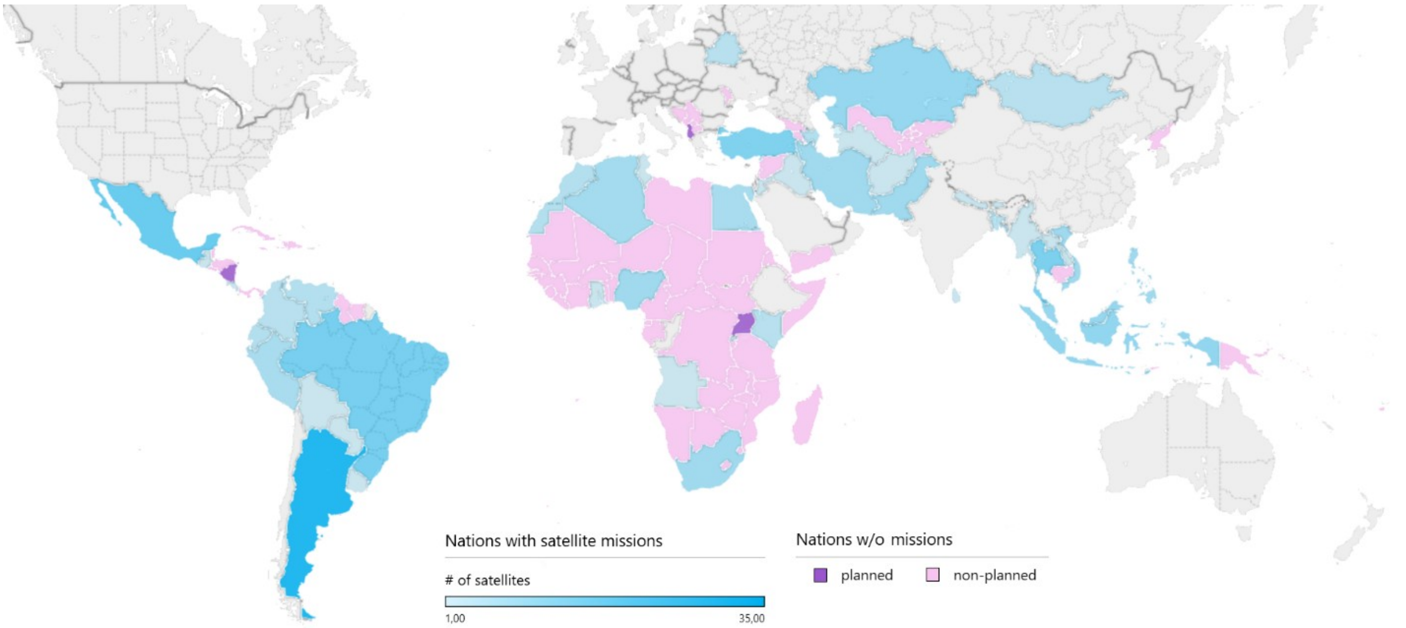

Figure 4. Overview of satellite missions of the global south (w/o Russia, China, India) as launched (different shades of blue, indicating numbers) or planned (violet). Nations w/o planned or operational missions are marked pink.

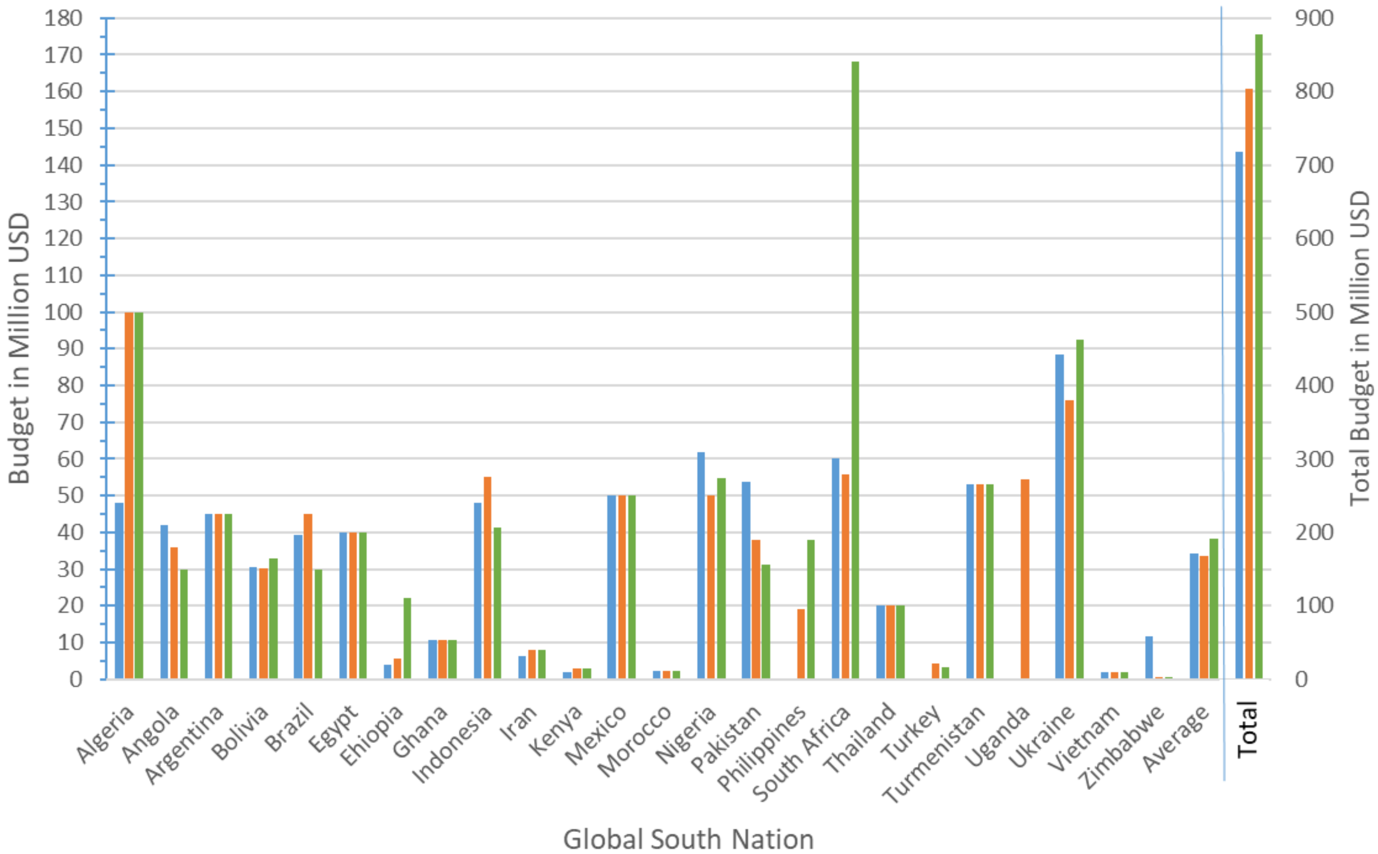

Figure 5. Space budget in million USD for 24 nations of the global south for the years 2018 (left, blue), 2019 (centre, orange) and 2020 (right, green) as well as average and total numbers (right axis). Based on data from (SpaceInAfrica, 2021).

3.1.1. Space budgets

SpaceInAfrica (2021) has collected data about space budgets for some nations of the global south, see Figure 5. The budgets differ by orders of magnitude between nations, from e.g. 0.69 million USD in Zimbabwe in 2018 and 2019 to 168 Million USD in the 2020 budget for South Africa. The exchange course is not explicitly given, neither is information about adaption for purchasing power parity, i.e. the numbers are not necessarily comparable among each other. In six cases (Angola, Brazil, Indonesia, Pakistan, Turkey, Zimbabwe), the 2020 numbers are the lowest amount in the respective sequence of budget numbers. In the remaining cases the latest budget is higher than at least one of the other numbers.

The total budget in the time frame from 2018 to 2020 ranges from 718 million USD, over 804 million USD to 879 million USD, showing an upwards trend. It has to be noted that the used list of nations of the global south is not covering all nations included in the set-up satellite database.

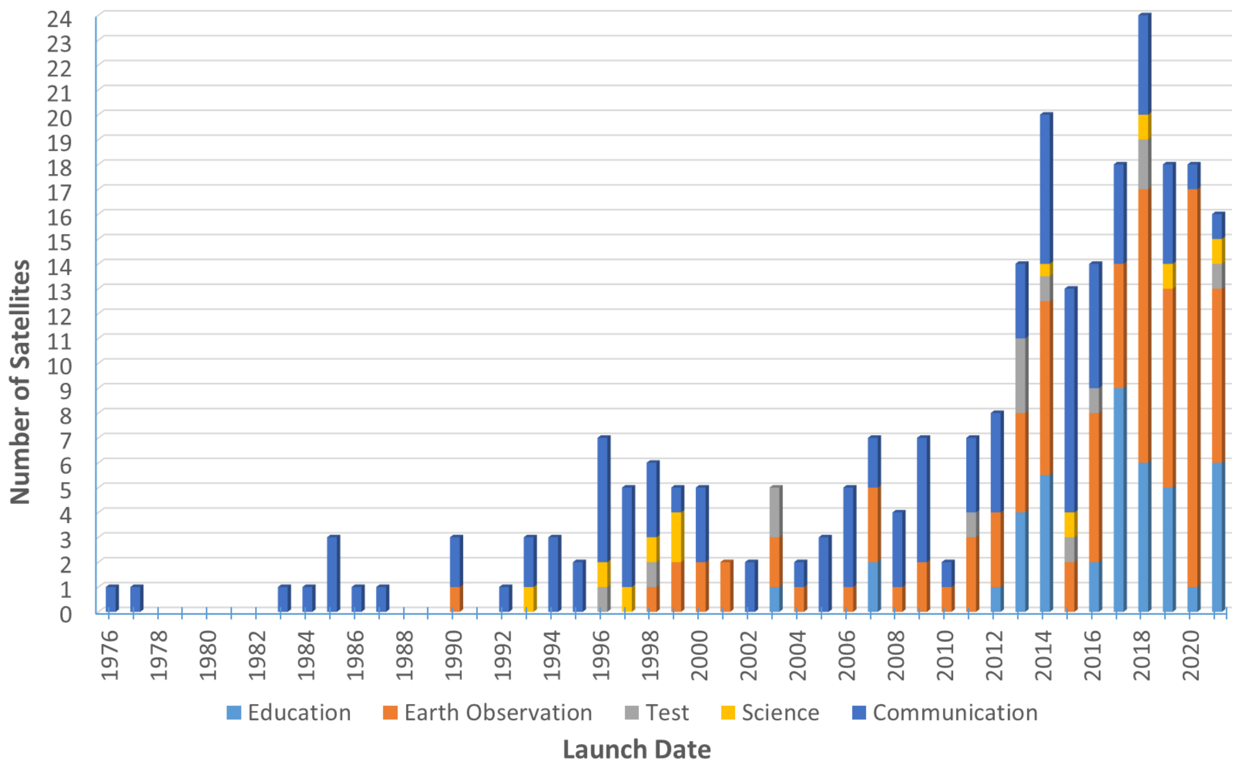

Figure 6. Launch numbers per year in global south countries (w/o Russia, China and India) from 1976 to 2021, based on primary mission objective category.

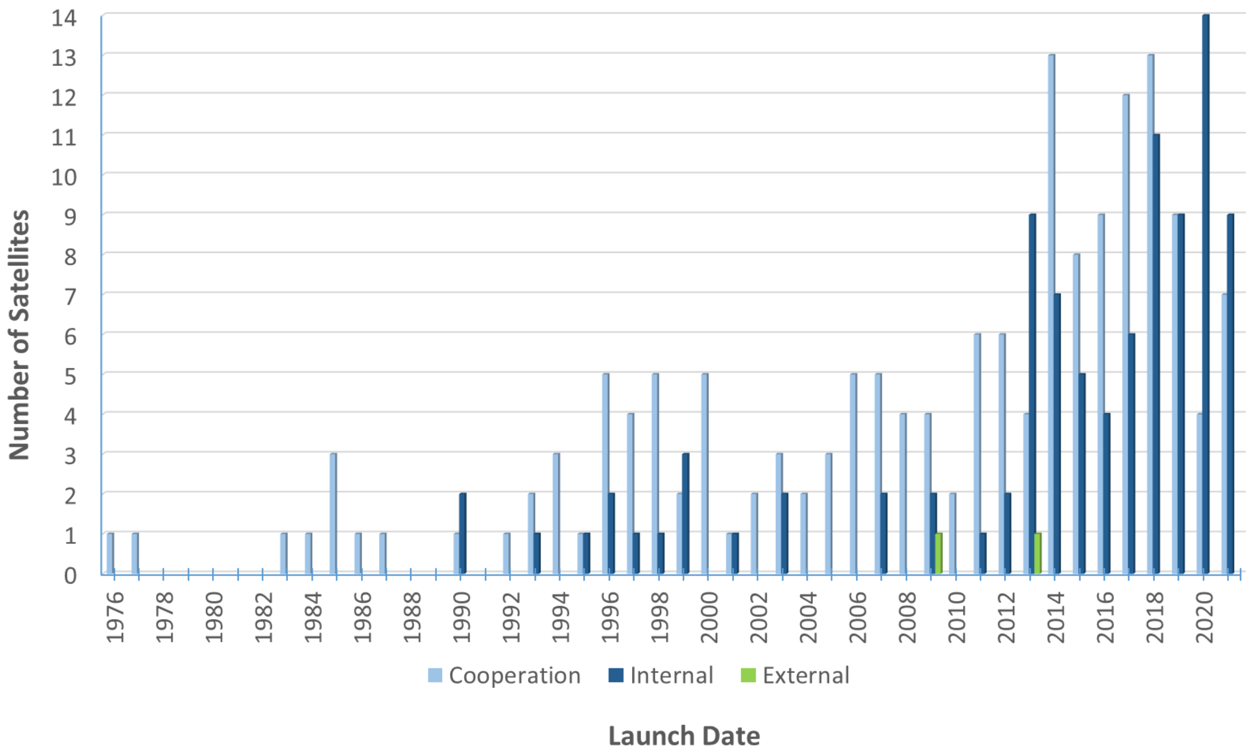

Figure 7. Launch numbers per year in global south countries (w/o Russia, China and India) from 1976 to 2021, based on type of cooperation. “Cooperation” designates missions with shared responsibility, typically one nation supplies the satellite and the receiving nation operates it domestically. “Internal” designates missions, which are done in single responsibility of the developing

country, which does not exclude e.g. mission payloads from other nations or organizations. "External" is describing missions, which occur for another country by one nation in all regards.

3.1.2. Mission types

Figure 6 shows the number of space missions over time per mission type, i.e. Education, Earth Observation, Test, Science and Communication. Some missions have different mission objectives, here the apparent primary objective is given as category.

The initial focus lies on communication, i.e. infrastructure. Earth observation missions gain more importance and become

dominant from the 2010s years onwards; in 2020 Earth observation missions dominate (16 of 18). In the late 2010s and early 2020s educational mission also gain more relevance, before the 2000s there have been no education missions at all. In 2017 educational missions had the largest share of all, i.e. 9 of 18 have been educational vs. 5 Earth observation missions and 4 communication missions. Some missions conduct science objectives or test satellite systems and components. These appear to be exceptions with numbers between 2 or 3 for some years.

3.1.3. Cooperative and non-cooperative missions

An overview about the amount of cooperative missions is given in Figure 7, where "cooperation" labels missions which are done with a non-domestic partner other than just launch of the satellite (which is usually one commercially and thus often non-domestic, even for nations which have own launch capabilities).

As can be seen, initial missions rely often on cooperation – up to 1990 all mission were done with external partners. The cooperation is usually involving a nation with existing infrastructure for satellite development, providing the satellite. These Initial missions often include set-up of a ground station in the receiving nation, i.e. operation of the satellite is realized domestically. An exception to this pattern is e.g. the Earth observation mission SAC-C from Argentina, launched in 2000 (Colomb, et al., 2004). For this mission, the satellite bus was domestically built, but NASA and other organizations supplied the payload (ibidem).

Missions, which are conducted internally usually have a smaller scale, i.e. nano- or pico-satellites. Two missions occur only externally, i.e. the spacecraft and operation are realized externally.

Internal missions have significantly increased in number in the 2010s, e.g. in 2020 14 missions have been conducted internally and only 4 missions with cooperation. The average launch mass is given in Figure 8. For the 2010s the launch mass has a decreasing trend, after a trend of increase in the early 2000s.

3.1.4. Commercialization

Figure 9 shows the commercialization of space missions in developing nations, i.e. whether a mission is realized by a public entity or a private one. Initially private missions occurred more frequently than public missions. This trend changed in the 1990s, when public missions became more common and the numbers are approximately balanced with commercial missions. From the 2010s onward public missions, e.g. educational university missions, become more common than private missions. In the timeframe up to 1995 private missions numbered 1 to 2. In the 2010s and 2020s these missions number between 1 and 14. Public missions range from 2 to 20 per year in the same time frame.

3.2. Discussion of general impact

The launch numbers increase over time including the ratio of internal to cooperative missions. Initially missions focus on infrastructure, i.e. communication and later Earth observation. Finally, education missions are also increasing. Missions become more affordable and thus also available for universities. Standardization and miniaturization of technology, e.g. in the CubeSat-Standard (NASA, 2020), make missions more affordable. Approx. 50% of all missions below 600 kg are CubeSat missions (ibidem). Commercial providers for CubeSat satellite parts, e.g. GomSpace4, enable customers to buy satellite components and thus reduce development costs for space missions. Decreasing launch costs make mission more affordable as well.

Jones (2018) reports approx. constant average launch costs in the 1970s to 2000s, after dropping from an all- time high in the 1960s. For these decades, the average launch cost was approximately 18,500 USD/ kg into LEO. The Space Transportation Systems, i.e. the Space Shuttle, launch costs were ca. 62,000 USD/ kg into LEO, adjusted to 2018 this would equal ca. 106,000 USD/ kg. Modern launch vehicles, like Falcon 9 or Falcon Heavy, reduce these costs by a factor of 20 to 40 respectively. Falcon 9 has costs of 2,700 USD/ kg and Falcon Heavy of 1,400 USD/ kg. (Jones, 2018)

The decreaeing trend in average launch mass, see Figure 8, is related to the increasing number of micro- and nano-satellite missions. Educational satellites are often CubeSats, which have small launch masses. Low launch mass further reduces launch costs. A single unit CubeSat (NASA, 2020) has a mass of 1 kg, i.e. leading to launch costs of some thousand USD if launched with a contemporary launcher like Falcon 9 or Heavy.

Relating average launch mass and costs reveals the trend that allows missions to be more affordable, i.e. leading to more numerous missions. The average launch costs for the year 2000 are 18,500 USD (Jones, 2018). The average launch mass is 2000 kg (see Figure 8). This means, the average launch cost $C_{av,l}$ for the year 2000 is:

$$\begin{aligned} \boldsymbol{C_{av,l,2000}} &= \mathbf{18,000\ USD \cdot\ 2000\ kg} \\ &= \mathbf{37,000,000\ USD} \end{aligned} \tag{1}$$

For 2018, the average launch mass is 750 kg (see Figure 8). Assuming launch costs for Falcon 9, this leads to average launch costs of:

$$\begin{aligned} \boldsymbol{C_{av,l,2000}} &= \mathbf{2,700\ USD \cdot\ 750\ kg} \\ &= \mathbf{2,025,000\ USD} \end{aligned} \tag{2}$$

Comparing both, shows that the average launch costs have been reduced by a factor of more than 18 (unadjusted for inflation). The miniaturization (reducing launch mass) and general reduction of launch costs by launch providers lead to overall reduced average launch costs for missions. Further reductions

[4] https://gomspace.com/

can be achieved by lower material costs originating in standardization.

Standardization makes satellites also more accessible from a qualification perspective. It requires less experience and qualification to assemble a satellite, which uses standardized components.

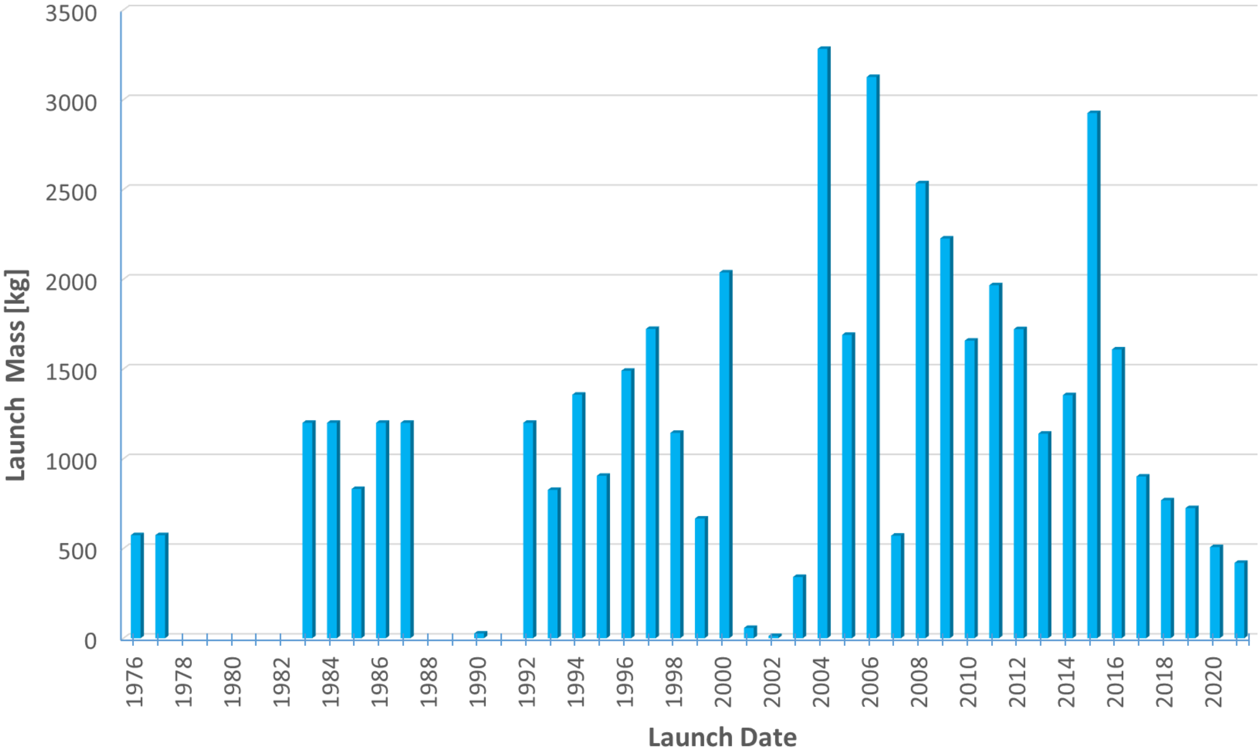

Figure 8. Average launch mass in kg of all missions associated with global south nations (w/o Russia, China, India) for 1976 to 2021.

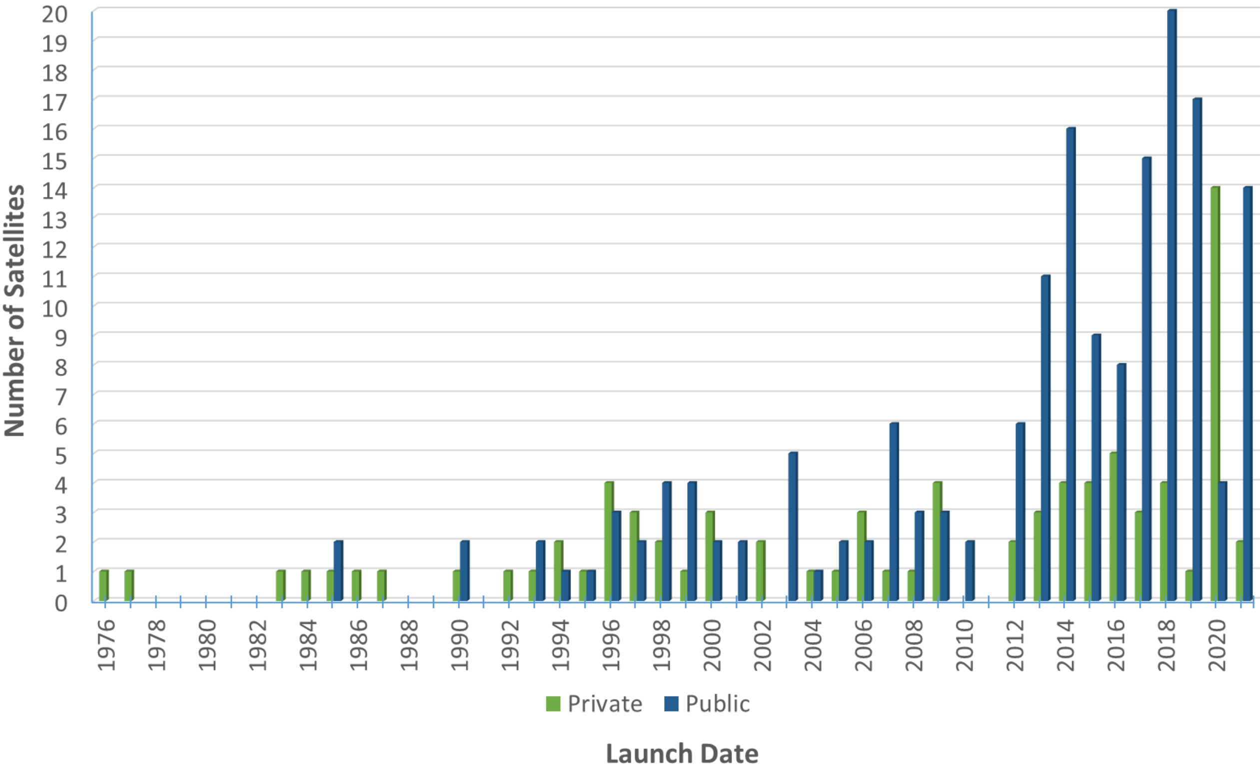

Figure 9. Launch numbers per year in global south countries (w/o Russia, China and India) from 1976 to 2021, based on commercialization status.

As mentioned before, typically early missions also involve set-up of ground stations, e.g. NigeriaSat-1 or Napa-1 (Thailand). These ground stations can be used for subsequent missions and create domestic jobs. This supports creation of qualified jobs, Element 1 in **Eroare! Fără sursă de referință.**.

Communication missions create infrastructure for a nation, Element 9 in **Eroare! Fără sursă de referință.**. Earth o bservation missions support Elements 2, 3 and 7 in **Eroare! Fără sursă de referință.**, e.g. the Colombian FACSAT 1 mission (Colombian Air Force, 2019) or Indonesian LAPAN A2 (NASA, 2015), have disaster relief as primary mission objectives. Independent Earth observation missions remove the dependence on foreign information supply for e.g. planning and evaluation. However, Earth observation data is often freely available from space organizations as ESA, but require expertise to be integrated into the management for sustainable development (Hargreaves & Watmough, 2021). Earth observation data has is important for managing sustainable development especially in rural areas, which are difficult to access, but are the regions the vast majority of the poor population lives in (ibidem). However, new methods and more effort are required to effectively use the data (ibidem).

Internal missions mean less money flowing abroad, because e.g. assembly or testing of a satellite are not paid for externally. Parts can be paid for, e.g. if the before mentioned CubeSats are used, but even then, if assembly occurs domestically, the personnel funds remain internal. The experience on the job is also awailable for later missions. This furthers nations' ability for bulding up its space industry. Domestic mission opportunities, which have increased in the 2010s, can also reduce the "brain drain" (Abiodun, 2012) that e.g. African nations suffered before, for lack of opportunities for qualified jobs.

The initial focus (see Figure 9) of missions on services and private entities, i.e. commercial aspects fits the focus of the second UN Development Decade on economic growth (United Nations General Assembly, 1970). In its goals, it is first defined that "the average annual rate of growth in the gross product of the developing countries as a whole (…) should be at least 6 per cent" (United Nations General Assembly, 1970). The next four goals further detail the goals for various aspects of economic growth (ibidem). Only the last goal concerns social aspects (ibidem). Only in 1985 public missions begin to be launched. The first science-oriented mission appears in 1993, SCD 1 from Brazil, designed as a communication satellite collecting data from science stations. This shows that with diversified development goals, also mission goals become more diverse.

3.2.1. Continuity of activities

Figure 6 shows the majority of missions was launched in the last decade. With typical satellite life-times of several to 15 years it is thus difficult to analyze or determine a continuity. However, some countries have established space activities early and remain active in that field.

Palapa A1 was the first Indonesian satellite, launched in 1976, and the first satellite of the global south (Ibrahim, 2004) (NASA, no date). Contractors were tasked with building and launching the satellite and with establishing a network of ground stations for its operation, including personnel training (Ibrahim, 2004). Indonesia has had 22 satellites in the years of 1976 to 2021. The last satellite of its initial system, Palapa D, was launched in 2009. In 2007 Indonesia launched its first Earth Observation satellite, Lapan A1, cooperating with the Technical University of Berlin (Anggari, et al., 2021). Several more satellites followed and some more are planned (ibidem). The number of satellites with various purposes shows that the activities in Indonesia were lasting and a continuous space activity was established.

A similar picture is painted for Brazil, which has 28 in the reviewed time-frame from 1976 to 2021. The first launch of a Brazilian satellite occured in 1985 with Brasilsat 1 (NASA, no date, b). In 1986 Brasilsat 2 launched. These satellites were operated by the publicly owned company Embratel (ibitem) and built by Canadian company Spar Aerospace (NASA - JPL, no date). More communication satellites were launched over several years.

Nettleton & McAnany (1989) report that the initial use was only commercial Brasilsat 1 and 2, and did not contribute to social development, even though this has been one part of their initial mission proposal. This was caused by lack of participation of ministries responsible for social resorts, e.g. Education, in the planning and execution of the mission and lack of funding for these ministries. (Nettleton & McAnany, 1989)

In 2021 Brazil launched its first Earth Observation satellite, Amazonia 1, for surveying agriculture and environment (NASA, 2021). Brazil also launched several educational missions, most recently FloripSat 1 (Marcelino, et al., 2021). Its first university satellite was UNOSAT, launched unsuccessfully in 2003 (Inovacao Tecnologica, 2003). Brazil also had an astronaut, Marcos Pontes, visit the ISS in 2006 (ESA, 2006). This shows a certain development within the activities.

Argentina has the greatest number of satellites in the group of investigated nations, actual and planned missions. For the year 2025 a total of 200 commercial micro-satellites are planned, supplementing a existing Earth Observation satellites (ESA Earth Observation Portal, no date). LuSat, a radio amateur satellite, was the first Argentina satellite, launching in 1990 (AMSAT-UK, 2020). In 1996 two missions were launched, one of which, SAC-B, in partnership with NASA (Colomb, et al., 2004). SAC-B failed to launch properly (ESA Earth Observation Portal, 2002), but the SAC program continued with international cooperation (Colomb, et al., 2004). From 2016 to 2021 Satellogic has launched 18 Earth Observation satellites (Clark, 2020). Overall, it can be said that space activities were continuous in Argentina and created business opportunities within the country.

About two decades ago, Reiss (2005) determined that "a growing number of emerging nations have started to utilize space technology as an essential service provider for information and communication" (Reiss, 2005). This trend for service-oriented mission continued in the global, see Figure 6, with a steady number of Communication and Earth Observation satellites.

These long-term development of continuous space activities, including the founding of domestic companies, e.g. Satellogic and Embratel, serves Element 1 in Table 1. In general, the elements reported as being supported in the previous paragraphs, are supported in a continuous manner, e.g. establishment of a communication infrastructure (Element 9). Yet, the most recent activities are also the most numerous ones, so a final evaluation of continuity is not final.

The budgets of parts of the nations in the global south, given in Figure 5, are not precise or numerous enough to determine a lasting trend. The comparability is limited, because e.g. information about purchasing power parity is not provided. The timeframe of three years is not sufficient to determine a lasting trend, especially since space projects typically last years.

3.2.2. Relevance of cooperation

For initial missions, see Figure 7, cooperation has been the almost exclusive mode for satellite missions in the global south. In the 2010s this changed, due to the reduction in costs associated with new launch vehicles and availability of low-cost satellites, as described before.

The cooperation for missions or even building ground stations, supports Element 12 in Table 1, i.e. cooperation and exchange of know-how. This is an example of acquiring new technology and using it for a nation's benefit (Wood & Weigel, 2012).

A relevant part of cooperation has been the BIRDS-project from the Japanese Kyutech-university (Kyutech, 2016). The project supports nations in launching of their first (nano-)satellite and training students for conducting such missions from beginning to end (ibidem). The program has been renewed three times, with the currently last generation of CubeSats having been launched in 2021 (Kyutech, 2021). Other cooperations with universities involved are the TUBSats, i.e. satellites built and operated by the Technical University of Berlin in cooperation with partners. Two such missions have been conducted with nations from the global south: Maroc-TUBSat from 2001 (NASA, no date, c) and Lapan-TUBSat from (Nabil Ihsan, 2022).

In case of Morocco, it is difficult to say if the cooperation has had a fruitful impact, as the nation has only two further satellites, built by Airbus and operated by the military (Spaceflight 101, 2017), launched in 2017 (ARIANESPACE, 2017) and 2018 (NASA, no date, d). A time difference of almost two decades makes it unlikely that this was a direct result of the cooperation with TU Berlin. The BIRDS-project has not run long enough to decide on the impact of the cooperation, yet no subsequent missions have been conducted by the involved nations. However, the cooperation has helped educate personnel, i.e. Element 5 in Table 1. Algeria, Nigeria, and Malaysia (and India) all set up their own satellite programs with the help of outside cooperation and developed it further in capabilities (Wood & Weigel, 2012).

Cooperation has also a downside, resp. the availability of cooperation. It can hinder development of domestic space industry, due to competition with already incumbent companies in developed nations (Leloglu & Kocaoglan, 2008). While e.g. Argentina has managed to establish its own industry, other nations simply buy satellites from companies in developed nations. Legal limitation for export of components is a further obstacle for manufacturing own satellites (ibidem). Purchasing satellites abroad leads to money drain (ibidem). Also, denying cooperation for political reasons has been a major reason why e.g. Iran was unable to develop its own space program (Tarikhi, 2009). This shows further the importance of cooperation to overcome the hurdles associated with the technology required for space activities. Iran only launched its first own satellite in 2005, decades after initiating attempts of an own space program (ibidem). However, it can be said that cooperation plays an important role for space activities in the global south. Of 257 missions for the reviewed time frame 158 (61%) have been realized in cooperation and it can also remove competition, especially regionally (Noichim, 2008).

Cooperation extends beyond missions, e.g. via memberships in international organizations, e.g. the Committee of Earth Observation Satellites (CEOS), an entity coordinating operation of such satellites (Reiss, 2005). Member nations include e.g. Nigeria, Brazil, Thailand and South Africa (CEOS, no date). This supports Element 12 in Table 1 by forming an equal participation in these organizations.

Establishing own (independent) space programs and membership in international organizations such as CEOS, better enables nations to participate in negotiations and regulation of the use of space and its resources, lessening opportunities for exploitation. The Outer Space Treaty prescribes that space should be used "for the benefit and in the interest of all countries" (Dennerly, 2016). This can be better ensured by nations of the global south, when they are participating and contributing to space activities and are part of space organizations. Political and diplomatic struggles remain, e.g. block-building by wealthier nations to foster their own interest (ibidem), but the interests of developing nations participating in the previously mentioned manner, can at least not be ignored.

Global south nations also form their own organizations to further their interests, e.g. the Asia-Pacific Space Cooperation Organization (APSCO) created by Bangladesh, China, Indonesia, Mongolia, Pakistan, Peru, Thailand and Turkey (ibidem). The African Resources and Environmental Management Satellite Constellation (ARMS) formed by Algeria, Kenya, Nigeria, and South Africa is another example of such cooperation among nations from the global south in the space sector (ibidem). Such establishment of cooperation is a direct support of Element 12 in Table 1.

4. IMPACT IN ARGENTINA AND PAKISTAN

Both Argentina and Pakistan have own space agencies. In Pakistan the Space & Upper Atmosphere Research Commission (SUPARCO) was founded in 1961. Pakistan's first satellite was BADR-A, which launched in 1990. The Earth observation satellite was built in cooperation with Surrey University and operated by SUPARCO. In Argentina the Comisión Nacional de Actividades Espaciales (CONAE) has been founded in 1991 and is the successor of a previous institution tasked with handling the nation's space activities. LUSAT was Argentina's first satellite, also launched in 1990 and built and operated by amateur radio operators in Argentina and thus was a radio satellite.

The SGAC member in Argentina was the only person to respond, which resulted in a teleconference. Neither CONAE or SUPARCO personnel offered a response to the inquiry.

4.1. Numbers and trends

4.1.1. Space budgets

Sources for the Argentina space budget are scarce. The OECD (2011, p. 53) reports a space budget of 54 million USD for 2009. The subsequent and most recent OECD report about space economy (2014) no longer contains such information about Argentina. A history of the budget can thus not be established.

The Inter-American Development Bank gives a national budget of 140 billion USD in 2020 for Argentina (Ferro, et al., 2020). A history is not available, which makes a comparison of the space budget with the overall national budget impossible from these numbers. SpaceInAfrica (2021) provide an overview of space budgets in the world, which includes Argentina and Pakistan.

As mentioned before, the data is hard to relate to other data, e.g. due to lack of exchange rates mentioned. A comparison with the total budget would be imprecise if the actual assumption for the conversion to USD is unknown. The available data for 2018 to 2022 is given in Figure 10.

The budget of Argentina remains constant in that timeframe, but is nominally about 20% smaller than in 2009 (2011, p. 53) (since inflation and changes in conversion course can have occurred, this number is likely subject to further change). Pakistan's budget drops from 53.8 million USD in 2018 to 31.2 million USD in 2020. However, in 2022 it has increased again to 46 million USD. Again, changes due to inflation and other factors could change this trend.

4.1.2. *Mission types*

Figure 11 shows the launch numbers per mission type for Argentina. Mission numbers are initially low with 1-2 missions per year and not every year. Mission types included test, education and mostly communication. In the 2010s test and communication missions continued and there has been a significant increase in Earth observation missions. In the last decade, a total of 12 satellites have been launched, in the current decade 14 have already been launched and in the two first decades 9 satellites have been launched.

Figure 12 shows the same information for Pakistan. The numbers are significantly smaller with only 7 launches. A trend in any direction is not detectable, but infrastructure missions prevail. In Figure 13 the average launch mass per year and mission is given for both nations. The largest value shows for 2011 with ca. 5,000 kg. The launch numbers along with launch masses show a trend to smaller launch masses for Argentina for the past decade into the current with intermittent larger missions.

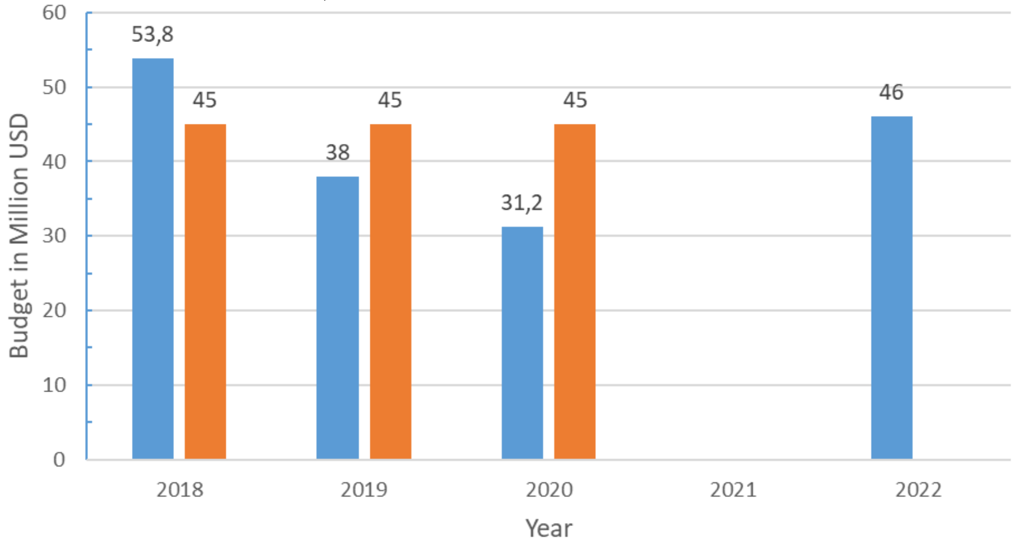

Figure 10. Comparison of Argentina (orange, right) and Pakistani (blue, left) space budgets in Million US dollars over the years from 2018 to 2022. The data is from (SpaceInAfrica, 2021) for the time frame from 2018 to 2020 and from (Economy.PK, 2022) for 2022. Data omitted here was not available.

4.1.3. *Cooperative and non-cooperative missions*

The type of cooperation for missions in Argentina and Pakistan is shown in Figure 14. For Pakistan no trend is visible. Missions conducted internally and with cooperation have an equal share. Especially larger missions (see Figure 13) have been conducted as cooperation.

Until 2000 missions in cooperation dominate for Argentina, since then only a single mission has been conducted in cooperation. Numbers increase afterwards and all missions occurred internally.

4.1.4. *Commercialization*

Figure 15 shows whether missions in Argentina and Pakistan have been privately or publicly conducted. With one exception (1996) all mission for Pakistan have been publicly conducted. For Argentina 24 missions have been conducted privately, 11 publicly with an upwards trend in later years.

4.2. Spacecraft technologies and manufacturing

Conducting own space missions requires the capability to develop new technologies (including processes for e.g. operation), unless all components are to be procured abroad, which however would mean loss of foreign currency and less economic benefits by jobs. Satellite manufacturing requires advanced skills, processes and equipment, e.g. clean rooms.

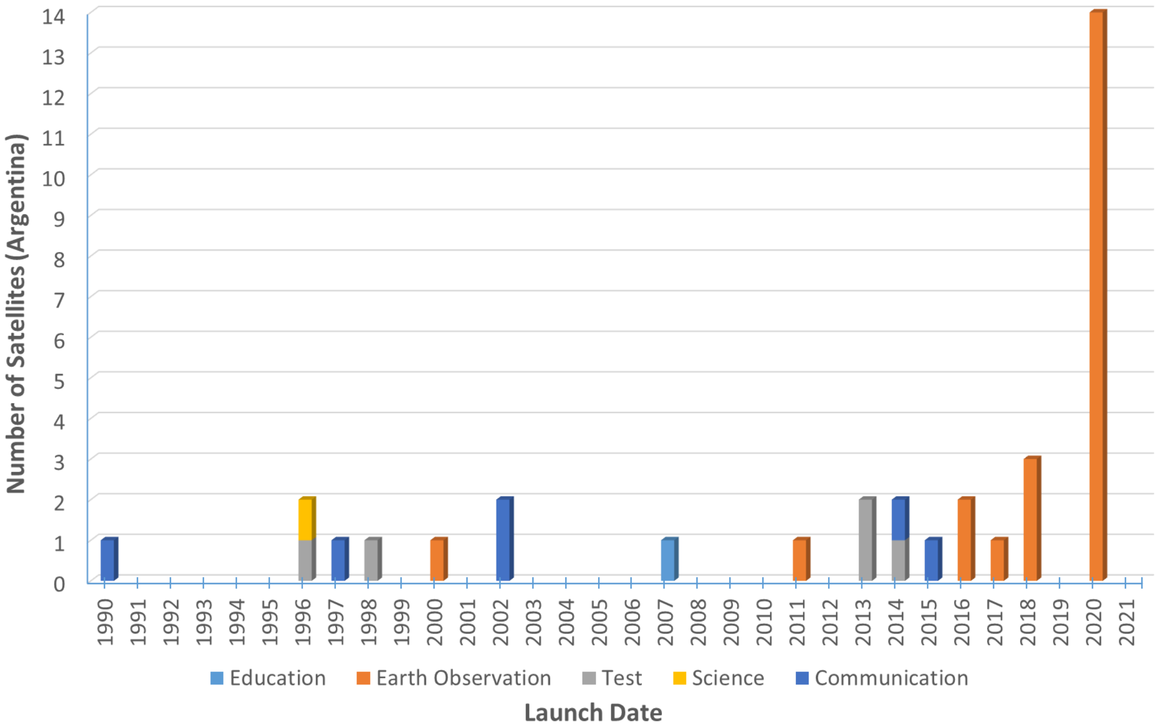

Figure 11. Launch numbers per year in Argentina from 1990 to 2021, based on primary mission objective category.

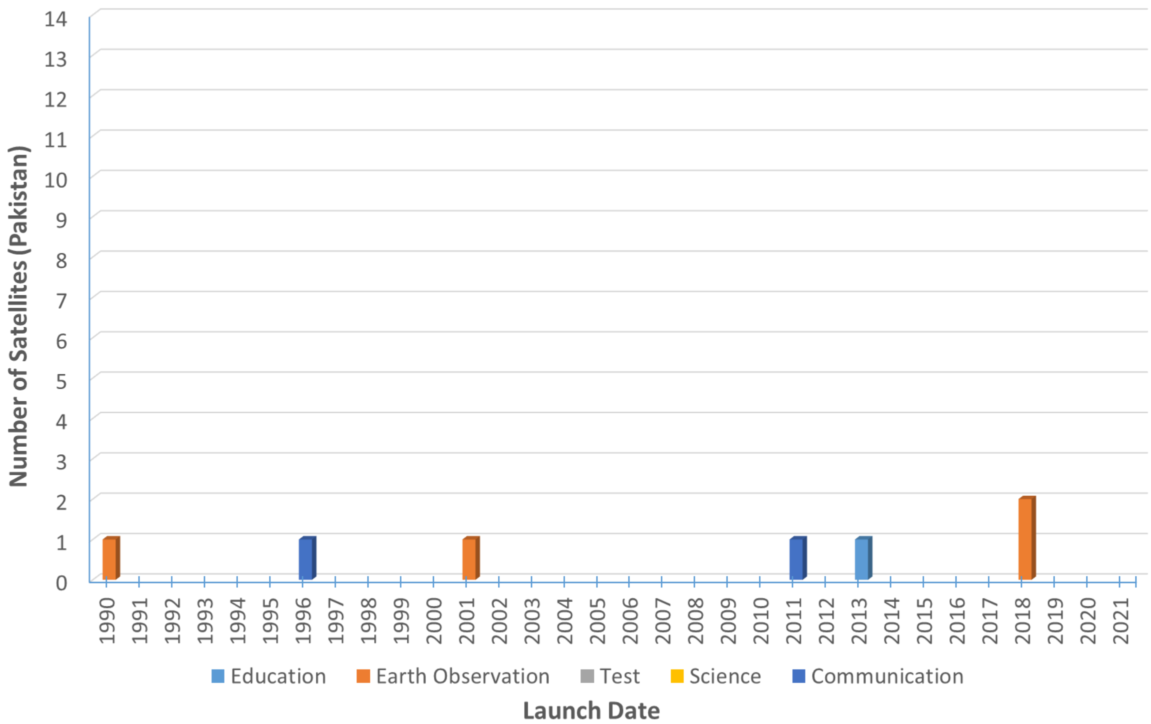

Figure 12. Launch numbers per year in Pakistan from 1990 to 2021, based on primary mission objective category.

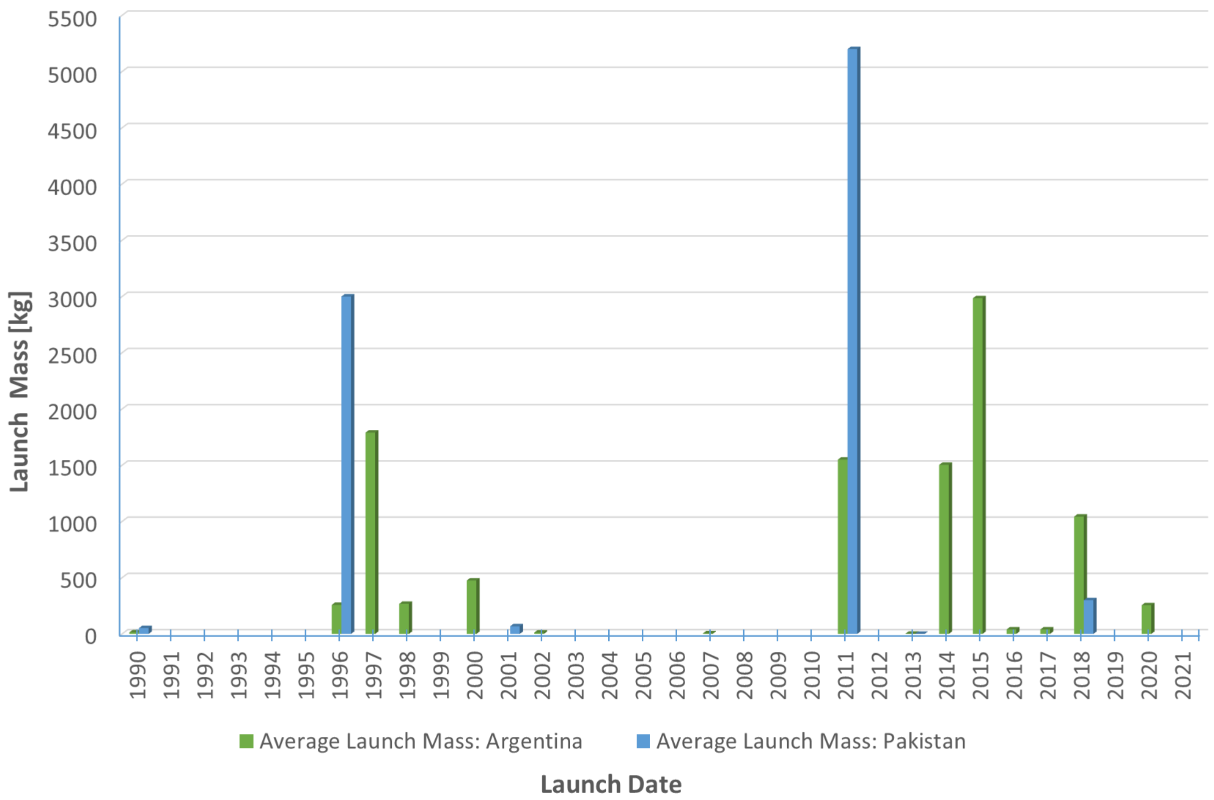

Figure 13. Average launch mass per year and mission for Argentina (left, blue) and Pakistan (right, green) from 1990 to 2021.

4.2.1. Argentina

Argentina has a significant space industry, capable of designing and manufacturing own spacecraft, such as the NuSats by Satellogic (ESPI, 2021). Argentina used to have an own launch vehicle program, but dropped it due to political pressure from abroad for many years and only recently re-adopted launch vehicles into its field of activities (ibidem). Its path into independent spacecraft manufacturing was enabled by its experience of domestic nuclear power projects (ibidem). The company, which has been responsible for the realization of nuclear power in Argentina, INVAP, is also the main contractor for satellite manufacturing (ibidem). Eight companies, founded between 1976 and 2020, are the major drivers behind the domestic space business. Five of these companies have been founded since 2010. This advancement can also be seen in the launch numbers in Figure 11, where launch numbers increase clearly since 2010.

Argentina has a so-called National Space Plan (Plan Espacial Nacional, PEN), drafted for several years and describing the nation's strategy for space development (ibidem). Specific plans exist for telecommunication (ibidem). This plan has several topics, among them strengthening of Argentina's ability for independent space missions, including development, and improving of education related to space activities. This supports Element 10 in Table 1. Its space-program is intended to support "socio-economic activities" (Delgado-López, 2012).

4.2.2. Pakistan

In the timeframe from 1976 to 2021 Pakistan built and launched three satellites as internal projects, BADR-B (2001), PakTES-1A (2018) (Earth observation missions), and iCube-1 (2013) (Education mission). Satellite operation has been conducted as well, included for satellites not built domestically. Pakistan's space plan, called Vision 2040, includes plans for 11 further satellites to be built and launched domestically (Mehdi & Su, 2019). Up to now, Pakistan built only three satellites without foreign support in the past twenty years. If the plan is successfully implemented, even if only partially, this would further increase job opportunities (besides the services of e.g. Earth observation being available for sustainable development of Pakistan) and also educational support, i.e. Elements 1 and 5 in Table 1.

4.3. Infrastructure

4.3.1. Argentina

Argentina's plans for telecommunication directly state the goal that satellite communication shall be used to connect rural areas (ESPI, 2021, p. 78ff). Furthermore, TV-connectivity is to be enhanced and Argentina shall be able to independently create and use Earth observation data (ibidem).

This has a variety of effects on social and economic dimensions. It allows better education, business opportunities and access to administration, e.g. Elements 1, 3 and 5 in Table 1 and in general the SDG4 (Education) as well as Element 9, set-up of communication infrastructure and Element 7 for using Earth observation data and both is available for disaster relief, i.e. Element 3. The communication and Earth observation satellites are designed to work in conjunction with other nations' satellites and supplement their data (Canales Romero, 2004), which enhances their utility and supports cooperation, i.e. Element 12. The launch numbers for Argentina show a clear dominance of infrastructure related missions in Figure 11.

4.3.2. Pakistan

With a single exception, all Pakistani satellites are Earth Observation or Communication missions. The exception being the educational university satellite i-Cube-1. SUPARCO's portfolio of activities clearly focuses on these activities as well (SUPARCO, no date).

Pakistan faces challenges typical for the global south, report Mehdi and Su (2019). Such challenges are e.g. linked to communication infrastructure and land development. Part of SUPARCO's mission is using satellite systems for set-up of communications infrastructure, but also for e.g. water management, supporting disaster relief and agriculture activities and even education, affecting Elements 2, Element 3, Element 5, Element 7 and 9 in Table 1. (Mehdi & Su, 2019)

The infrastructure built via satellites has also a military function, especially focused on tensions between India and Pakistan (Hussain & Ahmed, 2019). Earth observation capabilities are used for military purposes and Pakistan has a launcher program for military purposes (Hussain & Ahmed, 2019).

4.4. Education

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4.5. Cooperation

4.5.1. Argentina

Of 35 satellites, 28 were internal, Argentina missions, the majority, 19, conducted by Satellogic. The remaining ones happened in cooperation with other nations. More recent missions have been conducted mostly internally, see Figure 14.

Argentina's Earth observation missions enables cooperation. It has been a member of CEOS since 1999 (CEOS, no date), which supplies Element 12 in Table 1. It provides Argentina influence and a voice in international matters, especially in this case related to Earth observation. Earth observation data obtained by CONAE is typically available for anyone (Colazo, 2017). Earth observation and telecommunication satellites are designed to be usable in conjunction with satellites from other nations enabling cooperation (Canales Romero, 2004), which improves cooperation and also allows common projects.

ESA has cooperated also in terms of ground segment, e.g. antennae, with CONAE (ESA, 2008) since 1997.

Argentina is the location for one of ESA's large deep space antennae, needed for interplanetary missions (Colazo, 2017). A similar agreement exists with China (ibidem). Argentina can use 10% of the operation time for its own purpose, e.g. radioastronomy (ibidem). This concerns Element 12, also enables jobs and stimulates STEM education, i.e. Elements 1 and Element 5. Further cooperation, in various fields, e.g. Earth observation and satellite launches, are planned with other agencies, e.g. the Indian space organization ISRO (Siddiqui, 2020), the Polish Space Agency (Awad-Risk, 2022), the USA, France, Italy, Denmark and Brazil (Delgado-López, 2012).

4.5.2. Pakistan

Initially, Pakistan cooperated with mosty the USA, which trained scientists to build its own rocket program for atmospheric research (Mehdi & Su, 2019). They further established a communication station used for the Apollo-program in the 1960s (Mehdi & Su, 2019). Instability and the Afghanistan war ended this cooperation after Apollo (Mehdi & Su, 2019).

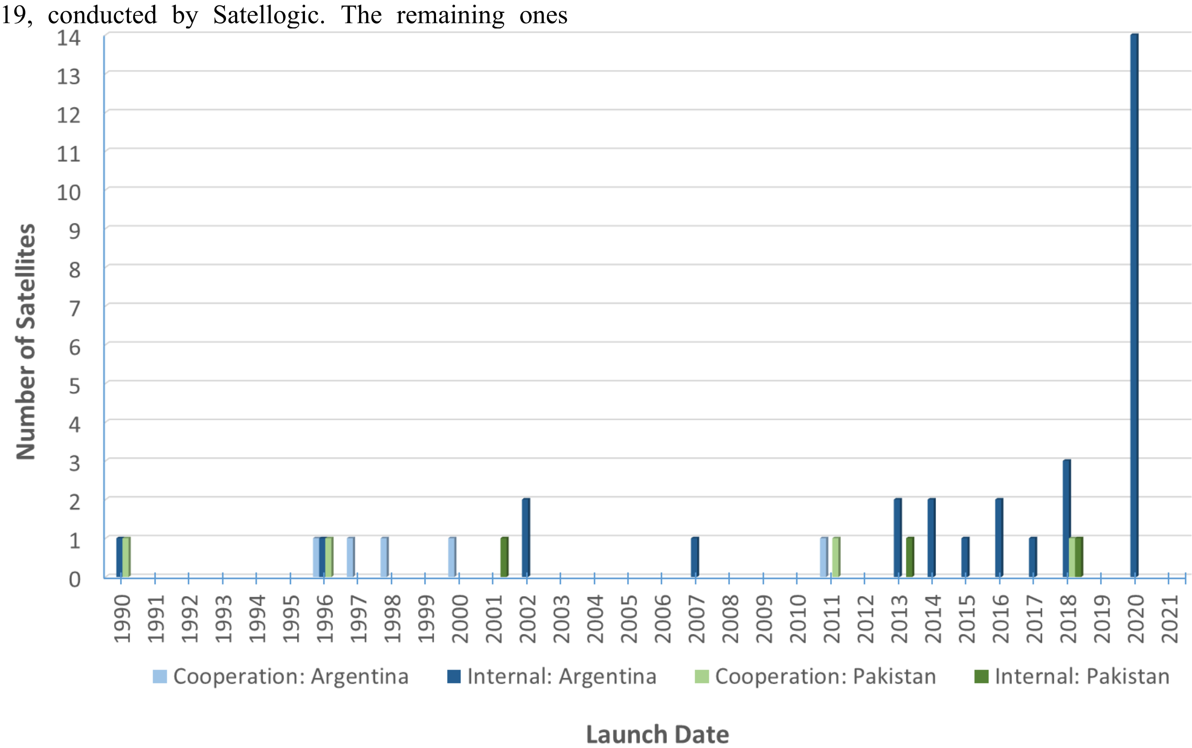

Figure 14. Launch numbers per year in Argentina and Pakistan from 1990 to 2021, based on cooperation. "Cooperation" designates missions with shared responsibility. "Internal" designates missions, which are done in single responsibility of the developing country, which does not exclude e.g. mission payloads from other nations or organizations.

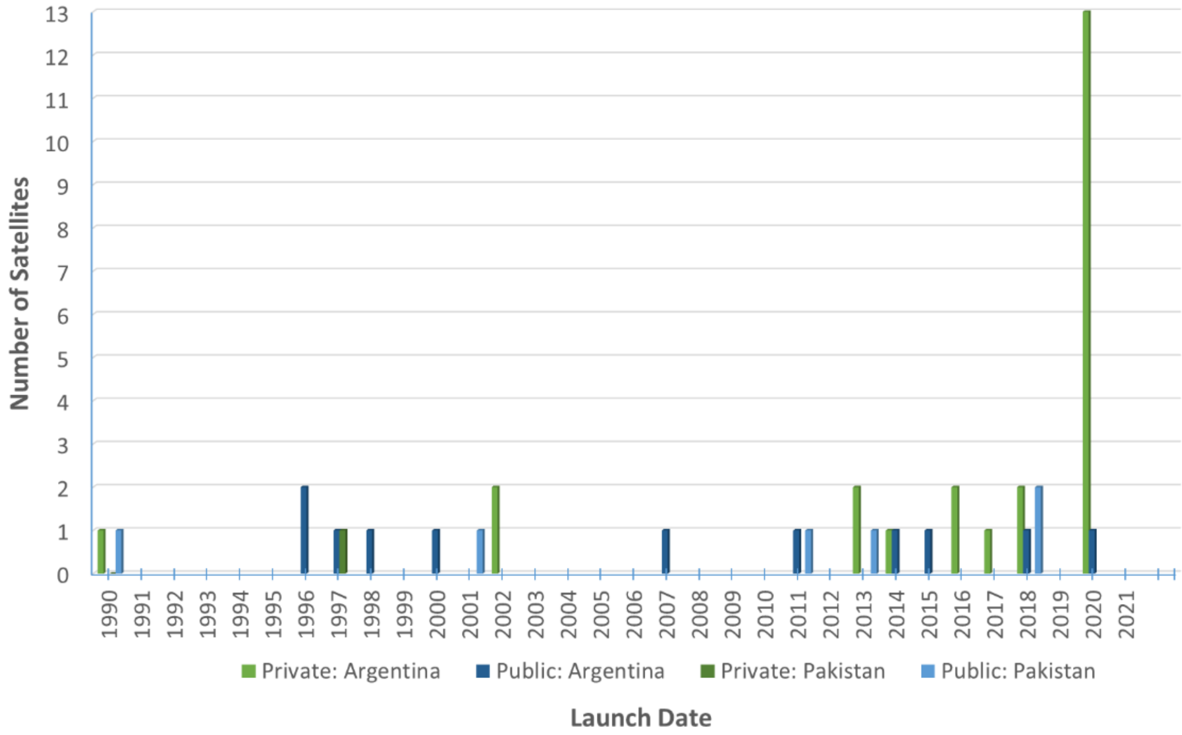

Figure 15. Launch numbers per year for Argentina and Pakistan from 1990 to 2021, based on their commercialization status.

More recently, e.g. for its first satellite BADR-A, Pakistan used foreign cooperation with China and the United Kingdom, establishing its own space industry and operational capabilities (as mentioned before, strengthening Element 1 in Table 1), however the country still regularly relies on cooperation for realizing space missions, see Figure 14. Pakistan has been actively involved in international organizations associated with space activities, e.g. the International Astronautical Federation (IAF) or the United Nations Committee on the Peaceful Uses of Outer Space (UN COPUS) in the 1980s (Mehmud, 1989) and beyond (Mehdi & Su, 2019), strengthening Element 12 of Table 1.

4.6. Ecological effects

Ecology in Argentina's case is not regarded in plans for space activities; only socio-economic concerns are (Delgado-López, 2012).

Environmental monitoring is key element for SUPARCO but review of ecological effects is currently not done; no launcher capability exists, i.e. little catastrophic risks in both cases.

4.7. Discussing impact in Argentina and Pakistan

4.7.1. Argentina

Argentina has established a self-sufficient space industry, capable of developing and assembling spacecraft. With first steps of space industry starting in 1976, in the past decade since 2010 five companies, of eight domestic ones active in the space business, have been founded. Recent missions were almost exclusively internal missions (see Figure 14).

This shows that Argentina has built a lasting space sector in its industry, i.e. there is positive economic impact. So much positive that the market is growing, which can be seen in the launch numbers (Figure 11 ff). More companies are now in the domestic market and offer their capabilities to foreign customers, which was enabled by a series of preparatory missions, including tests and education.

This has several effects on the support of space activities. First, there are economic effects, affecting Element 1 in Table 1:

- profit can be made in the existing market
- if foreign customers are won, foreign currencies can be gained
- in comparison to nations without an own space industry, less money is flowing outside Argentina (money then available for other development activities)

Argentina's Earth Observation satellites provide it with data for disaster relief (Element 2), agriculture support (Element 3) and in general support of development efforts, e.g. urban planning, with Earth Observation data (Element 7). That data can further generate profit, if sold or licenced for business opportunities internationally. Argentina's communication satellites fulfil Element 9, the set-up of communications infrastructure. The existing space industry lead to job opportunities for STEM-students and thus a drain of well-trained personnel can be opposed, supporting Element 1. The personnel can be trained domestically as well as in own companies.

The strong connection of the Argentinian space agency CONAE and the general introduction and development of dedicated space technology education at national universities further creates jobs (Element 1), but also supports STEM education (Element 5). It generally supports the economy in that field, because personnel can be trained and obtained domestically, securing a supply of such personnel.

Contributors are e.g. its space plan, which has been drafted and executed for several decades now and clearly steer the nation's space activities and development, guided by socio-economic needs (Delgado-López, 2012).

These plans directly address rural development by setting up a satellite-based communication infrastructure, which supports, e.g. education (SDG 4) and creating nwew business opportunities, i.e. Element 1 of Table 1. Farmers can access relevant information for agriculture, e.g. weather data, supporting Element 3.

The goal of connecting rural areas to the internet shows a dedicated and intentional development of these regions by the Argentina government, even though the space plan does not specifically mention development goals or SDGs, as recited in (ESPI, 2021). The plan also does not contain considerations directed at the ecological dimension of sustainable development. While Earth observation can be used for ecological effects, this is not a stated motivation.

Cooperation is also an important tool in Argentina space activities, as partner for ground stations. This provides incentives for qualified jobs and thus for trained personnel to stay in Argentina, i.e. there is less drain concerning financing of education, which is then lost due to people migrating out of Argentina because of lack of jobs. It also stimulates the economy. Further, these ground stations cannot easily be moved, i.e. this is usually a long-term committment. Space activities, supported by cooperations, limit “brain drain” (Delgado-López, 2012) as other nations, e.g. Peru, still suffer from, because of lack of investment in qualified jobs in science and technology (ibidem). Lack of investment is caused mainly by the lack of public support and space research is so limited that few understand its meaning and advantages (ibidem). This goes as far as that many still regard it as esoteric (ibidem). From this it can be derived that either the Argentina government took the risk of investment or was able to convince the public beforehand, e.g. with education.

The cooperation connects Argentina with cooperating countries, especially with China, resulting also in political support aside from space activities, even though China is not Argentina’s primary partner for these (Delgado-López, 2012).

Looking at Argentina’s space budget, it can be said that in the timeframe of 2018 to 2020 it remained constant (SpaceInAfrica, 2021), which signifies a stable political commitment. The available data does not allow a direct comparison with the numbers from 2009, as it is not clear under which assumptions SpaceInAfrica (2021) calculated these numbers. According to (GlobalEconomy, no date) the government’s budget in 2020 was 60 billion USD, after significant drops over the past years, due to loss of currency value compared to USD. This means comparisons concerning the relative spending are hardly possible.

Argentina’s Voluntary National Review from (VNR) from (2022), reports also on the usage of satellites for air quality control, which has an influence on public health (Argentina, 2022, p. 64). The report further informs that communication infrastructure is implemented i.a. with the help of satellites (Argentina, 2022, p. 212). According to the report, the Ministry of Environment and Sustainable Development established a cooperation with CONAE to provide air quality information and wild fire data (Argentina, 2022, p. 251f). Illegal fishing is acted against also with the help of satellite surveillance (Argentina, 2022, p. 281), having an environmental component as well as protecting food sources, addressing Element 7 in Table 1. There is some form of administrative cooperation, however apparently, based on the information given by the inquiry with Santiago Enriquez (2022), this link is not well communicated and not part of CONAE’s planning.

4.7.2. Pakistan

Pakistan has a larger population than Argentina (about six times larger), yet less space budget for most of the years with available data, see Figure 10 (e.g. 31.2 million vs. 45 million in 2019), which limits the success potential. Pakistan’s space spending is also focussed on military aspects, binding resources otherwise free for development, which is caused by what is essentially an arms race with India (Hussain & Ahmed, 2019). While certain satellite functions, e.g. concerning Earth observation, could have a dual use, other infrastructure is unlikely to be shared for reasons of security, e.g. communication satellites. Certain aspects can still be met, e.g. creation of jobs (Element 1 in Table 1), but societal costs would occur in other aspects of necessary funding, e.g. health care or education. This is especially hindering development if these services do not balance each other out. For instance, communication satellites used for enabling remote education for distant or underdeveloped domestic regions can balance out lack of funding in traditional educational infrastructure. Investing in such a satellite system has to be compared in an analysis to the costs of such a traditional infrastructure, including, e.g. traffic infrastructure necessary to allow access to schools, costs for training teachers as well as educational outcome. If a satellite infrastructure cannot supplement underdeveloped societal functions, there cannot be a break-even point. Security, including external security, is a need that has to be fulfilled. However other means than an arms race, which affects development in India and Pakistan negatively (Hussain & Ahmed, 2019) exist, e.g. negotiations.

The sustainable development impact is focused on the employment side, but Pakistan also seems to be aware of the potential use of space infrastructure for providing services that can help with development tasks, e.g. water or land management (Mehdi & Su, 2019). This awareness led to the action plan called Vision 2040, aiming to extend the satellite infrastructure. However, this plan does not explicitly link to a development plan (Mehdi & Su, 2019). To gain the most out of space activities, a more coordinated approach would possibly be needed, which would lead to measures which interact with and supplement each other. In the Pakistan’s most recent VNR (2022) it becomes apparent that the built-up satellite infrastructure is more an available tool than part of a larger strategy. There are two instances where the report refers to space technology. First, it is explained that Pakistan established a “TeleSchool” (Pakistan, 2022, p. 63) program implemented during the Covid-pandemic induced school lock-downs, which was among other means available through satellite communication. While this was not a planned application, it still shows that the infrastructure could be used to avoid or mitigate negative impacts from the lock-downs. The report does not provide any information on the rate of usage, which would be necessary to evaluate the utility. Second, it is reported that Earth observation data is used, in a planned manner, for “land planning” (Pakistan, 2022, p. 67f).

The VNR does not inform on a formal, administrative, programmatic link between space program and development activities. Therefore, the exact link cannot be analysed further.

Pakistan regularly uses cooperation to realize a mission. Own missions are rare, although planned for the future, therefore it is not possible at the moment to determine if the impact will last. However, domestic jobs were created, mostly in operation, but also some in manufacturing and education. Pakistan has gained some gradual self-sufficiency as it can cover relevant aspects of a satellite mission, even though it is not wholly independent, due to its limited experience and capacities, relying mostly on China (Mehdi & Su, 2019). The majority of Pakistani missions has also been conducted publicly, a commercial environment similar to Argentina does not exist, limiting the economic impact.

4.7.3. Case specific gaps

As mentioned before, ecological aspects are not mentioned in the space plans of Argentina or Pakistan, who both focus on infrastructure. While this can support ecological activities, the ecological dimension of sustainable development is not a specific motivation for the reviewed space programs. This imbalance concerning dimensions of sustainable development, is possibly caused by lack of awareness concerning the three dimensions of sustainable development, which is evident for the space community in general (Maiwald, 2022) and for the Argentina space community especially (Enriquez, 2022).

Even though Argentina has a substantial space program, renewable energy generation has a minor role in the nation's energy mix. For 2025 a target of 20% of the nation's electrical energy is aimed at to be generated by renewables (Schaube, et al., 2022). This is an oddity as solar based energy generation is a standard for space missions and thus a technology, which is available in Argentina as it has its own space industry. This is a gap concerning Element 8 in Table 1. The necessary link between both fields exists, as the major player in the space industry is the same company that is responsible for Argentina's nuclear power plants (ESPI, 2021). This link however is likely also the reason why a large-scale transfer of solar cells to Earth application is not occurring: lack of incentive. The company would produce competition for its own investment in nuclear power plants.

This lack of investment can become problematic in the long run, because costs of nuclear power plants are increasing and can no longer compete with renewable energy sources (Schneider, et al., 2022, p. 278). This means that more funding than necessary is spent on power supply, in addition to e.g. health and environmental risks associated with nuclear power. This funding is then unavialbe for sustainable development measures.

Table 1 summarizes the relevance of the space activities for the elements listen in Table 1 for both nations, Argentina and Pakistan, based on the previously mentioned trends and explained programs. The pattern is similar for both nations, but Argentina has a strong technology development program, which enables its independence in space activities, whereas Pakistan is counting mostly on international cooperation, lacking investment in technology development.

Both nations focus their space activities on infrastructure, i.e. communication and Earth observation, as well as associated activities to enable these, e.g. education. They apply these infrastructure elements in support of development, but there is no overall strategy for commercialization, especially not internationally, and more importantly actual spin-off of technologies and processes for terrestrial application. This is especially relevant for Argentina, which has a thriving space economy, with hundreds of planned satellites by e.g. Satellogic. Yet, technologies have not been applied terrestrially with regards to sustainable development.

Both nations should apply a more integrated development plan, where space activities are linked with other governmental departments' activities and are not just a tool for providing certain services. Common activities, or missions like Mazzucato (2018) labels, could contribute from shared know-how and transfer to terrestrial application could occur easier, if that purpose is intended and thus influencing a technology already during development. This requires coordination, common programs, communication, and awareness in all relevant fields (Maiwald, et al., 2021). For Pakistan building an actual space industry, which can conduct missions independently of public contracts, could help to improve the economic domain and also foster innovation. More companies working in this technologically advanced field could mean also more cooperation with other international partners, further strengthening Pakistan's position.

Possibly, this interaction could be strengthened further by public support for space missions and awareness for public missions related to sustainable development. This way, companies or other entities could submit proposals for activities how to support this development.

Table 2. Summary of relevance of Argentina and Pakistani space activities for the elements identified in Table 1 where sustainable development can be supplemented by space activities. "X" marks relevance, "O" marks no relevance.

No.	Description	Argentina	Pakistan
1	Create qualified jobs	X	X
2	Disaster relief support (observation and communication)	X	X
3	Supporting agriculture via technology	X	X
4	Basic research in human physiology (for human spaceflight)	O	O
5	Promoting STEM and offering training positions and advancing domestic education in high-tech fields	X	X
6	Support water usage efficiency with technologies and processes	O	O
7	Provide relevant data with Earth observation missions	X	X
8	Support electrical energy generation with improved solar cells, energy harvesting and battery technology	O	O
9	Set-up satellite communication	X	X
10	Promote technology development	X	O
11	Support development of closed economy technologies and processes	O	O
12	Realize cooperation and exchange of know-how	X	X

5. OVERARCHING DISCUSSION

The previous two sections described the separate layers of analysis of this work. This section addresses now aspects connecting both layers.

5.1. Evaluating the impact

As discussed before, investment in space activities is hindered by lack of public support, caused by a lack of understanding of space activities' benefits for the public. One approach to counter this could be education and information campaigns outside the space sector. Support is likely only to be gained once basic needs are safely fulfilled (e.g. water supply). Successes as in Argentina could encourage similar approaches in other nations. Public support is likely more relevant in democratic nations than in autocratic ones, because in the latter, decisions are made without a necessary democratic majority. Space activities can be used by autocracies to increase their nations' stauts (Delgado-López, 2012). Yet, also non-autocratic nations see space activities as means to gain regional leading roles (ibidem).

Both the global trends as well as the case studies have shown that space activities become more accessible and relevant for nations in the global south, which can in itself become a valuable social benefit, by increasing the publicly felt self-esteem of a nation capable of spaceflight, generally perceived as a difficult undertaking and related to advanced nations.

Likewise, technological development in industrial nations, e.g. in the field of affordable launch vehicles, enable nations or organizations with less budget than was previously required for spaceflight to engage in such activities. Technology and services become more accessible. This way, nations can 'leap-frog' ahead, using recent space technology, without diverting over developing own technologies, which would be less advanced, usually more expensive and thus not competitive. The developments, such as e.g. CubeSat standardized and miniaturized components also enable nations, e.g. Argentina, to make meaningful contributions in space technology and even establish an own thriving space industry. Successes of private companies, like SpaceX, in industrialized nations and in global south nations, such as Satellogic in Argentina, highlight the possibility of private entities to become relevant space actors. The trend for miniaturization is likely to continue, therefore lowering the bar further and making space accessible for entities, previously barred from such activities.

5.2. Gaps in potential use

Figure 16 shows the actual implementation in a global perspective in comparison to the potential shown in Figure 3. Unused potential is marked here with dotted lines. The evaluation occurs based on the previously reported missions and implementation.

For instance, economic means for reducing poverty, SDG 1, are used via services in the global south, such as communication or Earth observation services and technology, e.g. by developing and manufacturing satellites. Not all global south countries active in space are similarly active, e.g. not all built own satellites in the same amount. However, generally, this potential is used.

Only technology related potential remains unused. The reasons are different, e.g. for SDGs 2 and 3, human spaceflight technologies would be required, e.g. for addressing human physiology issues, and nations from the global south, except Russia, China and India, which are not regarded here, do not develop human spaceflight technologies.

African nations have already a significant number of satellites in operation, yet they are lacking in space situation awareness (e.g. concerning space debris or space weather such as solar storms) to protect these assets (Abiodun, 2012). Next to Earth observation and communication satellites, which dominate launch numbers, satellites used for solar science and observation are required as well as ground or space-based methods for debris detection and avoidance or cooperation with existing missions. Considering the costs involved and the few satellite numbers that are available to individual nations, the loss of one satellite can be catastrophic. Even if a satellite is insured and can be replaced, such replacement takes years, which leaves people jobless and thus risks losing them to "brain drain" (Abiodun, 2012).

5.2.1. *Strategic implementation*

The review did not produce evidence for a planned manner in which space activities support sustainable development, e.g. by integrated measures of different governmental departments. Even Argentina, a nation with an advanced space program, does not have an integrated plan, which relates to the SDGs. Societal, economic, and infrastructural aspects are part of the program, but sustaianbel development as an integrated concept is not. This is confirmed by the personal inquiry (Enriquez, 2022), which stated that the concept of Sustainable Development is not part of Argentina's space policy or planning, neither on the industrial nor the institutional side (i.e. CONAE).

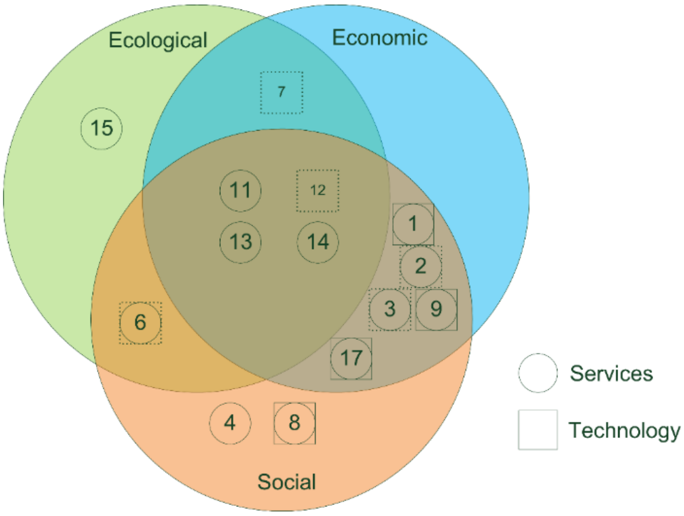

Figure 16. Distribution of the SDGs in relation to the dimensions of sustainable development as addressed with spaceflight activities as reviewed in this study, either based on services (marked by a circle), on technology (square) or both. Dotted lines marked unused potential.

Another example of such lack of coordinated effort and its consequences is the failure of exploiting Brazilian satellites for sustainable development, as mentioned before and as reported by Nettleton & McAnany (1989). Usage was focussed on commercial opportunity and not e.g. social development, although initially intended. However, back then neither the SDGs did exist, nor processes for their implementation. A nation needs an integrated strategy, including all departments of administration, for sustainable development and space activities need to be part of such a strategy, if their full potential for supporting sustainable development is to be used.

It has been discussed before by the author that an integrated approach can further the sustainable development of nations, but requires more coordination to be effective and awareness also in the space community (Maiwald, et al., 2021). This is supported by suggestions of Mazzucato (2018), who proposes to implement mission-oriented projects, where "mission" means for her a clearly defined target within a policy, e.g. the SDGs, which is supported by a number of individual projects (e.g. satellites). The fact that such missions are worked on in several projects avoids the risk of a single-point failure, but also requires more coordination and integration of various areas of e.g. research, production and administration.

Formulating integrated strategies requires fundamental understanding of sustainable development and the SDGs. They need to be understood as a useful approach for development on all levels from local to national and international. This way, e.g. local companies can be inspired to develop and apply new technologies for immediate, terrestrial benefit. Establishing new, space related business opportunities can be one tool, also in nations of the global south, to improve their economy and support sustainable development by supplying services with satellites or space technologies. Funding opportunities for such companies could be one project in an integrated strategy, especially if the respective product is meant to support sustainable development further (by one of the means described in the introduction).

Business opportunities for space activities in nations of the global south could possibly be even more numerous in basic services (such as internet access) compared to industrialized nations and therefore could be used, if strategically planned, to boost an own industry, creating jobs and profit as well as improving such services. Especially communication services need not to compete with already existing, e.g. landline-based systems for previously unaccessed regions and thus become the only option available. Telemedicine needs not to compete with an existing health infrastructure in nations where it is lacking. If such processes are mastered in nations of the global south, this business model can be exported even to indsutrialized natoons, where e.g. demographics lead to lack of personnel, especially in rural areas.

The understanding of sustainable development is lacking in the space community in general (Maiwald, 2022), which reflects in the lack of links between the respective domestic space community and sustainable development responsibles. The understanding has to be improved in all communities on all levels of education and community, to improve general realization of sustainable development and exploit the full potential of spaceflight for sustainable development.

5.2.2. Spin-off and Spin-in Technologies

The review has shown that spin-off technologies are not a relevant outcome of space activities in the global south. One reason could be that immediate usage is often linked to human spaceflight, e.g. agriculture technologies, where nations of the global south are usually not part of. However, other technologies could be terrestrially applied as well and belong to other fields, such as solar cells. Just like addressed before, technologies exploitation via spin-off requires a planned effort, including participation of possible target populations in the respective adaption (Maiwald, et al., 2021). The technology needs to fit the e.g. needs, level of skill, and living environment of the people supposed to use them.

A further reason for the difference in exploitation of technology potential and services is possibly accessibility. Services, e.g. access to Earth observation data can be realized with commercially available computers. To utilize such services for e.g. urban planning effectively, some trained personnel is needed, but not necessarily on all levels. Decision makers and planners can use the services, whereas those working on the plans only need the data, not necessary the skill to obtain it. Application of technology on a wide scale, even adaptation and adoption require competencies on more levels, which might not be available.

Another option for participation in space missions would be spin-in technologies, e.g. for agriculture. Nations of the global south often have extreme environments, which require specialized methods for successful agriculture. These could be analyzed and possibly adapted for space missions. Research in that field requires more coordination, communication and international cooperation.

5.3. Open issues

Especially the “costs” side (e.g. ecological costs in the form of pollution) of space activities are not documented in publications of any sort. This is likely a side-effect of lack of coordinated, integrated strategies, which means possible negative effects of space activities are no reviewed, discovered or at least documented. Since space activities are prestigious, negative aspects are possibly not reported to not diminish this prestige.

Analysing possible negative repercussions requires experts from various fields as they have to regard all three dimensions of sustainable development. Especially launches, but also space debris can cause negative effects for nations in the global south, as evident by failures of Chinese satellite launches (Zak, 2013) (Sheetz & Li, 2019). While such failures occur as well in fully developed nations, usually safety standards prevent loss of life. Creating a domestic space industry but with less stringent social or environmental protection standards, has the risk of other nations or companies exploiting that and outsourcing activities, such as a launch, to these nations. The social and environmental costs would then be paid by these nations, instead of those who are the customers – a situation, which is present in other industries as well, e.g. textile industry. This is what occurred during the failed Intelsat 708 launch in the 1990s via a Chinese launch vehicle, where a company from a developed nation bought the launch in China, which was at the expense of safety standards and eventually lead to at least 6 deaths (Zak, 2013). These less stringent safety standards are still in place in China and are still causing harm (Sheetz & Li, 2019).

Such dynamics need to be further researched, which is hindered by little publicly available information, to gain a complete understanding of the impact on sustainable development. It has to be investigated if there is a trend of buying launch opportunities in nations of the global south, if there are reduced standards in comparison to industrialized nations.

Further research needs to address how space activities affect people in isolated tribes, e.g. culturally. What impact do have e.g. visible Starlink satellites culturally, in any nation, but especially for isolated people who might not even be aware of spaceflight. Also, environmental issues need to be researched, e.g. what kind of pollution space activities, launches or satellite manufacturing, cause on Earth. What is e.g. the impact of battery production for satellites on pollution on Earth? What impact do toxic propellants, e.g. hydrazine, have for pollution on Earth? What impact does non-environment-friendly energy production have on e.g. climate change for components and materials required for space activities?

While positive effects can be estimated for space activities in the global south, even though for determining long-term effects the timeframe is still too short, negative effects have to be weighed, once researched, against these positive effects to determine if space activities are a valuable contribution to sustainable development in the global south, resp. advising for adaptation of activities to make them effective contributions with no or at least not relevant negative effects.

6. CONCLUSION

Spaceflight has become a part of the activity portfolio of global south nations. This work analysed how these activities could and actually do impact the sustainable development for these nations. It has been shown that potentially, the majority of SDGs can be supported by spaceflight, e.g. by creating qualified jobs and education and in turn reduction of foreign fund drain poverty can be reduced. Space systems can also provide infrastructure, e.g. to improve education or medical care in remote areas or support urban planning and monitoring of ecosystems such as forests and oceans. Generally, two fields of potential support can be seen: technology spin-offs and services.

Via a set-up database consisting of 257 satellites from nations in the global south, it was shown that currently there is a trend of increased satellite numbers in the global south, fuelled by reduced launch costs and miniaturization of satellite systems. These satellites are often infrastructure-related, i.e. communication or Earth observation tasks prevail. The number of space mission under own domestic control and with domestically built satellites are is increasing and nations of the global south are contributing in international forums, such as CEOS, based on their space missions, which is enhancing their international status.

While short-term effects, e.g. built-up of domestic industry, competence and infrastructure, can be detected, the activities typically have not lasted long enough to determine a long-term effect besides the mentioned trends. Case studies of Argentina and Pakistan have shown no formal link between these nation's space programs and plans for stustainabel development.

Generally, the services contribution of spaceflight is exploited more for sustainable development than technology spin-offs, likely because of easier implementation. Further research is also needed about negative impact, especially on the social and ecological dimensions of sustainable development.

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REFERENCES

1. Abiodun, A. A. (2012) Trends in the global space arena - Impact on Africa and Africa's response. *Space Policy*(28), 283-290.
2. AMSAT-UK. (2020) *Special certificate to celebrate 30 years of LUSAT*. Retrieved July 11th, 2022, from https://amsat-uk.org/tag/lusat/.
3. Anggari, E. A.; Herawan, A.; Salaswati, S.; Hakim, P. R.; Syafrudin, A. H. (2021) Preliminary Study of the Potential Utilization of Imagery from LAPAN-A4 Satellites. AIP Conference Proceedings.
4. Argentina. (2022). *Tercer Informe Voluntario Nacional.*
5. ARIANESPACE. (2017). *VV11 Mohammed VI-A Launch Kit.*
6. Awad-Risk, I. (2022) *Argentina CONAE signed an agreement with the Polish Space Agency*. Retrieved September 24, 2022, from https://www.aviacionline.com/2022/04/argentine-conae-signed-an-agreement-with-the-polish-space-agency/.
7. BDI. (no date) *NewSpace*. Retrieved October 17th, 2022, from https://bdi.eu/themenfelder/sicherheit/newspace-initiative/.
8. Bhatia, B. S.; Rangarajan, S. (1999) Satellite Communication Applications for Distance Education. *Cooperation in Space*(430), 164-171.
9. Caldwell, B. S. (2015) Spaceflight-relevant stem education and outreach: Social goals and priorities. *Acta Astronautica, 112*, 174-181.
10. Canales Romero, J. M. (2004) Technology, limitations and applications of space technology in developing countries. *Advances in Space Research*(34), 2203-2208.
11. CEOS. (no date) *Agencies*. Retrieved July 30th, 2022, from https://ceos.org/about-ceos/agencies/.
12. Clark, S. (2020) *Ten Satellogic Earth-imaging satellites successfully launched*. Retrieved July 9th, 2022, from https://spaceflightnow.com/2020/11/06/ten-satellogic-earth-imaging-satellites-successfully-launched/.
13. Colazo, M. (2017) Space Science in Argentina – CONAE's Experience and International Cooperation. Vienna: United Nations / Italy Workshop on the Open Universe Initiative.
14. Colomb, F. R.; Alonso, C.; Hofmann, C.; Nollmann, I. (2004) SAC-C mission, an example of international cooperation. *Advances in Space Research, 34*(10), 2194-2199.
15. Colombian Air Force. (2019) *Colombian Satellite FACSAT-1 of the Colombian Air Force, one year in space*. Retrieved July 10, 2022, from https://www.cgfm.mil.co/en/blog/colombian-satellite-facsat-1-colombian-air-force-one-year-space.
16. Delgado-López, L. M. (2012) Sino-Latin American space cooperation: A smart move. *Space Policy*(28), 7-14.
17. Dennerly, J. (2016) Emerging space nations and the development of international regulatory regimes. *Space Policy*(35), 27-32.
18. Economy.PK. (2022) *UAE's New Space Project for $820mil, Whereas Pakistan's Space Agency Annual Budget is $40.7mil*. Retrieved October 1st, 2022, from https://www.economy.pk/uaes-new-space-project-for-820mil-whereas-pakistans-space-agency-budget-is-40-7mil/.
19. Enriquez, S. (2022, October 7) Regional Coordinator for Argentina - Space Generation Advisory Council.
20. ESA. (2006) *Marcos Pontes: Brazil's First Astronaut onboard the ISS*. Retrieved July 19th, 2022, from https://www.esa.int/About_Us/ECSL_-_European_Centre_for_Space_Law/Marcos_Pontes_Brazil_s_First_Astronaut_onboard_the_ISS.
21. ESA. (2008) *ESA and Argentina sign extension of Cooperation Agreement*. Retrieved September 20, 2022, from https://www.esa.int/About_Us/Corporate_news/ESA_and_Argentina_sign_extension_of_Cooperation_Agreement
22. ESA. (2018) *CEOS Database*. Retrieved July 2nd , 2022, from http://database.eohandbook.com/.
23. ESA Earth Observation Portal. (2002) *SAC-C (Satélite de Aplicaciones Científicas-C)*. Retrieved July 9th, 2022, from https://directory.eoportal.org/web/eoportal/satellite-missions/s/sac-c.
24. ESA Earth Observation Portal. (no date) *Satellogic-ÑuSat EO (Earth Observation) Microsatellite Constellation*. Retrieved July 8th, 2022, from https://directory.eoportal.org/web/eoportal/satellite-missions/s/satellogic.
25. ESPI. (2021) *ESPI Report 79 - Emerging Spacefaring Nations* (Full Report ed.).
26. Ferro, P.; Jaramillo, M.; Delgado, R.; Almeida, D.; Rodriguez, G. (2020) *Climate Commitments and National Budgets: Identification and Alignment - Case Studies of Argentina, Colombia, Jamaica, Mexico and Peru.* Inter-American Development Bank.
27. GlobalEconomy. (no date) *Argentina: Government spending, in dollars*. Retrieved October 1st, 2022, from https://www.theglobaleconomy.com/Argentina/government_spending_dollars/.

28. Hargreaves, P. K.; Watmough, G. R. (2021) Satellite Earth observation to support sustainable rural development. *International Journal of Applied Earth Observations and Geoinformation*(103).
29. Hilser, K. (2013) Wirtschaftswachstum und nachhaltige Entwicklung – ein Widerspruch? In R. Öhlschläger, H. Sangmeister (Eds.), *Von der Entwicklungshilfe zu internationalen Zusammenarbeit* (75-94).
30. Hofmann, M.; Rettberg, P.; Williamson, M.; Haese, M. (2010) *Protecting the Environment of Celestial Bodies: The Need for Policy and Guidelines.* International Academy of Astronautics.
31. Hussain, M. Z.; Ahmed, R. Q. (2019) Space Programs of India and Pakistan: Military and Strategic Installations in Outer Space and Precarious Regional Strategic Stability. *Space Policy, 47*, 63-75.
32. Ibrahim, M. D. (2004) Planning and Development of Indonesia's Domestic Communications Satellite System Palapa. *Online Journal of Space Communication*(8).
33. Inovacao Tecnologica. (2003) *Satélites desenvolvidos no Brasil serão lançados ainda este ano*. Retrieved July 13th, 2022, from https://www.inovacaotecnologica.com.br/noticias/noticia.php?artigo=010130030430.
34. Jones, H. W. (2018) The Recent Large Reduction in Space Launch Cost. *48th International Conference on Environmental Systems.* Albuquerque, New Mexico, USA: 48th International Conference on Environmental Systems.
35. Krebs, G. D. (no date) *Spacecraft by country*. Retrieved July 10th, 2022, from https://space.skyrocket.de/directories/sat_c.htm
36. Kulu, E. (2014) *Nanosats database*. Retrieved July 12th, 2022, from https://www.nanosats.eu/.
37. Kunhikrishnan, P. (2019) India's Human Spaceflight Programme: Gaganyaan. Vienna: 56th Session of STSC-UNCOPUOS.
38. Kyutech. (2016) *Press Release - Joint Global Multi Nation Birds (Birds Satellite Project).*
39. Kyutech. (2021) *Release of BIRDS-4 CubeSats from ISS*. Retrieved July 10th, 2022, from https://www.kyutech.ac.jp/english/en-news/topics/entry-8134.html.
40. Lan, C. (2013) Mist around the CZ-3B disaster. *The Space Review*. Retrieved June 10th, 2022, from https://www.thespacereview.com/article/2323/1.
41. Lechner, K.; Michael, N.; Kiefl, R.; Enenkel, M.; Papp, A.; Scherkenbach, C. (2017) Earth Observation for SOS Children's Villages: Deployment of cutting-edge technology to support a humanitarian NGO in emergency. *GI Forum 2017: Advances in GIScience*(1).
42. Leloglu, U. M.; Kocaoglan, E. (2008) Establishing space industry in developing countries: Opportunities and difficulties. *Advances in Space Research* (42), 1879-1886.
43. Long, L. (2016) China's space station project and international cooperation: Potential models of jurisdiction and selected legal issues. *Space Policy*(36), 28-37.
44. Maiwald, V. (2022) Concepts of Sustainability and Sustainable Development in the Context of Human Space Exploration. 18th-22nd Sep Paris, France: 73rd International Astronautical Congress.
45. Maiwald, V.; Schubert, D.; Quantius, D.; Zabel, P. (2021) From space back to Earth: supporting sustainable development with spaceflight technologies. *Sustainable Earth, 4*. doi:https://doi.org/10.1186/s42055-021-00042-9.
46. Maiwald, V.; Schubert, D.; Quantius, D.; Zabel, P. (2021) From space back to Earth: supporting sustainable development with spaceflight technologies. *Sustainable Earth, 4*.
47. Maiwald, V.; Vrakking, V.; Zabel, P.; Schubert, D.; Waclavicek, R.; Dorn, M.; . . . Zeidler, C. (2021b) From ice to space: a greenhouse design for Moon or Mars based on a prototype deployed in Antarctica. *CEAS Space Journal*(13), 17-37.
48. Marcelino. G. M.; Filho, E. M.; Martinez, S. V.; Seman, L. O.; Bezerra, E. A. (2021) In-orbit preliminary results from the open-source educational nanosatellite FloripaSat-I. *Acta Astronautica*(288), 64-80.
49. Mathieu, C. (2010) Assessing Russia'sspacecooperationwithChinaandIndia—Opportunities and challengesforEurope. *Acta Astronautica*(66), 355-361.
50. Mazzucato, M. (2018) Mission-oriented innovation policies: challenges and opportunities. *Industrial and Corporate Change, 27*(5), 803-815.
51. Mehdi, M.; Su, J. (2019) Pakistan Space Programme and International Cooperation: History and Prospects. *Space Policy, 47*, 175-180.
52. Mehmud, S. (1989) Pakistan's space programme. *Space Policy, 5*(3), 217-226.
53. N2Yo. (2008) *N2Yo*. Retrieved July 2nd, 2022, from https://www.n2yo.com/.
54. Nabil Ihsan, M. (2022) *LAPAN-A1 satellite still functional after 15 years of orbiting earth*. Retrieved July 12th, 2022, from https://en.antaranews.com/news/209309/lapan-a1-satellite-still-functional-after-15-years-of-orbiting-earth.
55. NASA - JPL. (no date) *Mission and Spacecraft Library - Brazilsat 1 & 2*. Retrieved July 10th, 2022, from https://space.jpl.nasa.gov/msl/QuickLooks/brazilsatQL.html.
56. NASA. (2014) *Planetary Sustainability: Our Vision*. Retrieved September 21, 2021, from ttps://www.nasa.gov/content/planetary-sustainability-our-vision/.
57. NASA. (2015) *Lapan A2*. Retrieved July 10, 2022, from https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2015-052B.
58. NASA. (2020) *Small Spacecraft Technology State of the Art.*
59. NASA. (2021) *Amazonia 1*. Retrieved July 10th, 2022, from https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2021-015A.
60. NASA. (no date) *Palapa 1*. Retrieved July 10, 2022, from https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1976-066A.
61. NASA. (no date, b) *Brazilsat 1*. Retrieved July 10th, 2022, from https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1985-015B.
62. NASA. (no date, c) *Maroc-Tubsat*. Retrieved July 10th, 2022, from https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2001-056D.
63. NASA. (no date, d) *Mohammed VI-B*. Retrieved July 12th, 2022, from https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2018-095A.
64. NASA. (no date, e) *Spacecraft Query*. Retrieved July 2nd, 2022, from https://nssdc.gsfc.nasa.gov/nmc/SpacecraftQuery.jsp.
65. Nettleton, G.; McAnany, E. (1989) Brazil's satellite system: The politics of applications planning. *Telecommunications Policy, 13*(2), 159-166.

66. Newman, C. J. (2015) Seeking tranquility: Embedding sustainability in lunar exploration policy. *Space Policy*(33), 29-37.
67. Noichim, C. (2008) Promoting ASEAN space cooperation. *Space Policy*(24), 10-12.
68. OECD. (2011) *The Space Economy at a Glance 2011.*
69. OECD. (2014) *The Space Enonomy at a Glance 2014.*
70. Oluwafemi, F. (2021) Space food on celestial bodies and on the way there. In R. Bhat (Ed.), *Future Foods - Global Trends, Opportunities, and Sustainability Challenges* (451-468). Academic Press.
71. Pakistan. (2022) *Pakistan's Voluntary National Review.*
72. Perlin, J. (1999) *From Space to Earth: The Story of Solar Electricity.* Chelsea Green Pub.
73. Preu, P.; Braun, M. (2014) German SIMBOX on Chinese mission Shenzhou-8: Europe's first bilateral cooperation utilizing China's Shenzhou programme. *Acta Astronautica*(94), 584-591.
74. pwc. (2016) *Assessment of the socio economic impact of the ESA participation to the International Space Station (ISS) programme.* ESA.
75. Reiss, C. (2005) A new setting for international space cooperation? *Space Policy*(21), 49-53.
76. Satbeams. (2007) *Satbeams*. Retrieved July 10th, 2022, from https://www.satbeams.com/.
77. Schaube, P.; Ise, A.; Clementi, L. (2022) Distributed photovoltaic generation in Argentina: An analysis based on the technical innovation system framework. *Technology in Society, 68*.
78. Schneider, M.; Froggatt, A.; Hazemann, J.; Ramana, M. V.; Sailer, M.; Suzuki, T.; . . . Meinass, F. (2022) *The World Nuclear Industry - Status Report 2022.*
79. Secure World Foundation. (2013) *Space Sustainability 101*. Retrieved October 10th, 2021, from https://swfound.org/space-sustainability-101.
80. Sheetz, M.; Li, Y. (2019) *'Adjust your location quickly' — How China warns residents before rockets crash down from space*. Retrieved October 17th, 2022, from https://www.cnbc.com/2019/11/26/chinese-rocket-crushes-houses-after-government-warning-to-residents.html.
81. Siddiqui, H. (2020) *India and Argentina to deepen its cooperation in the space field*. Retrieved September 24, 2022, from https://www.financialexpress.com/lifestyle/science/india-and-argentina-to-deepen-its-cooperation-in-the-space-field/2109110/.
82. Spaceflight 101. (2017) *Moroccan Image Reconnaissance Satellite Sent into Orbit by European Vega Rocket*. Retrieved July 12th, 2022, from https://spaceflight101.com/vega-vv11/vega-launches-mohammed-vi-a-satellite/.
83. SpaceInAfrica. (2021) *Global Space Budgets – A Country-level Analysis.* Retrieved October 1st, 2022, from https://africanews.space/global-space-budgets-a-country-level-analysis/.
84. SUPARCO. (no date) *Space Technology Applications*. Retrieved October 2nd, 2022, from https://suparco.gov.pk/major-programmes/space-technology-applications/.
85. Tarikhi, P. (2009) Iran's space programme: Riding high for peace and pride. *Space Policy*(25), 160-173.
86. The Planetary Society. (no date) *Cost of the Double Asteroid Redirection Test (DART) mission*. Retrieved October 10th, 2022, from https://www.planetary.org/space-policy/cost-of-dart.
87. UCS. (2005) *UCS Satellite Database*. Retrieved June 29th, 2022, from https://www.ucsusa.org/resources/satellite-database.
88. United Nations General Assembly. (1970) *Resolution 2626 (XXV) - International Development Strategy for the Second Development Decade.*
89. United Nations General Assembly. (1987) *Report of the World Commission on Environment and Development: Our Common Future, Chapter 2: Towards Sustainable Development.*
90. United Nations Office of Outer Space Affairs. (2017) *International Space Law: United Nations Intruments.*
91. Wilkins, A. (2022) Science lab module joins China's Tiangong space station. *New Scientist, 255*(3397), p. 12.
92. Wood, D.; Weigel, A. (2012) Charting the evolution of satellite programs in developing countries - The Space Technology Ladder. *Space Policy*(28), 15-24.
93. Zak, A. (2013) *Disaster at Xichang.* Retrieved October 17th, 2022, from https://www.smithsonianmag.com/air-space-magazine/disaster-at-xichang-2873673/