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Role of Emerging Nations in Ensuring Long-term Space Sustainability

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Abstract

Over the past decade, the number of member states at the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) has risen by 40%. The UNCOPUOS continues to be one of the largest Committees in the United Nations, with recent additions representing many emerging space nations including the Dominican Republic, Rwanda, Angola, and Bangladesh amongst many others. This paper addresses the role of emerging space nations in updating and refining current policies and norms of behaviour related to the long-term sustainability (LTS) of the space environment. The paper provides examples of recent implementation of LTS in the national space strategies of several emerging space nations, highlighting the importance given by nations to the development of legal mechanisms to regulate the peaceful use of the space environment. Examples include Thailand's 2021 Draft National Space Act, aimed at creating a national legal regime and establishing a governmental agency dedicated to developing space policies for the registration of objects launched into outer space and space debris mitigation measures, and the National Space Law Initiative (NSLI) study group consisting of Australia, Indonesia, India, Japan, Malaysia, Philippines, Republic of Korea, Thailand and Viet Nam to create a framework that aims to promote information sharing and mutual learning in relation to the participant's respective national regulatory frameworks for LTS.

More recently, new initiatives have been developed that celebrate the efforts of satellite mission operators who work to reduce the likelihood of space debris and collisions among space objects. The Space Sustainability Rating (SSR) was created by the World Economic Forum, the European Space Agency, the University of Texas at Austin, BryceTech and the Massachusetts Institute of Technology, and is now hosted by the EPFL Space Centre. The SSR is a rating system to assess and recognize missions that are designed to be compatible with sustainable and responsible operations that reduce the potential harm to the orbital environment and the impact on other operators. The paper provides an exploratory multi-case study approach to assess the SSR Detection, Identification and Tracking (DIT) scores for satellite missions launched by emerging space nations. Based on the outcome of the analyses, the paper identifies barriers and unique challenges emerging space nations might face, including the experience of operator organisations, launch options, financial constraints, or available technical options, among other possible factors.

Keywords: Long-Term Space Sustainability, Emerging Space Nations, Space Sustainability Rating

1. Introduction

The global space economy is experiencing rapid growth from countries engaging in space activities for the first time. As the costs of building and operating satellites have decreased with the maturation of CubeSats and other small satellite technology, greater numbers of national and commercial actors have resulted in the emergence of nations as viable space entities. Several scholars have studied this trend, developed definitions for emerging space nations, and created frameworks to use for analysing the development of the space programs in these nations. The term 'emerging space nations', as defined by Lifson [1] and built on definitions from Wood [2] and Dennerley [3], are "countries that possess some demonstrated level of national interest and involvement with space but are not so engaged as to be considered established space actors". According to Martinez [4], space activities in emerging space nations are invariably driven by government, and it is the interactions among the various levels of government and the coalitions that define the space arena and trajectory that a country takes in its space development. Research investigating emerging space nations in the context of international regulatory regimes was expanded on by Dennerley [3], defined emerging space nations as "a small band of States that have demonstrated an intention to develop their own space capabilities and industries".

Heires [5] noted the limited participation from emerging space nations in the formation of international space regulations and standards, such as the International Organisation for Standardization (ISO), have resulted in laws and rules that may be regarded as unrepresentative or invalid. Similarly, the Space Benefits Declaration [6], adopted by the UN General Assembly in 1996/1997, was in part a response to the dissatisfaction felt by developing countries as to their perceived lack of international space cooperation [3], outlining the adoption of "the Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries, set forth in the annex to the present resolution." [6]. The Declaration further highlights "particular attention should be given to the benefit for and the interests of developing countries and countries with incipient space programmes stemming from such international cooperation conducted with countries with more advanced space capabilities".

Recognising the growing space economy and reliance on space, emerging space nations have voiced their concerns about the fragility of the space environment, and challenges to the long-term sustainability of outer space activities. Over the past decade, the number of member states at the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), the leading UN intergovernmental forum for space policy discussions, has risen by 40%. The COPUOS continues to be one of the largest and fastest-growing multilateral policy-making fora Committees in the UN, with recent additions representing many emerging space nations including the Dominican Republic, Rwanda, and Singapore amongst many others.

Emerging space actors recognise space sustainability as a priority and is reflected in their increased involvement in international fora such as COPUOS. On both an international and nations level, emerging space nations have begun developing internal guidelines and regional and national strategies aimed towards the sustainable and responsible use of the space environment. The paper provides examples of the recent importance given by emerging space nations to the development of legal mechanisms to regulate the peaceful use of the space environment, with the aim of creating a national legal regime and framework to promote information sharing and mutual learning. One such example is the study conducted by Lifson [1] on the perspectives of emerging space nations on Space Traffic Management systems. The author conducted a series of interviews with emerging space nation representatives and concluded that emerging space nations want to be included in ongoing discussions, with a strong preference for COPUOS as the venue for these conversations to take place.

This paper provides an overview of initiatives taken by emerging space nations to develop, review and update national space policy and domestic legislation to consider the engineering and operational processes of space sustainability. An analysis of regional national study groups are also presents that focus on implementation and adoption of the LTS Guidelines, and allow for discussions amongst emerging space nations on areas that require further work.

1.1 International mechanisms to address space sustainability

Increasing awareness of the instability of the space environment with the projected growth of space activities in the 1990's led to the establishment of the Inter-Agency Space Debris Coordination Committee (IADC) in 1993, founded by ESA (Europe), NASA (USA), NASDA (now JAXA, Japan), and RSA (now Roscosmos, Russian Federation). Nine more agencies have joined the IADC since: ASI (Italy), CNES (France), CNSA (China), CSA (Canada), DLR (Germany), KARI (South Korea), ISRO (India), NSAU (Ukraine), and UKSA (United Kingdom). In its primary purpose, the IADC is a forum to exchange information on research activities, facilitate opportunities for co-operation in space debris research, review the progress of ongoing co-operative activities, and to identify debris mitigation options. In 2002, the IADC published the first version of the IADC Space Debris Mitigation Guidelines with a focus on: (i) limitation of debris released during normal operations; (ii) minimization of the potential for on-orbit break-ups; (iii) post-mission disposal; and (iv) the prevention of on-orbit collisions.

Space debris has been a recurring agenda item for the Scientific and Technical Subcommittee of the UN COPUOS since 1994. In 2010, the COPUOS Scientific and Technical Subcommittee established the Working Group on the Long Term Sustainability (LTS) of Outer Space Activities, with the aim of producing a series of best practices for space sustainability, of which the IADC space debris mitigation guidelines as its foundation. At its 62nd session in June 2019, COPUOS adopted the 21 LTS guidelines by absolute consensus of its 92 member States. While the guidelines are not legally binding under international law, the LTS guidelines reflect the latest global consensus on what responsible and sustainable space activities look like in practice and provides legal character such that States may choose to incorporate elements of the guidelines into their national legislation. In this respect, States and international intergovernmental organisations are encouraged to "voluntarily take measures, through their own national or other applicable mechanisms, to ensure that the guidelines are implemented to the greatest extent feasible and practicable..." [7].

International coordination bodies that consist of State and commercial operators of spacecraft have sought to actively promote responsible space safety and sustainability through the adoption of relevant international standards, guidelines, and best practices. Some examples include:

- Space Safety Coalition: an ad-hoc coalition of space operators (including governmental or intergovernmental entities), space industry associations and space industry stakeholders that have a direct and material interest in space safety and sustainability. The SSC publishes, coordinates, and updates a "Best Practices for the Sustainability of Space Operations" [8] document to address gaps in current space governance and promote better spacecraft design, operations and disposal practices aligned with long term space operations sustainability.
- United Nations International Code of Conduct against Ballistic Missile Proliferation, which seeks to increase efforts against the proliferation of ballistic missiles
- Hague Code of Conduct put forward by partners of the Missile Technology Control Regime (MTCR) to establish guidelines for States to exercising maximum possible restraint in the development, testing, and deployment of ballistic missiles
- United Nations Group of Governmental Experts (GGE) on Transparency and Confidence-Building Measures (TCBMs) in Outer Space Activities which aims to improve transparency in space and reduce the risk of misunderstandings and miscommunications among outer space actors
- Consortium for Execution of Rendezvous and Servicing Operations (CONFERS) is an industry-led initiative that aims to leverage best practices from government and industry to research, develop, and publish non-binding, consensus-derived technical and operations standards for on-orbit servicing and rendezvous proximity operations.

2. Implementation and adoption of space sustainability initiatives by emerging space nations

Since the adoption of the LTS guidelines, COPOUS member States have been increasingly reporting their measures to incorporate the guidelines during the COPUOS Committee meetings. These include the development of national space policy; the creation, review and updating of relevant domestic legislation; the ratification of relevant international treaties; expanded government-private sector partnerships to increase communication; the design of space missions so as to reduce the length of their presence in protected regions of space; the development of instruments to incentivize sustainable space activities; national study groups focusing on implementing the Guidelines; the mapping of areas in which more work was needed to better implement the Guidelines; industry outreach, including work with domestic space research and industry sectors to understand their awareness, perspectives and activities related to the implementation of the Guidelines; and close cooperation between space agencies and stakeholders from various backgrounds, including space operators, industry and the scientific community [9].

2.1 UN COPUOS Long-Term Sustainability Guidelines

During 64th Session of UNCOPUOS in 2021, delegations expressed the view that the LTS guidelines of Outer Space Activities should, "promote the safe and sustainable use of outer space, in the interest of all countries, irrespective of their degree of economic or scientific development, without discrimination of any kind and with due regard for the principle of equity" [9]. In recent years, emerging space nations have actively demonstrated the importance of implementing the LTS guidelines in the development of national legal mechanisms to regulate the peaceful use of the space environment. The rise of initiatives to support emerging space nations to pursue space sustainability has also increased. One such initiative project of the Office for Outer Space Affairs entitled "Space law for new space actors", funded by multiple donors, including Belgium, Chile, Japan, Luxembourg, Asia Pacific Space Cooperation Organization (APSCO), the Kyushu Institute of Technology and Secure World Foundation. The project is a dedicated advisory service to assist emerging space faring nations on national space legislation and national space policy, with the aim to: (i) identify, in collaboration with requesting States, space law needs and provide tailored advisory services; (ii) raise global awareness levels of the fundamental principles of international space law; and (iii) support the universalisation, adherence and implementation of the key components of the normative framework [10].

In 2021, Australia, New Zealand, and Nigeria joined Canada, France, Italy, Japan, Luxembourg, Netherlands, and the United States of America in proposing a 'Terms of Reference Methods of Work and Workplan' for the establishment of a new Working Group on the LTS guidelines (LTS 2.0 Working Group) at the 58th session of UNCOPUOS Scientific and Technical Subcommittee [11]. The proposed objectives of the new LTS Working Group are aimed at reviewing relevant practices and procedures to support the practical implementation of the 21 adopted, LTS guidelines, the identification and compilation of possible new guidelines, and strengthening capacity building efforts to assist nations in their implementation of the specific guidelines and the associated development of national space practices, policies, and legislation. Specific mention of emerging space nations was made in the report, noting the need to establish a geographically balanced bureau of the Working Group and in particular the role of emerging space faring nations and developing nations. Given the steady increase in the number of emerging space nations opting to become members of COPUOS, and the dissatisfaction felt by developing countries in previous drafts of space sustainability guidelines, the inclusion of diversity of States is considered a beneficial step in sharing experience and reviewing best practices and lessons learned in the practical national implementation of the LTS guidelines, and enhance overall communication, international cooperation, awareness-raising and capacity building.

It is evident that emerging space nations are taking an active role in contributing to realising a shared vision of long-term sustainability. Initiatives such as the 'Space law for new space actors' has been a useful guidance document for essential information intended to assist States in accessing the space treaties. The increased involvement and participation of emerging space nations at UN forums are further evidence of their understanding of the potential implications of space activities carried out under their jurisdiction, and steps needed to be taken to achieve long-term sustainability.

2.2 Regional and national space strategies of emerging space nations

Since the adoption of the 21 LTS guidelines in 2019, some emerging space nations have taken action to implement the LTS guidelines in their national space strategies, highlighting the importance given by nations to the development of legal mechanisms to regulate the peaceful use of the space environment. Moreover, in geographical regions where several emerging space nations are located, initiatives for regional discussions on space sustainability have also been developed, such as the prioritisation of the safe use of space under the Association of Southeast Asian Nations Subcommittee on Space Technology and Applications. The following section provides examples of regional and national initiatives taken by emerging space nations.

Regional: National Space Law Initiative (NSLI)

In response to a growing number in the establishment of national space agencies in the Asia Pacific region, the National Space Legislation Initiative (NSLI) was implemented under the framework of the Asia-Pacific Regional Space Agency Forum (APRSAF) in 2019. Made up of representatives from seventeen national governmental organisations and related ministries from nine countries in the Asia-Pacific region (Australia, India, Indonesia, Japan, Korea, Malaysia, Philippines, Thailand, and Vietnam), NSLI stemmed from the APRSAF 'Nagoya Vision' adopted at the APRSAF-26 in 2019, whereby specific mention was made to, "continue to enhance the activities of space policy community in the region, and contribute to the enhanced capability in policy implementation of each country on common regional issues in the region. In addition, as players in the space field continue to increase, we, as a whole region, will contribute as a region to global issues such as ensuring the long-term sustainability of space activities and the stable use of outer space" [12]. Moreover, in a joint statement of APRSAF-26, participants recognized, "the importance to promote domestic efforts to ensure implementation of the international standards (i.e. (1) LTS guidelines, (2) space debris mitigation guidelines, (3) IADC guidelines, (4) ISO standards), and the importance of enhanced transparency and confidence building measures through space object registration, pre-launch notifications, and implementation of other related measures to facilitate sustainable development and the use of outer space" [13].

NSLI membership is open to national government organisations in the Asia-Pacific region, with the aim of effectively studying the status of national space laws in the Asia Pacific region; enhancing capacity to draft and implement national space legislation and policies in Asia-Pacific countries in accordance with international norms; and jointly drafting a report on the status of national legislation in the region to the Legal Subcommittee of COPUOS. Based on a research survey from its member organisations, NSLI presented three key findings from its study on the region, namely [14]:

i) Expansion of space activities and actors in the NSLI States makes national space legislation increasingly important.
ii) Establishing national legal frameworks in line with the advancement of space activities was reported to be "a common challenge", and further laws and regulations needed (e.g., registration of space objects yet to be a common practice).
iii) NSLI is regarded as an effective regional model for enhancing capacities in establishing and implementing national space legislation.

The second phase of NSLI was launched in 2022, along with a dedicated NSLI Working Group on space policy and law.

National: Thailand's 2021 Draft National Space Act

In 2020, Thailand's National Space Policy Committee tasked the Geo-Informatics and Space Technology Development Agency (GISTDA) to draft a preliminary Space Act (2021 Draft National Space Act), passing Cabinet's approval in mid-2021. The Act aims to create a national legal regime and establish a governmental agency dedicated to developing space policies for the registration of objects launched into outer space and space debris mitigation measures.

While Thailand does not have a national legal to implement the Inter-Agency Space Debris Coordination Committee's (IADC) Space Debris Mitigation Guidelines [15], the country has practised the guidelines, demonstrating post-mission disposal and the prevention of on-orbit collision of the THAICHOTE satellite and the deorbiting of THAICOM satellites [16]. Since 2020, Thailand has enhanced its practice of conducting space activities for peaceful uses and sustainability but adopting the 21 LTS guidelines. In accordance with LTS Guideline A.5 Enhance the practice of registering space objects, Thailand launched its domestic procedure for registering space objects launched into outer space. Satellite operators (in Thailand) are required to complete the space object registration form and seek approval by GISTDA before sending the space object registration information to The Ministry of Foreign Affairs (of Thailand), responsible for a protocol arrangement before submitting the space object registration submission form to UN Office of Outer Space Affairs [17]. Recognising the expected growth of space object population and subsequent number of Conjunction Data Messages (CDMs) leading to increase potential collision risk to active satellites, GISTDA initiated the development of a space traffic system known as "ZIRCON" to monitor and warn all potential risks of space objects to Thailand satellites. ZIRCON [18] is capable of screening possible on-orbit collisions of all trackable objects provided by Space-Track.org, resulting in essential analysis to support operators for a decision and planning of avoidance manoeuvre. In addition, Thailand is establishing a regional network centre for space situational awareness and research collaboration that support and provide the data of space weather, space debris monitoring and mitigation among countries in Southeast Asia.

2.3 UNOOSA Stakeholder Engagement Study

In 2021, the United Nations Office of Outer Space Affairs (UNOOSA) published the 'Space Sustainability: Stakeholder Engagement Study Report' [19], co-organised by the United Arab Emirates and the Office of Outer Space Affairs. The report aimed to convene stakeholders to gather and share best practices on space sustainability, deliver the capacity building for emerging space-faring countries and support research on the topic by capturing the views of over 50 key stakeholders from the global space economy. Amongst the key findings of the study, the report highlighted the sense of immediacy from many stakeholders and the need for space sustainability to be urgently mainstreamed across the global space sector.

With respect to emerging space nations, stakeholders interviewed in the study noted that space sustainability standards should not be a barrier to non and emerging space faring nations, referencing a perceived lack of necessary guidance and capacity-building options available. It was of a general view from across those interviewed from the study that the United Nations is seen as an integral mechanism to encourage emerging space nations to adopt space sustainability concepts as a central element in their activities, in-built from the outset of the operation rather than as an external option that could be excluded. To this point, participants noted that the financial sector also needs to be aware of the importance of space sustainability and need to consider it as a central element in their investment decisions.

The study additionally interviewed commercial space actors residing in emerging space nations. The responses noted the role these companies play in actively leading the practical investigation for space sustainability by mapping commercial activities and providing policy input and advice to their governments and space agencies regarding space sustainability priorities and capabilities. Based on knowledge and research that might otherwise by lacking governmental agencies, advise national space sustainability legal measures and practices, and provide guidance for investment and research opportunities to be undertaken by the State.

From a technical viewpoint, several respondents observed differences between satellite missions launched by established and emerging space nations, pointing to emerging space nations' deorbiting capabilities might not be necessarily available nationally. The distinguished availability and access to technology to conduct space operations, as compared to technology to conduct space operations sustainably was highlighted in the report.

Based on the interview responses from the study, a several recommendations for further action to increase the adoption of space sustainability, specific to emerging space nations can be made, including:

i) Enhancing existing Transparency and Confidence Building Measures (TCBMs) to develop greater confidence and political trust, especially between spacefaring and emerging space nations;

ii) The need for need for multi-stakeholder dialogues, as national space agencies often become the central "guides" for emerging space countries;
iii) The direct need for educational, and cultural programmes within the space sustainability initiative framework to further mature the policymaking landscape around space sustainability.

The UNOOSA Stakeholder Engagement Study is a clear indication of the progress made to be more inclusive of emerging space nations when considering space sustainability, however, as pointed out by several participants, further work is needed to customise these approaches to consider specific challenges faced by emerging countries such as limited budgets, perceived lack of capacity, and need for continued education and outreach.

2. Space Sustainability Rating

The Space Sustainability Rating (SSR) is an initiative commissioned by the World Economic Forum through their Global Future Council on Space to create an incentive system describing the sustainability of a given space mission by quantifying how the mission contributes to maximising debris mitigation and collision avoidance. The SSR could accelerate the establishment and practice of norms of behaviour among operators of satellites in all orbital regimes, underscoring safe and sustainable operations, especially as the number of operational satellites in Low Earth Orbit and in constellations is dramatically increasing. The SSR has been designed by a consortium that includes the Massachusetts Institute of Technology, the European Space Agency, the University of Texas at Austin, and BryceTech. The World Economic Forum recently announced that the École Polytechnique Fédérale de Lausanne Space Center (EPFL eSpace) will lead the operational phase of the SSR [20]. The SSR comprises of six modules, with each module addressing a different aspect of the mission's sustainability. They include:

i) the Mission Index which is used to calculate the Space Traffic Footprint, and quantifies the level of negative physical interference caused by the planned mission on the space environment;

ii) Collision Avoidance module emphasises what operators can do to reduce the risk of collision with debris and other active satellites;

iii) Data Sharing quantifies the amount of relevant information operators share with the space community and how that information affects safety in orbit;

iv) Standards and Regulations refers to whether a mission adopts published standards that limit debris creation in the congested environment;

v) External Services module is relevant only for bonus ratings and focuses on whether a satellite mission is prepared to receive services such as life extension, repair, and deorbiting from a service provider; and

vi) Detectability, Identifiability, and Trackability (DIT) encourages satellite operators to consider how the physical attributes of their satellite design and their operational approach during launch, operations and disposal affect the level of difficulty for observers to detect, identify, and track the satellite.

An overarching verification module is also incorporated to verify the data inputs provided for each module.

Ratings from the SSR are assigned with a tier scoring system, where module scores are weighted and combined to produce a final tier, within a range of Bronze, Silver, Gold, and Platinum. Further information about the Space Sustainability Rating can be found in multiple previous publications [21-26].

As the Space Sustainability Rating has been evolving since its inception, the design consortium has worked diligently to ensure that the scoring systems for each module reflect sustainable space practices, not based upon their own views, but those from the community writ large. There have also been several rounds of beta testing with large American or European commercial operators who volunteered to participate, and with several NASA missions for which data were publicly available. However, one objective of the SSR program is to enable the most widespread space operator participation and to then achieve sustainable outcomes for those that follow sound design and operating practices. This includes operators from regions outside of the United States and Europe, some of which are in emerging space nations. In this study, work has not been done to investigate whether missions in these other regions, and particularly in emerging space nations, face any unique barriers to being able to score a rating on par with large operators from the United States and Europe.

3. Detection, Identification and Tracking module of the SSR: Emerging nations case studies

The DIT module quantifies how easy it is for an independent operator who does not receive data from a mission operator to detect, identify, and track space objects; these are the three main activities that contribute to space domain awareness. The following section describes an exploratory multi-case study approach to assess the DIT module scores of the SSR for three missions that represent a diversity of emerging space nation's mission types and regions. The missions selected in this analysis are the Thailand Earth Observation System (THEOS), China-Brazil Earth Resources Satellite Program (CBERS), and South Africa's SumbandilaSat.

The section examines both technical features of the missions themselves and aspects of the mission's national context that might have affected the DIT scores the mission received, such as launch options, financial constraints, or available technical options.

Detectability

Detectability is defined as the likelihood that the mission being scored will be observed by a predefined ground network of optical and radar sensors without utilising information about the location of the space objects provided by the operators [23]. Detection is important because in order for Space Data Association (SDA) providers to be able to add the satellite into their catalogue and make accurate measurements and predictions about its location, they need to be able to detect it. A catalogue refers to the collection of space objects being tracked by a given SDA provider. One of the most well-known of these catalogues is that maintained by the U.S. Space Command, which releases its unclassified data on Space-Track.org [27]. The Detectability score combines optical and radar sub-scores into an overall score.

Identifiability

The Identifiability score aims to quantify how difficult it is to identify a satellite based on ground sensor observations. This is useful because having the ability to identify satellites and match sensor observations with objects in the catalogue allows for better coordination among operators and SDA providers, hopefully leading to safer manoeuvres and better collision avoidance procedures.

Trackability

Trackability is defined as how well the already detected and identified satellite can be tracked over time and how well its future location can be estimated [23]. This is a key metric and part of the SDA process as the ability to frequently update the catalogue of space objects means that their locations and collision predictions will likely be more accurate. In practice, for the SSR Trackability analysis, the score reflects the quality of the ground station access to observe an object and update tracking assumptions.

3.1 Methodology

The analysis is organised using a Systems Architecture Framework that is further defined below, which includes methods to formally describe and explain the Context, Stakeholders, Forms and Functions of a given system. The factors that potentially influence the DIT scores of these missions that will be investigated are primarily related to the national Contexts in which the selected space missions were developed, as defined from the perspective of Systems Architecture. Contextual factors could include the experience of operator organisations, launch options, financial constraints, or available technical options, among other possible factors. The Context analysis done for each mission will focus around the areas of Technology, Economics, Collaboration, and Policy at the national level, as defined in previous studies using Systems Architecture [28]. Space sustainability is especially important to many of the space actors in these case studies because they are having to deal with the effects of debris created by larger operators, even as they start to operate in the domain.

Exploratory multi-case study approach

This study uses an exploratory multi-case study approach, a type of research design described by Yin [29] that includes five components: (i) the study's question; (ii) propositions; (iii) units of analysis; (iv) the logic linking the data to the propositions; and (v) the criteria for interpreting the findings. The research question proposed is, "*How do missions of diverse types and from regions outside of the United States and Europe score in the DIT module of the SSR and what factors might affect those scores?*" Because this study is exploratory, there are no explicit propositions. The unit of analysis is a space mission, which could refer to either one satellite or a constellation of satellites, and the study contains three of these cases.

Systems Architecture Framework

Several scholars have studied this trend, developed definitions for emerging space nations, and created frameworks to use for analysing the development of the space programs in these nations. Wood and Weigel created a Space Technology Ladder framework and a Space Participation Metric with the purpose of understanding the implementation challenges facing new space actors and how small satellite programs can be leveraged to support national development goals [30]. Wood continued this research by performing six case studies of satellite projects in four developing countries with a Systems Architecture Framework and showed that the case studies can be summarised by three archetypal types of satellite projects [2]. Work on emerging space nations in the context of international regulatory regimes was also done by Dennerley, who listed a specific set of established space nations and then defined emerging nations as those that are not yet established but have demonstrated an intention to develop space capabilities [3]. Finally, in his study of different stakeholder preferences for space traffic management, Lifson identified a set of countries that "possess some demonstrated level of national interest and involvement with space, but that are not so engaged in space as to be considered established space actors" [1]. This research project draws from these definitions while selecting space missions for the case study analysis, but also considers actors that are more established space nations but still in the regions of interest.

As described previously, the overall method for this chapter is a multi-case study, where each case is a space mission from a different region. For each case, a Contextual analysis was performed, which is the first step in the Systems Architecture Framework. Systems Architecture is concerned with understanding how the different entities in a system work together and with predicting the emergence that comes from their relationships [31].

Wood [2] adapted a general form of the Systems Architecture Framework based on work by Cameron, Crawley and Selva [32] to analyse many types of space and social systems, including the satellite programs in emerging space nations. This Framework includes six steps:

i) Describe System Context;
ii) Identify and Categorise Stakeholders;
iii) Describe Stakeholder Needs;
iv) Desired Outcomes, and Values, Identify Desired System Objectives;
v) Describe current System Functions and Forms;
vi) Describe proposed System Functions and Forms and evaluate against System Objectives

Before the first step, it is important to define the System Boundary to ensure the entire System is included in the analysis but narrow enough that the System's scope can be comprehended by the designer. In this study, the System Boundary is the satellite itself as this is what the Primary Stakeholders are directly controlling.

The SSR could be modelled with the entire Systems Architecture Framework, but this paper is only concerned with the first step of the Framework, which is describing the System Context. The Context includes the factors that are beyond the control of the System's Primary Stakeholders. For a technology-based System, the factors can be grouped into the areas of Technology, Policy, Economics, and Collaboration. The System is situated within the different Context levels of organisational, supporting, national, and international, but this research includes only the national level as it focuses on factors specific to emerging space nations from different regions [2]. After the DIT scoring and Contextual analysis are completed for each case, the results are summarised and compared to investigate if there are any trends about how Contextual factors in different nations affect a mission's SSR score.

3.2 Case Studies and Analysis

The first section of results is the Detectability and Trackability scores for each of the three space missions being studied. Detectability and Trackability each contain both a radar and an optical score. In practice, low Earth orbit (LEO) missions are tracked typically with radar sensors and geostationary (GEO) missions are typically tracked with optical sensors. All missions selected for this analysis are in LEO orbit. These scores, along with the orbital regime of each mission, are summarised in Table 1. For comparison, Table 1 additionally shows the DIT scores for LEO NASA missions for which orbital and characteristic data could be publicly found. The NASA missions DIT scores were initially calculated as part of the validation of ASTRIAGraph for the DIT module analysis [26] and is included in this paper as a point of comparison for those missions from emerging nations.

Each score of the DIT module (radar and optical detectability, and trackability) are scored out of 1, whereby 1 represents the highest, most 'sustainable' result. Based on previous beta testing done with publicly available data, these scores are relatively on par with missions from NASA and U.S. commercial operators, with the exception of the SumbandilaSat trackability scores being fairly low [26]. The radar and optical detectability scores all achieve full marks which is typical for LEO missions of a certain size. LEO missions tend to receive low trackability scores because they are in the sensor fields-of-view for shorter periods of time and have longer intervals between access opportunities.

Table 1. Detectability and Trackability scores for mission

Mission	Radar detectability	Optical detectability	Trackability
LEO Emerging Space Nations missions [28]			
THEOS	1.0	1.0	0.5
CBERS	1.0	1.0	0.42
SumbandilaSat	1.0	1.0	0.25
LEO NASA missions [26]			
GRACE	1.0	1.0	0.33
Hubble	1.0	1.0	0.44
ISS	1.0	1.0	0.33

Thailand Earth Observation System (THEOS)

Thailand Earth Observation System (THEOS) is an Earth observation mission with the primary goals of providing Thailand with affordable access to space and using the experience to develop personnel capability and infrastructure within the country for future space missions. It was launched in 2008 with a mass of 715 kg and a volume of 8 m^3 to an altitude of 725 km and is still active. It uses an optical instrument for applications in the fields of land use, agriculture, forestry management, coastal zone monitoring, and flood risk management. It also reduces the cost of purchasing satellite images from other countries [33]. Technologically, Thailand was an early adopter of satellite communication technology and was also receiving earth imagery data from many foreign sources at the time of the THEOS project. A university and a Thai Ministry had previously collaborated with foreign organisations on satellite hardware projects, but THEOS was the first remote sensing satellite project at the national level [2]. Economically, the Thai government was anticipating a potential severe budget deficit in the years of the THEOS project, but the economy remained relatively stable [34]. As stated in Section 2.2, Thailand has long been a party to the Outer Space Treaty, however has not yet enacted a master law governing space affairs and activities. In 2000, Thailand established GISTDA, a public organisation to unify their development of satellite-related technology. In the area of collaboration, Thailand worked closely with France on THEOS. France provided capabilities such as launch, ground control, spacecraft hardware, and training of Thai engineers [2, 34]. This brief Contextual analysis demonstrates that Thailand likely had all the pieces in place to have success with the THEOS program. Even though they are less experienced than some more established space actors, Thailand's national-level factors did not affect the mission's DIT scores in a noticeable way as compared to those of other nations.

China-Brazil Earth Resources Satellite Program (CBERS)

China-Brazil Earth Resources Satellite Program (CBERS) is a technological collaboration program between China and Brazil that was established in 1984. Together, they have launched six satellites between 1999 and 2019, all of which are Earth observation satellites for applications in agriculture, geology, hydrology, and the environment. The satellite payloads include multiple sensors with different spatial resolutions and data collecting frequencies [35]. While China is not considered an emerging space nation, CBERS was selected as a case study as an interesting example of international collaboration between an established and emerging space nation. CBERS-4A, the most recent satellite in the program, was launched in 2019 with a mass of 1980 kg and a volume of 38 m^3 to an altitude of 628 km and is still active. It received Detectability and Trackability scores on par with missions from NASA and other large operators. Regardless, performing a brief Contextual analysis for CBERS could still help to show any relevant factors that enabled them to achieve these scores. The four areas of the national-level Contextual analysis are complicated by the fact that both China and Brazil are relevant and directly involved in this mission. However, because this paper is concerned with emerging space nations, Brazil will be the focus of the Technology, Economics, and Policy sections, but China will be included in the area of collaboration.

CBERS-4A was launched on a Chinese Long March 4 rocket from Taiyuan Satellite Launch Center, however it is important to note that the Brazilian Space Agency also operates launch sites at Alcantara Space Center and Barreira do Inferno [36, 37]. Brazil has also worked on several launch vehicle projects in the past that have been unsuccessful, however they continue their efforts to develop launch capability [38]. While CBERS incorporates Chinese hardware and systems, the collaboration between the two partners has allowed Brazil to advance in the field of space technology. Economically, Brazil and China contributed equal amounts of funding to the project, demonstrating the equality of their partnership in the project [39]. Politically, Brazil has gone through a lot of transition and unrest over the course of the CBERS project. In the years leading up to the launch of CBERS-4A, there were waves of protest over poor public services, a corruption scandal around the State oil company, and political corruption and unrest [40]. These events, particularly the changes in national leadership, have affected the budget and priority given to different government projects and groups, including the Brazilian Space Agency. Finally, Brazil's collaboration with China for CBERS-4A is the key element of this Context analysis. Both countries have benefited from the partnership over the years it has been active. Brazil gained the chance to develop larger, more advanced satellites at a time in the history of its space program when it was only capable of building small 100 kg satellites. China received an international partner that posed no military threats and allowed it to gain more international relevance as it came out of its period of internal reform. The two countries have exchanged important technical information and visited each other's facilities, renewing the agreement two times so far [41]. After examining the four Context areas of Policy, Technology, Economics, and Collaboration for Brazil and the CBERS program, there seem to be a few factors that might have positively affected CBERS Detectability and Trackability score, as shown in Table 1. The long-term collaboration between China and Brazil on this project demonstrates a commitment to the development of the nations' space programs and capabilities, resulting in the launch of larger, more expensive, and reliable satellites than other emerging space nations considered in this case study.

South Africa SumbandilaSat

SumbandilaSat is South Africa's third satellite project. Launched in 2009, it is a micro Earth observation satellite with the primary mission of collecting data to monitor disasters such as flooding, oil spills, and fires in South Africa. It has a mass of 81 kg and a volume of 0.32 m3. The key organisations in constructing it were the University of Stellenbosch, SunSpace which is a South African Space company, and the Council for Scientific and Industrial Research's Satellite Application Centre. As seen in Table 1, SumbandilaSat received lower Trackability scores than the other LEO Earth observation missions tested in this and in previous work [26]. Based on the structure of the SSR DIT model, this lower Trackability score means that the assumed ground sensor network has shorter access opportunities and longer intervals between access opportunities. This is usually a function of altitude, as satellites that are further from Earth spend more time in the field of view of the sensors. SumbandilaSat was damaged by a solar storm in 2011 in such a way that the power supply to the onboard computer stopped working and images were no longer being sent back to Earth. SunSpace decided to write it off as a loss and stopped operation or repair SumbandilaSat [42]. The orbit then slowly decayed to below its intended operational altitude and the set of orbital elements from ASTRIAGraph used to calculate its Trackability scores show the satellite with a semimajor axis of only 6611km, making it even lower than the International Space Station. This alone can explain the lower Trackability scores. A Contextual analysis of South Africa's space program at the time of building SumbandilaSat shows a few factors that might have contributed to this performance. Technologically, SumbandilaSat was built from commercial off-the-shelf equipment that did not have adequate radiation hardening. Part of the reason for the satellite's failure in 2011 can be attributed to this outdated technology. This is not particularly surprising as the mission was meant primarily to be a technology demonstrator that provided experience for the construction of future national satellites. Economically, the satellite was built for approximately one-tenth of what NASA spent on a satellite of a similar size. This slim budget, according to the head of business development at Sunspace, was the reason that more money could not be spent on better radiation hardening [42]. In the area of Policy, SumbandilaSat ended up sitting on the shelf for three years before it was launched due to "political reasons". A new launch had to be negotiated after years of frustrating delays [43. Also, South Africa was facing a national-level transition for their space policy as they adopted a new National Space Policy that changed the structure and priorities of their space industry [44]. Finally, the Collaboration surrounding this project came mostly in the form of a partnership between university, commercial, and government agency groups. This approach allowed for extremely valuable capability building, sharing of knowledge and experience, and set strong foundations for future South African space projects, which made the mission a resounding success in terms of what it set out to do [45]. Taking these fourContextual areas into consideration, there are some clear factors that contributed to the risk of the satellite being damaged and failing. The most important are the tight budget that led to the use of outdated technology with poor radiation hardening and political factors that delayed launch. These factors, though still possible, are less prominent in the programs of established space nations.

4. Conclusion

The increase in space activities has led to the prioritisation of discussions on the long-term sustainability of the space environment. Leveraging the work by numerous international fora, recent developments of guidelines and norms of behaviour for sustainable operation and responsible use of space has gained traction by both emerging and established space nations. This paper highlights the dissatisfaction experienced by emerging space nations in the early development of regulatory policies concerning the safety, sustainability and security of space activities, and the evolution over recent years to actively incorporate these viewpoints in the discussions. This is evidenced by the rapid growth in the number of States who have joined the COPUOS, as well as regional and national initiatives to encourage and aid emerging space nations in the development and implementation the LTS guidelines in their national space strategies, highlighting the importance given by nations to the development of legal mechanisms to regulate the peaceful use of the space environment.

The paper provides a regional example, the National Space Legislation Initiative (NSLI), implemented under the framework of the Asia-Pacific Regional Space Agency Forum (APRSAF) in 2019 with the aim of effectively studying the status of national space laws in the Asia Pacific region; enhancing capacity to draft and implement national space legislation and policies in Asia-Pacific countries in accordance with international norms; and jointly drafting a report on the status of national legislation in the region to the Legal Subcommittee of COPUOS. The *2021 Draft National Space Act is used as a* national example in this paper to showcase how a nation that does not have a national legal to implement the Inter-Agency Space Debris Coordination Committee's (IADC) Space Debris Mitigation Guidelines, has made efforts to practise the guidelines, demonstrating post-mission disposal and the prevention of on-orbit collision of the THAICHOTE satellite and the deorbiting of THAICOM satellites.

To aid space actors in achieving space sustainability, the Space Sustainability Rating was developed by an international consortium of actors. The paper uses exploratory multi-case approach and Systems Architecture Framework to analyse three space missions that represent a diversity of emerging space nation's mission types and regions, namely Thailand Earth Observation System (THEOS), China-Brazil Earth Resources Satellite Program (CBERS), and South Africa's SumbandilaSat. Using the Detection, Identification and Tracking module of the SSR, the study examines both technical features of the missions themselves and aspects of the mission's national context that might have affected the DIT scores the mission received, such as launch options, financial constraints, or available technical options. These case studies emphasised that operators of all sizes and from many different regions are doing important work in the space sector that should be recognized. While emerging space nations may not always be the loudest contributors in the space community when compared to larger commercial operators and national programs in established space nations, the paper demonstrates actions taken by emerging space nations to prioritise space sustainability and responsible operations in space.

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