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A Space Ecosystem Maturity Index: Proposition to Assess and Identify the Development Level of Space Innovation Ecosystems Around the World

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Abstract

With the advent of NewSpace and the pressing global challenges the space industry is seeking to solve, we are seeing a widening gap between space-faring nations and those that aspire to build a space ecosystem. This highlights the need for a maturity index or “rubric” to help aspiring space nations assess and identify areas of strengths, needs and opportunities to participate in the global space industry. It can also be beneficial for developed nations to understand where to focus resources and investments of space assets both upstream and downstream. As part of the Team Project “Creating a Space Innovation Ecosystem” which was carried out during the Southern Hemisphere Space Studies Program (SHSSP23) in Adelaide, Australia, offered by the International Space University (ISU), in cooperation with the University of South Australia (UniSA), the team focused on identifying some of the key pillars of a space innovation ecosystem and developed a “maturity index/rubric” as a tool for others to create a short- and long-term plan.

Together with profitability, sustainability is underpinned within the index, in line with the United Nation’s sustainable development goals. Ecosystems were assessed based on five key pillars: Political, Funding Instruments, Legal Framework, Education Outreach, and Innovation, R&D. The Index explores these key indicators for different levels of ecosystems, evaluates them and weights them over time. The proposed maturity index also incorporates other established metrics relating to the pillars, such as the Educational index, European space index, and the Space Sustainability Rating.

The result of the self-assessment can be a starting point for any space innovation ecosystem, to create a strategy, and a business plan at a macroscopic and microscopic level. Thus, targeting initiatives (e.g., financial, political, or educational) in the critical areas that would yield the maximum impact. As we believe that ultimately space is for Earth, we wish and envisage that the maturity index will promote cooperation, awareness, and knowledge transfer among states by identifying areas for partnerships as more actors contribute to the growing global space economy.

Lastly, we provide some actionable steps for private, especially start-ups, and public stakeholders, such as governments, to take. We also account for the major role that space enthusiasts, non-governmental organizations (NGO's) and others can play in ecosystem building. These recommendations are not prescriptive and may be applicable to different extents depending on the maturity level of the space innovation ecosystem, the nation's governmental structure, and other instrumental variables.

Keywords: space ecosystem, innovation, rubric, space strategy.

Acronyms

CDSCC – Canberra Deep Space Communications Complex
CEO – Chief Executive Officer
CLPS – Commercial Lunar Payload Services
CNES – National Centre for Space Studies
COPUOS – Committee on the Peaceful Uses of Outer Space
COTS – Commercial Orbital Transportation Services
ESA – European Space Agency
GII – Global Innovation Index
ISU – International Space University
NAMRIA – National Mapping and Resource Information Authority
NASA – National Aeronautics and Space Administration
NGO – non-governmental organization
LSA – Luxembourg Space Agency
PAGASA – Philippine Atmospheric Geophysical and Astronomical Services Administration
PhilSA – Philippine Space Agency
PPP – Public-Private Partnership
R&D – Research and development
SDG – Sustainable Development Goals
SHSSP – Southern Hemisphere Space Studies Program
SKA – Square Kilometre Array
SME – small to medium enterprise
SPACE – Space Promotion, Awareness, and Capabilities Enhancement
STEM – Science, Technology, Engineering, and Mathematics
UniSA – University of South Australia
UNOOSA – United Nations Office for Outer Space Affairs
VC – Venture capital

1. Introduction

The global space sector is experiencing a profound transformation characterised by the emergence of complex space ecosystems that include both public and private actors. This shift poses unique challenges, particularly in ensuring that space applications serve the broader good of humanity.



Fig. 1. The Collaboration between Actors in a Space Innovation Ecosystem

An ecosystem in the space industry describes a complex network of connections and actors within the private and public sectors that drive capability and the development of space technologies.

As global space ecosystems continue to evolve, it becomes clear that different nations possess varying levels of infrastructure, capabilities, and innovation needed to contribute to and sustain it.

To address this disparity there is an urgent requirement for a framework to guide the establishment and growth of a sustainable space ecosystem, particularly in developing nations.

Our analysis is framed around five strategic pillars: political support, research and education, innovation in research and development (R&D), funding instruments, and legal frameworks, which were based on the Luxembourg Space Agency strategy pillars. NewSpace is based on the democratisation of space, centred around making space systems and space services cheaper and

accessible to new players and markets [1]. The operational paradigm of the NewSpace sector is particularly noteworthy, distinguished by its reliance on private equity funding and its concerted efforts to create new markets through the commercial application of space technologies [1]. Moreover, an increasing value is being ascribed to each segment of the space economy value chain [2]

The importance of creating a space innovation ecosystem for developing nations is highlighted by the socio economic and commercial possibilities deriving from space activities in the future. If not addressed, the disparities between nations will only continue to grow, worsening the digital divide, hunger, access to water, gender inequality in the sector, and use of resources. Instead, space services can mitigate and contribute to all these challenges and help address the goals presented in the United Nations' Agenda 2030.

Sustainable development refers to activities of development that meet the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable Development Goals (SDGs) are a universal call to action to end poverty, protect the planet and ensure that by 2030 all people benefit from peace and prosperity [3].

The 17 goals are divided into 169 sub-objectives and 241 indicators [3]. To reach the SDGs it is crucial to harmonise three elements: economic growth, social inclusion, and protection of the environment. The space sector is seen as a major driver and contributor to the achievements of the SDGs and as a powerful vehicle driving us towards a better future by immensely contributing to the existing goals [4]. Space economy has the potential to provide more capillary services and technologies that could assist with disaster, resource, crops management and many other applications that directly contribute towards SDGs.

2. Method

The complexity of establishing and shaping a space innovation ecosystem, particularly in the context of a nation's level of maturity, poses a significant challenge. To address this issue, we have devised a rubric that serves as a self-assessment tool, enabling states to evaluate their current standing and formulate strategic plans accordingly.

In order to facilitate the development of the maturity rubric, a foundation of “themes” that were applicable across the different aspects of an ecosystem were necessary in order to identify relevant indicators for the rubric.

Many strategic priorities were looked at across space agencies and governments. The Luxembourg Space Agency (LSA) strategic pillars encompassed all the pertinent areas and it was decided to base the rubric off indicators gleaned from these pillars.

2.1 Luxembourg's Space Ecosystem Definition

The strategic pillars of a space ecosystem as proposed by the LSA are [5]:

- Political Support
- Research and Education
- Innovation R&D
- Funding instruments
- Legal Framework

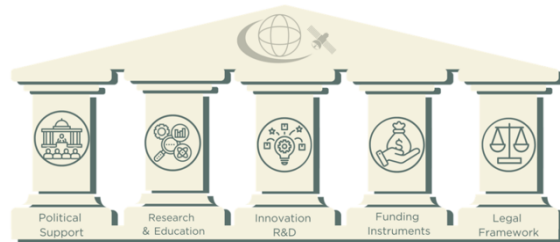


Fig. 2. The Five Strategic Pillars of a Space Innovation Ecosystem

The LSA has been vigorously working to create a unique and competitive business environment to attract international space organisations. Their strategy is well established and provides a solid base to study different space ecosystems [5].

2.2 Space Ecosystem Rubric Development

Once the strategic pillars were decided upon, each pillar was investigated and a list of possible relevant indicators for each were researched, prioritized and eventually down selected into the final rubric.

During our work on proposing and evaluating the rubric, which is designed to measure a state's maturity level in the space ecosystem index, we found three distinct levels of maturity. These levels help to gauge how advanced a country is in terms of its space capabilities and infrastructure. Three maturity levels were defined as:

- **Aspiring:** a nascent network of actors working towards building a presence in the space industry. It is characterized by a high degree of innovation and experimentation as new players seek to establish their niche and find a path to growth and profitability.
- **Emerging:** a growing network of actors starting to establish themselves in the realm of space exploration, exploitation, and utilization. It is characterized by a rapidly growing demand for space-based products and services, and an increase in investment and innovation in the sector.
- **Developed:** a complex network of actors typically involved in the development of new technologies, the creation of new business

models, and the expansion of human activity in space.

3. Results

There are 20 indicators evaluated for the rubric. The indicators listed were down selected from a much larger list, based on their relevance, availability of information and importance within the space ecosystem as a whole and within the pillar.

3.1. Political Indicators

For the development and sustainability of an ecosystem, political support is crucial. Nations lacking an active space program or limited space activities need leaders and decision makers to promote the importance and benefits of having a national space program, taking into account national priorities. The government can play a critical role in driving economic growth and diversification through space activities, which may include funding specific space related projects, missions, or capabilities either directly or as a customer [6].

To further stimulate the space sector, the government can encourage the participation of private companies either through a centralised or decentralised structure. In centralised models, the government controls development, operations, and regulation, with private companies contracted to perform specific tasks, such as seen in the traditional space agency model of developed space nations such as the United States, India and Japan. In a decentralized approach, decisions are made at different levels, with various agencies assuming responsibility and closely coordinating with each other. For example, this could be observed in the Philippines prior to the establishment of the Philippine Space Agency (PhilSA) in 2019, where over the years various different decentralized agencies conducted Filipino space technology research and cooperative space activities [7]. The missions were funded through the Department of Science and Technology's National Space Promotion, Awareness, and Capabilities Enhancement (SPACE) Development initiative, but then overseen by different agencies such as the National Mapping and Resource Information Authority (NAMRIA) and the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) [7].

3.1.1 National Space Agency

A key indicator of the degree of institutionalised support, influence, and participation within a specific space innovation ecosystem, both at a national and international level, is the existence and maturity of a National Space Agency. The maturity and reach of a nation's space agency clearly reflects the developmental stage of each particular ecosystem [8].

- **Aspiring:** In the context of an aspiring space ecosystem, this ecosystem exhibits either no

agency that specifically caters to space-related pursuits or has an agency that exists as an incipient entity grappling with limited financial resources. The latter functions primarily on a political front and lacks substantial endeavours, thereby remaining inconspicuous within the national and international spheres.

- **Emerging:** An emerging space ecosystem includes agencies with modest funding allocation and specialisation in a particular role, be it policy formulation, commercial facilitation, or another discernible area. These organisations are becoming increasingly well recognised on a national and international scale. Despite this upward trend, they have not yet taken major actions that have led to implementation.
- **Developed:** At the pinnacle of the index, developed space innovation ecosystems offer fully established, well-funded national space agencies. Overseeing activities that cover the broad spectrum of a space ecosystem, this kind of agency also adopts a proactive international approach to global space cooperation. As a respected figure in the industry, it has the ability to shape policy at both a national and international level.

3.1.2 National Space Strategy

A country's recognition of the importance of space operations and formulation of a strategic road map to negotiate the challenging environment of space innovation are both reflected in the presence and prioritisation of its national space strategy [6]. The space strategy can influence a range of imperatives within the space sector from national security to inspiration and education.

- **Aspiring:** The lack of a national space strategy without a systematic approach to space operations indicates an aspiring level of space ecosystem. This degree of ecology suggests that efforts to advance space-related goals have not been prioritised or coordinated.
- **Emerging:** The presence of a national space strategy with defined stakeholders denotes a growing level of complexity in an emerging space ecosystem. A recognition exists of the importance of space technology and applications, with specific goals and stakeholders clearly identified, but the true impact of their strategy has yet to be fully implemented. Strategy at this maturity may still be at a regional level but not as yet integrated into a single national strategy.
- **Developed:** A defined national strategy implemented as a funded national policy that

names space as a priority sector underlines a high level of maturity and commitment to the international space industry in a developed space ecosystem. This level of ecosystem not only has a defined plan, but it also invests a lot of resources in reaching its goals. The use of space technology and applications to solve certain socioeconomic problems would also be prioritised by this plan.

3.1.3 International Collaborations on Space Initiatives

Assessing the degree to which a nation's space ecosystem engages with global partners, showcases the level to which cooperative efforts, exchange of knowledge, and collective advancement are prioritised [9].

- **Aspiring:** Amid the context of a budding space environment, this ecosystem is typified by a noticeable scarcity of transnational affiliations. Involvement in global collaboration concerning space undertakings remains minimal, with the focus largely confined to internal endeavours.
- **Emerging:** This landscape exemplifies an inclination to reach beyond national confines, stimulating cooperative initiatives alongside foreign counterparts. Nations in the early stages of space development synchronize their goals with global space agendas, highlighting their cognizance of the significance of collaborative partnerships on a global scale to foster mutual progress.
- **Developed:** An active engagement in international partnerships within space undertakings serves as an emblem of high-level maturity and comprehensive integration. A developed space ecosystem actively participates and leads in intricate international collaborations that span a wide range of endeavours that produce benefits for all collaborators involved.

3.1.4 Sovereign Capability

A nation's capacity to successfully undertake sovereign space capabilities, of varying degrees, measures their ability to independently conceive, progress, and accomplish successful space operations [10]. It also underscores their ability to successfully develop new space technologies and initiatives, whether that be in downstream digital capabilities or upstream hardware and infrastructure. This indicator reflects the level of a nation's technical aptitude and self-reliance.

- **Aspiring:** This ecosystem's capacity to autonomously envision and accomplish intricate space capabilities is rudimentary. Aspiring space ecosystems are typified by their heavy

reliance on external collaborations and assistance to realize their space ambitions.

- **Emerging:** This ecosystem illustrates an emerging ability to develop specific space capabilities independently, but continues to seek external expertise and partnerships for intricate endeavours.
- **Developed:** Within a developed ecosystem, there exists a notable capability to proficiently manage intricate space capabilities in an independent manner. Developed space ecosystems exhibit the aptitude to autonomously conceptualize, engineer, and successfully execute space initiatives, positioning them as distinguished frontrunners within the worldwide space sector.

3.1.5 Space Related Policy

A nation's acknowledgment of the significance of space operations and the development of a strategic framework to navigate the intricate domain of space innovation are both mirrored in the existence and emphasis on its national space policy. Much like the illustrative example of Australia's 2019–2028 Civil Space Strategy, a well-crafted space policy serves as a blueprint outlining a nation's objectives, priorities, and resource allocation in the pursuit of space-related endeavours [11].

- **Aspiring:** The absence of a national space policy, coupled with the absence of a systematic approach to space operations, signifies an aspiring stage within the space ecosystem. This level of development implies that endeavours aimed at advancing space-related objectives have not been accorded priority or subjected to coordinated efforts.
- **Emerging:** The presence of a national space policy featuring well-defined stakeholders signifies a maturing phase within an emerging space ecosystem. It reflects an awareness of the importance of space technology and applications, with clear-cut objectives and stakeholders identified. However, the complete realization of the policy's impact has not yet been achieved.
- **Developed:** A well-funded national policy that designates space as a priority sector underscores a high level of maturity and dedication to the global space industry within a developed space ecosystem. At this stage, the ecosystem not only possesses a well-defined strategy but also commits substantial resources to its attainment. Additionally, the utilization of space technology and applications to address socio-economic challenges assumes a prominent position in this policy's priorities.

3.2 Research and Education Indicators

Under the pillar of research and education, a few critical factors play a pivotal role in shaping the future of both scientific advancements and educational pursuits. These indicators not only provide insights into the state of our educational systems but also reflect our commitment to fostering innovation, particularly in the fields of Science, Technology, Engineering, and Mathematics (STEM), as well as space education. In this context, we will explore these indicators with a focus on aligning them with the SDGs, considering the experiences of an aspiring, emerging, and developed space nation.

3.2.1 Funding for Space Education

Training and education build national expertise in countries with emerging space capabilities [12] and the use of public funding in education grants is an investment in a growing space ecosystem.

- **Aspiring:** Grants are unlikely to be found at this stage, however, an aspiring space ecosystem ideally has given consideration to this and forecasts this in future budgets. Grants are likely available to adjacent sectors, which could allow for crossover opportunities.
- **Emerging:** An emerging space ecosystem will have several grants available which focus on space education. Some of the population has already taken advantage of this and accessed courses or programs which may have otherwise been unattainable.
- **Developed:** An abundance of grants exists to help stimulate access to space education for a growing number of interested people. This ecosystem understands that a wide array of properly administered grants is an investment in the future of the nation.

3.2.2 STEM Higher Education

Assessing the proportion of STEM bachelor's degrees awarded by a nation is a critical metric for evaluating a nation's readiness and ability to develop a space innovation ecosystem. STEM education forms the foundation for innovation, research, and technological progress in space and related fields, directly impacting the commercial success of new space start-ups and growth of a commercial space industry.

Many nations across Europe have a developed space ecosystem and it could be assessed this is correlated to their participation in space, with 65% of the countries in Europe hosting at least one programme in Space related education [13]. A new space ecosystem which fosters an environment for further education can move towards becoming developed space ecosystem, as it grows

intellectual capital across the population, while stimulating new ideas.

- **Aspiring:** Opportunities for tertiary education which is reputable outside of the host nation are limited but this ecosystem may consist of a number of people who have received an internationally delivered tertiary education. The percentage of the population that has progressed to achieve tertiary-level education is less than 10%.
- **Emerging:** Categorized by widely accessible education, this ecosystem has a large number of universities within its national borders and there are several specifically space related tertiary education programs or courses which are provided domestically. At least one in every ten across the population is educated to a tertiary level.
- **Developed:** The ecosystem has a strong focus on attaining a high level of education nationally. The ecosystem also has a considerable portion of the population with an understanding of space or space-related topics. Teaching staff have access to a number of resources for professional development to remain current and sharpening their delivery of educational material. It is common that across the population that at least 20% have completed some degree of tertiary education.

3.2.3 Space in Youth Education

Space topics routinely spark curiosity and imagination and encourage youth involvement in the sciences [12]. One primary indication for the longevity of a nation's growth in space activity is the availability of STEM education at school.

- **Aspiring:** The ecosystem is not yet focused on implementing STEM education programs. Schools are likely to provide a degree of STEM education, though it would likely receive less support from public servants in education departments or with school staff. While some programs may exist, it would not be common for an aspiring ecosystem to have a national or state-level strategy in increasing program availability.
- **Emerging:** Some schools have a strong offering of STEM. Government bodies recognise the importance of STEM in this ecosystem and have a plan for implementing continuously improving programs across schools.
- **Developed:** Many opportunities exist for students to pursue interests in STEM throughout the entirety of their schooling. Participation in STEM is heavily encouraged and well supported by suitably qualified teaching staff.

Not only are there extensive program options within school, but several extra-curricular STEM education programs operate and are considered as desirable in future career decision-making.

3.2.4 Commercialisation of R&D in Academia

The commercialization of R&D in academia serves as a critical indicator for assessing the maturity of a space ecosystem. It demonstrates how effectively research and innovation carried out by universities is transformed into tangible applications and profitable enterprises. Notably, successful cases include Tel Aviv University in Israel, which established a venture capital fund – TAU Ventures – that has raised over US\$70 million to invest in student start-ups. To date, TAU has played a pivotal role in establishing 43 privately held start-up companies valued at over US\$1 billion, meaning it has nurtured more start-up "unicorns" than any other university in the world [14].

- **Aspiring:** In an aspiring ecosystem, the commercialization of research and development in academia is limited. There is little collaboration between academic researchers and industry partners to drive the commercialization of research findings and the ecosystem lacks dedicated programs or initiatives to incubate and support student or university start-ups. Start-up success stories are rare.
- **Emerging:** Academic institutions are increasingly involved in commercialization efforts, with emerging programs or offices focused on bridging the gap between research and commercial applications. Collaboration between academic researchers and industry partners is becoming more common, leading to technology transfer agreements and modest start-up incubation programs.
- **Developed:** A strong commercialization ecosystem exists in academia, with successful collaborations between academic institutions and industry players that lead to technology transfer, incubators, accelerators, and start-up success. Academic research has also led to numerous successful start-up companies in the commercial space sector.

3.3 Innovation R&D Indicators

Investment in early-stage R&D can see benefits in increased space capability in the future. UNOOSA positioned space-based technologies as a next generation enabler for sustainable development on earth [15]. NewSpace applies agile methodologies, with quick turn around times and a customer centric focus. These indicators are a good measure of the response of a space ecosystem to these changing needs. It must also be mentioned that the growing space accelerator / incubator

community is providing many opportunities to accelerate innovation in the space sector by providing much needed funding, access to expertise and coordinating vital networking and collaboration events.

3.3.1 Existing Private Space Industry - Companies

An important indicator of a space innovation ecosystem is the number of private businesses engaged in space activities [16]. These can be large established aerospace primes, medium to large corporations with some interest in space, e.g., telecommunications companies, or small to medium enterprises (SMEs) dedicated to space business.

- **Aspiring:** A few medium sized businesses with a glancing interest in space, with foreign players providing services to these businesses. There are only a handful of, if any, SMEs dedicated to space. The ecosystem is focused entirely on downstream applications of space.
- **Emerging:** SMEs are starting up to be able to locally provide space services. Foreign aerospace primes work with businesses in the ecosystem and may procure local talent for projects or establish outposts. While the ecosystem is still largely focused on downstream applications, some ecosystem actors are developing upstream applications.
- **Developed:** Several large aerospace primes are established that reliably provide space services, medium sized corporations have teams dedicated to space activities and locally procure services. SMEs continue to emerge to fill niches in the market. The ecosystem has a both upstream and downstream application focused actors and is largely independent of external ecosystem players.

3.3.2 Existing Space Industry – Jobs

The type of employment and the number of space and space related jobs can provide valuable insights into the maturity of the space ecosystem. The diversity of roles, specialization and government space related jobs all point to a growing and expansive space sector [17].

- **Aspiring:** job opportunities may be limited to a few core areas like basic research, academia and government funded small space programs with few opportunities in private industry. With a lack in supporting areas like space law, insurance and commercial start-ups its likely more job openings will be centered around education and outreach and K-12 STEM programs.
- **Emerging:** There would be a broader scope of jobs available like engineering, advanced research, policy and more commercial roles. Evidence of more commercial and supporting

roles within private industry especially start-ups and government will show an actively growing space sector and ecosystem. General public engagement and an expansion of STEM programs would typify the emerging landscape.

- Developed: characterized by highly specialized job roles in areas of propulsion, satellite design and space robotics as examples with expanded supporting roles like policy engagement and international relations. There is a thriving entrepreneurship scene creating jobs in cutting edge fields of space exploration, ISRU and mining. Flourishing supporting industries emerge like space law companies, financial and insurance positions, environmental sustainability and space tourism. Government jobs equally diversify in these areas.

3.3.3 Research & Development Investments in Space

Investing in Research and Development is crucial to building a space innovation ecosystem in a nation. It fosters technological advancements, national and international collaboration and partnerships, knowledge generation and commercial growth [18].

- Aspiring: The R&D funding for space related projects is typically limited and only a small portion of R&D funding will be allocated to space ******(approx. 0.01 – 0.1%). The majority of R&D efforts will focus on basic research and fundamental science prioritizing knowledge generation over practical applications. The activities are also carried out largely by government funded R&D organisations and academic institutions. These nations often seek international collaboration to access additional resources and build capability.
- Emerging: There will be a notable increase in R&D investments for space-related research ******(approx. 0.1 – 0.4%). The focus of the research also shifts to more applied research directed to practical technologies and applications. Private companies and start-ups become more involved in space R&D and generally the areas of R&D become more diversified to cover other aspects of space like space -based services etc.
- Developed: Substantial financial resources allocated to R&D activities and many players in the ecosystem invest heavily in R&D ******(approx. 0.4 – 0.9%). The R&D efforts are at the forefront of technological advancements, and focus is on cutting edge technologies for many different areas of space activities. The R&D activities are also multidisciplinary for e.g., Space science, advanced materials, AI etc. R&D investment in the private industry are

geared towards commercially viable products and services. There are multiple international collaborations on major space missions and project. There are often established research hubs that contribute significantly to knowledge and technology advancement.

******In considering how we can use R&D investments to measure a space ecosystem, we have taken the spend in R&D in Space as a % of the total R&D spend of a nation, looking at a few key examples as the benchmarks (Kenya-aspiring, Australia-emerging, USA-developed) [18].

3.3.4 R&D Innovation Programs

These are important initiatives that boost growth within the space sector aimed at advancing technology and capabilities and harnessing opportunities within the gaps in current offerings. Examples of programs include accelerators which are short term programs, incubators which tend to be longer term programs and innovation hubs that offer physical spaces within a certain sector or industry. All of the above have mixed offerings of training, mentorship, funding and collaboration opportunities all specifically focused on the space sector. There are other programs like space competitions and corporate innovation programs as well.

- Aspiring: Along with the need for foundational training, the focus is on early-stage start-ups and entrepreneurship. Mostly early-stage seed funding and possibly for more downstream activities (space derived value-added services like earth observation data etc). There may be a lack of established networks and limited access to facilities.
- Emerging: Focus is on accelerating growth through proven concepts or market need. Programs facilitate connections with global space organisations and investors. Programs here assist with product development and market access through the different funding programs.
- Developed: Programs focus is on commercialisation and scaling up of production, including market expansion. Cutting edge technology across the sector has support and there is often training related to areas like regulatory frameworks and global leadership.

3.3.5 Global Innovation Index

The Global Innovation Index (GII) is an annual ranking that assesses and ranks countries' innovation capabilities and performance [19]. It is designed to provide insights into how well countries are fostering innovation and driving economic growth. The GII takes into account a wide range of factors that contribute to innovation, such as R&D investment, human capital and

research, infrastructure, business sophistication, market and business dynamics, and more [19].

Using the GII as an indicator is not straightforward, as the GII itself considers many different indicators as part of the index, some of which have already been incorporated within other indicators mentioned in the rubric. A simplified approach to using the indicators points to differing levels of ecosystems. There are some differences within the GII that can be construed from the score. We have attempted to give an indication on the score and a few more discerning outcomes.

- **Aspiring:** Low GII Scores, approximate range for this ecosystem 0-20. These nations are facing multiple challenges in building a robust space ecosystem, typically lacking in infrastructure, human capital and R&D investments to make significant strides in space development.
- **Emerging:** Moderate GII Scores, approximate range for this ecosystem 20-40. These nations have made some notable progress, have investment and infrastructure in place and are engaging in space activities like satellite launches, basic to advanced space research and collaboration programs.
- **Developed:** High GII Scores, approximate range for this ecosystem 40+. Here we see well established and mature space ecosystems, excelling in most areas of space activities. They usually have development and launch capabilities and manage advanced space missions.

3.4 Funding Instruments Indicators

Securing funding is a pivotal part in the accomplishment of a project, and in order to do so it is fundamental to have the right dialogue between governments, research centres, universities, and private investment groups. In addition, it is important to share failure and successes in an honest yet constructive way to engage citizens in tax expenditure and advertise the spin-off that come even from apparent “failure” in space projects [20]. Generally, funding can come from public, private entities, or from a combination thereof.

3.4.1 Private Investment for Space

Private investment is an approach where investors and high net worth individuals invest capital directly into private companies with the aim of acquiring ownership stakes, facilitating growth and ultimately generating a return on their investments. There are different types of private investment that may be applicable to the space domain. Collectively private investments make up an important part of space investment, and although there is the perception that the private sector is more willing to

take risks than the public sector, often times it is the public sector to guide private investments [21].

Under the umbrella of Private Investment, one finds Venture Capital (VC), Private Equity, Debit Financing, Public Offering, and Acquisitions [6].

VC is the largest single start-up space investment category, representing AU\$9 billion of the AU\$15 billion raised in 2021 [6]. It allows investors to finance or provide other required expertise to start-up companies and small businesses whom are foreseen to have long-term growth potential. Whilst VC often refers to financial support, it also encapsulates other technical or subject-matter specific expertise that an organization does not yet possess [22]. Accelerators and Incubators are usually the main mechanisms for disbursing private investments but there is distinction within the ecosystem levels.

- **Aspiring:** Limited private equity and investment available, due to lack of private space companies and a small or undeveloped space sector. Typically, nations in the early stages of building space capabilities and characterised by majority angel investing which provides early-stage seed investment.
- **Emerging:** Likely to see an increase in private equity for space due to the growing interest of private investors for space start-ups, technologies and commercial ventures. Usually experience a budding entrepreneurial ecosystem. More traditional investments seen for start-ups and VC’s investing in space technologies.
- **Developed:** There is significant private equity investment and a scene of established space companies, a history of successful space ventures and established funding models. Full range of financing options available including debt financing, separate space funds and space VC’s.

3.4.2 Government Expenditure

Without government support no space programme would be successful, however it is important to put into perspective the space budget expenditure. The majority of space budgets constitutes less than 0.05% of GDP (including civil and military activities where data are available) [2]. The countries investing the most are (in descending order) USA, Russia, France, China, Japan, Luxemburg, India, Belgium, Italy, Germany, Israel and Korea. The strongest funding growth is seen among newcomers and in certain segments (e.g., military) [2].

- **Aspiring:** Characterised by generally financially unstable or restricted governments, emerging nations are unable to see large shares of GDP directed to the space industry and its related programs. These nations may be able to support space-based activities and missions through

other portfolios, such as environmental protection and natural disasters prevention as well as defence, they would not be able to invest heavily in exploratory technological advancements or major national/international projects.

- **Aspiring:** With a reasonable proportion of the nation's GDP available to be allocated to the space industry, these nations will likely see some small to medium scale, long-term tender and grant programs released for industry and research partners to compete for. These nations will likely have a funded national mission, ensuring that industrial efforts are being directed to achieving strategic priorities.
- **Developed:** On the other end of the economic spectrum would be developed nations who would be able to contribute a high value of investment (from citizens taxes e.g.) to space technologies and applications. These nations would see significant engagement in both internal tender and grant programs, with an international extension for further engagement made available as well. The nations would further see commercialization of government developed technologies into spin-off organizations which can in turn provide additional industry funding, e.g Arianespace coming out of the National Centre for Space Studies (CNES) and the European Space Agency (ESA).

3.4.3 Public-Private Partnerships (PPPs)

Public-Private Partnerships are collaborative agreements, arrangements between government or public sector entities and private companies or organisations to jointly develop, build, fund and operate space related projects or initiatives [23].

They are a powerful way to leverage the strengths and resources of both partners to advance the space sector and achieve shared goals [24].

- **Aspiring:** Limited PPPs due to the nascent state of the space industry where typically the government plays a more dominant role in the space sector with fewer opportunities for private industry. The focus is also on small projects to build foundational capabilities, not commercial outcomes.
- **Emerging:** Witness a growth in the number and diversity of PPPs in development, infrastructure and research initiatives. Commercial opportunities evolve to collaborations in areas like space tourism, on orbit mining or space manufacturing with increased sovereign capability. Typically, the private players

become more active partners to government making significant contributions.

- **Developed:** Wide range of established and ongoing PPPs. These cover major space missions, technology and massive infrastructure projects. The commercial aspects of space are dominated by the private sector through PPPs. Nations engage in bilateral and multinational PPPs with international partners and space agencies on complex space endeavours and missions such as the International Space Station Consortium, NASA's Commercial Lunar Payload Services Program and Commercial Orbital Transportation Services.

Other elements to consider when evaluating PPPs is the commitment and level of funding, technology transfer mechanisms and some measurable outcomes like commercialisation.

3.5 Legal Framework

In the context of space activities, a legal framework could refer to a set of laws, agreements, regulations and higher-level treaties that govern and guide the conduct of space activities within a nation [25]. It provides the legal structure within which to undertake space exploration, research, commercialisation and collaborations. A robust and comprehensive legal framework can serve to foster growth in a space ecosystem by clarifying responsibilities, encouraging investment, fuelling innovation, commercialisation and collaboration and ensuring safety and security through compliance to national and international obligations [26].

3.5.1 National Regulatory and Legislative Environments

A national regulatory framework dictates the directives and management of all space and space-related activities taking place within a nation or performed by organisations registered to a nation that are implemented and performed outside of that registered nation [25]. National regulations are generally dictated by a collection of policies, acts and legislative documents that ensure safe and appropriate activities are performed [25]. These regulatory items are developed to reduce risk levels and ensure that all functions of the industry are performed in socially and ethically responsible manners with penalties imposed for misconduct or lack of adherence [26].

- **Aspiring:** In the context of an aspiring nation the national regulatory environment exhibits very little to no space activity specific legislation dictating the safe practices of the nation's space sector. These nations will likely be looking to other more industry mature nations for guidance on implementing appropriate and comprehensive, yet not limiting regulations into their own ecosystems. Without defined

regulatory provisions, nations will have great difficulty in progressing or holding inappropriate behaviour accountable within the sector, making regulatory provisions one of the very first activities for a nation looking to become spacefaring or space-enabled.

- **Emerging:** The presence of defined regulations and associated penalties for key activities within the space industry is evident of an emerging nation. Key activities will relate directly to the nation's priority pillars – ensuring that innovation is not hampered by out-of-date governance. These nations will aim to build the regulation to be significantly more comprehensive of all industry practices whilst remaining dynamic to account for updated technology, innovations and strategic redirections
- **Developed:** Featuring the most advanced regulatory framework are the developed nations which have deeply integrated and comprehensive legislation and precedence addressing a majority if not all areas of risk which can be mitigated through legal review. The integrated nature ensures that industry and academia are not being hampered by the regulations imposed but are instead functional and operative elements that ensure the nations continued prosperity and reputation through produced goods.

3.5.2 International Policy Engagement

The United Nations Office for Outer Space Affairs (UNOOSA) through their Committee on the Peaceful Uses of Outer Space (COPUOS) was established to 'govern the exploration and use of space for the benefit of all humanity: for peace, security and development' and has been fundamental to the development of the 5 treaties and principles of outer space that today govern all international space industry activities [27]. The five treaties which cover topics from activities for exploration through to rescue and return, international liability requirements, registration conventions and activities specifically relating to moon exploration are fundamental not only to the development of national legal frameworks but for governing international best practices [27]. In addition to the guiding treaties and principles, the UN's SDG's, discussed in the introduction, underpin a number of policy decisions and strategic directions adopted by nations as communally the world strives to achieve the goals by 2030. Instilling in nations a focus on achieving global good.

- **Aspiring:** Lack of engagement with international treaties or an absence of member state status amongst the General Assembly of UNOOSA is indicative of an aspiring nation due

to potentially limited resources, interest and access to participate in such activities.

- **Emerging:** Emerging nations would be categorised within the UNOOSA structure as being not only a member state to the 102-member strong UNOOSA General Assembly, but a strong supporter and signatory of the treaties to ensure the common good protection of outer space. In addition, these nations would be greatly improving their industry practices to be in keeping with the SDG's, included amongst legislative and regulatory governance. Furthermore, these nations would likely be improving in their individual metrics for each of the individual SDG's.
- **Developed:** With the most comprehensive approach to engaging with international policy would be the developing nations whom would not only support, but advocate for and work directly on improving and expanding such policy to better govern other nations interests in space. These nations would be member states of the General assembly, signatories on treaties and likely have representation amongst the committee working groups to ensure active participation. These nations would furthermore be actively involved in the pursuit of reaching the goals as outline for achievement in 2023 – with major improvements made in a majority of areas alongside implementation within current legislation.

3.5.3 Compliance Programs

Continuous assessment and the distinct allocation of accountability to organisations operating within the space industry against dynamic and comprehensive standards is key to ensuring a sustainable and considered sector is developed [28]. Whilst historically the space industry has seen stages of stagnancy nestled between periods of great advancement, reliable controls over the conduct, impact and products of an organisation independent of demand are crucial. This ensures that developed goods and services are fulfilling their intended function in an adequate and safe manner whilst not significantly disadvantaging other factors, such as workers health and safety and environmental protection [28]. Essentially developing best-practice approaches to all avenues of commercialisation or research within the space industry.

- **Aspiring:** No formal internal Agency audit, compliance or pre-qualification program has been established or implemented to maintain management of local organisations registered and recognised as those belonging to the space sector. This leaves space organisations subject to overarching business rules and regulations of a nation only, resulting in expert analysis not

being provided to potentially higher risk activities.

- **Emerging:** Emerging ecosystems will feature national Agencies who have an established and functional compliance program inclusive of audit and pre-qualification activities that act as a guiding force for the operations of a majority of businesses. Local and residing businesses, specifically those engaging in potentially high-risk space applications, such as launch and spacecraft development, will adhere to established compliance requirements to ensure legal deliver of products and services, ensuring that all deliverables have been quality checked against a number of indicators including quality, information security, environment, workplace, health and safety.
- **Developed:** A developed and consequentially mature ecosystems compliance landscape will feature a comprehensive, mandatory pre-qualification program for all local space industry organisations. This pre-qualification program will be integrated into the daily operations of organisations, with clear performance indicators provided to not only achieve, but maintain said compliance and pre-qualification programs. Such programs may feature organisational incentives, such as tax reduction or preferential tendering opportunities for organisations that maintain and develop upon their positive local footprints. Ensuring that all space activities are recognised as best practices both locally and internationally.

nation's dedicated commitment to the space sector [29]. This agency not only coordinates and supports industry initiatives but also plays a crucial role in formulating policies for the burgeoning space economy.



Fig. 3. Representation of the Rubric Indicators & Ecosystem Maturity Levels

4. Rubric Implementation Discussion

4.1 Characterizing a Nation Using the Rubric

The aim of developing this rubric was to create a tool that both governance and industry stakeholders can utilize to determine a specific nation's position within the innovation ecosystem of the space sector. The rubric serves as a guide for future focus areas and activities, depending on the objectives of a nation, research organization, university, commercial entity, or individual within a nation involved in the space sector.

4.2 Australia – Emerging Case Study

Taking Australia as an illustrative case study, we can extract important insights and observations using the rubric's indicators. Australia's journey in the space sector reflects a transition from aspiration to a noticeable emergence. Several key milestones shed light on Australia's path of growth:

- **Policy and Governance:** The establishment of the Australian Space Agency in 2018 marked a significant turning point, demonstrating the

- **Historical Precedents:** Australia's historical contributions to space infrastructure, including the Honeysuckle Creek tracking station's role in broadcasting Neil Armstrong's moonwalk and the NASA's Canberra Deep Space Communications Complex (CDSCC), underscore the nation's legacy in space collaboration [29].
- **Infrastructure Development:** Investments in launch facilities like Woomera, along with emerging sites such as Whalers Way, indicate Australia's ambition to strengthen its space infrastructure [30].
- **Innovative Start-ups and Enterprises:** Companies like Gilmour Space Technologies, Saber Astronautics, and Myriota amongst others have emerged as leaders in space innovation. These entities contribute to enhancing

Australia's space capabilities while addressing domestic and global challenges [31].

- International Collaboration: Initiatives like the Australia-UK Space Bridge and the International Space Investment India Projects grants run by the Australian Space Agency, underscore Australia's strategy to foster international alliances and synergies.
- Research and Education: Leading Australian universities and research institutions increasingly focus on space science and technology, highlighting the academic drive towards space exploration and study.

Australia combines significant historical contributions to space exploration, such as the transmission of Armstrong's moonwalk, with ambitious projects like the Square Kilometre Array (SKA), showcasing a balanced integration of space heritage and futuristic aspirations [30]. These achievements and endeavours signify Australia's systematic and ambitious progression in the space sector, establishing itself as an emerging space power. By comparing this progress against the rubric, one can discern how other nations may replicate Australia's successes and navigate potential challenges.

4.3 What the Rubric Reveals

Australia's impressive strides in space activities and its promising trajectory towards becoming a well-established space nation still herald many opportunities to grow.

Australia's Space Agency funding, while commendable, remains comparatively modest when compared to established space nations like the USA, Russia, and more recently, India [6]. While space may not currently hold the highest priority in Australia, there is potential for growth by inviting increased support in cultivating a thriving space sector with significant socioeconomic benefits.

Australia's international space partnerships are promising and taking note of the sovereign capability, exemplified by the CDSACC, shows that ability to be mentored on managing, engineering and executing space missions or programs.

While education programs and outreach have seen impressive growth, additional funding and grants are welcomed to facilitate a seamless transition from education to industry development. It's worth noting that Australia's R&D investments in space, although currently below 0.4% of total R&D spending, have the potential to increase and align more closely with the approximately 0.7% allocated by the USA [32].

Australia may benefit from further advancements in its national regulatory framework and compliance programs for space activities, even though it already aligns with more developed nations on the international

stage. The rubric underscores the areas where Australia can enhance its efforts to foster a complete and robust space ecosystem.

4.4 Key Points on Aspiring and Developed Nations

Aspiring nations like Kenya, South Africa, Costa Rica, UAE and Azerbaijan show us the nature of the aspiring ecosystems [6]. Kenya has had success through collaborative programs in launching satellites and though there have been limited space activities, favourable conditions such as their geographical location, young Space Agency support underpinned by the governments vision for 2030 that space activities contribute to economic growth by almost 5% per year brings a good environment for growth and progression of the sector [33]. South Africa has a history of satellite development and deployment and is a key partner in the SKA project together with Australia [34]. South Africa is an example of an ecosystem on the cusp of aspiring and emerging.

Developed Ecosystems like China, USA, Russia and India show us the outstanding achievements that come with having an established ecosystem in place. India has taken the world by storm with its latest endeavours of Chandrayaan-3 and Aditya-L1 [35]. The USA's NASA has been the benchmark for managing advancements in space for decades. The USA remains at the forefront of the global space industry with 52% of all space related companies worldwide hailing from the nation [36].

It can be seen that while we use Australia as a case study the rubric is flexible enough to be used by any country at any stage in their ecosystem progression.

5. Conclusions

The work presented here is the beginning of a goal established by a passionate team of space advocates during the International Space University's SHSSP23 Program (Southern Hemisphere Space Studies Program 2023) and this was to establish an index that could be used by anyone as a guide to evaluate their current space ecosystem and have a guide as to which activities would be best to begin the journey of growth of the space sector in their immediate environments.

This Rubric we present in this paper is the beginning of this research and it will take more effort for this to be adopted into an index.

The figure below shows an example of how such an index could be represented to show areas of strengths and opportunities within a nation. This graph was the culmination of the work done during the Space Studies Program.

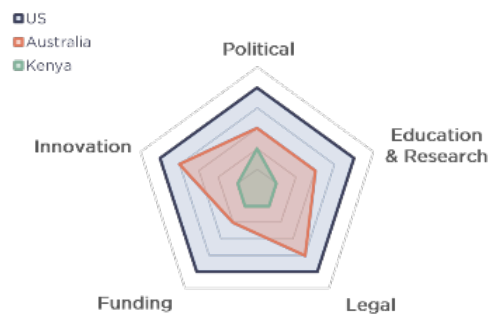


Fig. 4. Potential Visual Representation of Ecosystem Indicators Mapped against the Pillars [37]

Some of the next steps of this work would be to explore would be:

- Further research into more indicators to include or prioritise.
- Apply the full rubric to other countries or engage countries to carry out a survey based on the rubric and use this data to guide further development of the rubric into an index.
- Wider consultation with key stakeholders and experts to improve on the development of the rubric and progress to an index.

In closing the space ecosystem rubric, tailored for evaluating a nation's standing within the space sector's innovation ecosystem, demonstrated its robustness when applied to Australia's space activity. This tool, both diagnostic and prescriptive, offers a strategic lens for nations to introspect, enabling policymakers and industry leaders to craft informed strategies.

Australia, with its momentous leaps in space — from historic feats to establishing its own Space Agency and bolstering international ties — still faces hurdles. The rubric astutely points out areas such as funding gaps, the urgency for a robust regulatory milieu, and the imperative of fortifying international collaborations for palpable gains. It seamlessly weaves a narrative, linking a nation's history, economy, environment, societal nuances, and governance to its space odyssey. With its inherent adaptability, this rubric stands as an invaluable asset for emerging nations, illuminating paths to success while cautioning against pitfalls.

By championing diverse stakeholder involvement and championing bespoke solutions, the rubric lays the foundation for comprehensive, enduring, and inclusive advancements in the space sector across the globe. Echoing Neil Armstrong's words as he stepped onto the lunar surface, "That's one small step for [a] man, one giant leap for mankind." Space is not just a frontier for exploration but a testament to our shared humanity. Its vastness beckons not just to an elite few, but to every

nation, every culture, every individual — a resonating reminder that space, in its infinite majesty, is indeed for everyone.

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