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The intersection of space and sustainability: The need for a transdisciplinary and bi-cultural approach

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ABSTRACT

Aotearoa New Zealand's emerging New Space economy provides an opportunity for key actors to focus on space and sustainability issues beyond space debris. The conflict between competing definitions and paradigms of sustainability highlights the importance of diverse values, assumptions, and drivers of change that shape the normative understanding of space sustainability issues. This paper recognises that Indigenous knowledges and practices are in parallel with systems-thinking and transdisciplinary approaches to space and sustainability. The aim of this paper is to describe how current actions can have long term impacts on using and accessing space commercially, scientifically, and culturally.

1. Introduction

This paper provides a range of sustainability perspectives for the Aotearoa New Zealand space sector to consider as broadening the scope of sustainability issues could reveal unforeseen risks and opportunities for businesses, government, communities and indigenous tribes. Aotearoa New Zealand is uniquely positioned to provide insight into the intersection of space and sustainability because it is a settler colony with a bi-cultural[2] framework founded on the Treaty of Waitangi [1] and a country with a newly developing, market-driven space sector.

For several decades there have been growing concerns about the management of space activities, particularly related to risks posed by orbital debris. For example, the Brundtland Commission [2] recognised that outer space was essential to planetary management activities such as Earth observation, Earth orbits, and weapons testing. However, the report also identified that Earth's orbital environment is a valuable and limited resource under threat from the accumulation of orbital debris. That threat continues to grow with the increasing number of countries and private organisations operating within Earth's orbital environment, which now also increasingly includes large constellations of satellites. Risks of collisions of debris with hardware and humans in orbit concern safety and the long-term sustainability of space operations in Earth orbit. This paper explores various interpretations of sustainability from an Aotearoa New Zealand and global perspective and how it could intersect with the local space sector. The perspectives include the key issues the sector may want or need to consider and show that the scope of sustainability is a broader issue than just space debris.

Envisioning a sustainable space sector for Aotearoa New Zealand and understanding the impacts of any changes needed to achieve such a vision is advantageous for policymakers and commercial companies interested in the long-term viability of accessing and benefiting from outer space activities. By going beyond the issues posed by orbital debris and limited Earth orbits, the discourse can shift to the various paradigms of sustainability for outer space and the role that outer space plays for terrestrial sustainability, for example, meeting net-zero emissions targets. The paper aims to frame the discussion on what sustainable development entails for Aotearoa New Zealand's space sector.

Applying the concept of sustainability to space is complex and raises a range of transdisciplinary issues within the realms of law, geopolitics, culture and science. This includes:

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[1] The views and opinions expressed in this research do not reflect the views and opinions of Auckland Council or the wider council group.

[2] In Aotearoa New Zealand, biculturalism—accorded by the Treaty of Waitangi/Te Tiriti o Waitangi signed in 1840—refers to the coexistence of two distinct cultures: Māori (indigenous) and non-Māori in partnership [1].

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Abbreviations

ADR	Active Debris Removal
ESA	European Space Agency
ESG	Environmental, Social, and Governance
GEO	Geostationary Orbit
GHG	Greenhouse Gases
IADC	Inter-Agency Space Debris Coordination Committee
LEO	Low Earth Orbit
LTG	The Limits to Growth
MBIE	Ministry of Business, Innovation, and Employment
MDG	Millennium Development Goals
NASA	National Aeronautics and Space Administration
NZSA	New Zealand Space Agency
OECD	Organisation for Economic Co-operation and Development
PwC	Pricewaterhouse Coopers
RMA	Resource Management Act
SDG	Sustainable Development Goals
UN COPOUS	United Nations Committee on the Peaceful Uses of Outer Space

- The need for domestic arrangements to be integrated politically, particularly of Indigenous governance, rights, and interests.
- The lack of globally acknowledged legal boundaries defines or demarcates outer space from airspace [3–5].
- The predominance of guiding research for space policy, diplomacy, and development from the Global North (China, Japan, Turkey, and the United States) [6].
- The lag in time for governments to implement adequate legislation for technological and innovative space activities [7].
- The lack of international agreements on managing and mitigating space debris through orbit break-ups, intentional destruction, and impacts of space weaponisation [8].
- Definitions and interpretations of sustainability and how to apply it in practice vary across organisations, governments, and academia [9].

With regards to the definition of outer space, this paper is guided by the Outer Space and High-Altitude Activities Act 2017. It is operational at an altitude above flight level 600 and the highest upper limit of controlled airspace under the Civil Aviation Act 1990 [10]. High altitude activity also includes the aerospace sector and advanced aviation but is not in the scope of the paper.

Some of this complexity and different interpretations, particularly regarding sustainability, reflect underlying differences in worldviews and political and philosophical values. For example, in general, Western society[3] considers sustainability from a sustainable development point of view' which is about how much to compromise economic growth and the extent to which the environment should be preserved [11]. Exploring how the concept of sustainability has emerged and changed over time can reveal different values and what has been driving change in the first place. These drivers are essential to identify because they help indicate future pressures the space sector could respond to. Additionally, it informs what role the sector plays in influencing desired future changes—for example, achieving long-term emissions reduction, adapting to climate change, and much wider issues such as zero hunger and affordable clean energy [12]. It also leads to discussions on tensions introduced by different worldviews, values, and drivers, as those can influence how the future of the space sector could play out [13].

The development of the New Space economy is an example of a global trend mainly arising from the ease of entry barriers for private sector operators. Outer space is easier to access with the reduced launch and accessibility costs, subsidies from the public sector, and reusable technology [14]. There are also trends showing an increased demand for commercial activity, with many satellite payloads to set up constellation programmes. The growth of space services and innovations has made the satellite industry invaluable to Aotearoa New Zealand for telecommunication, navigation, remote sensing, and national security [7].

Whilst there are benefits from this growth, such as broadening access to space and stimulating innovation, there are also risks of over-exploitation of the space environment. Suppose, left unchecked, continuing to reinforce biases and assumptions that lead to issues such as inequality, inequity, and environmental degradation. If such risks are not recognised and not addressed, there is a risk of losing access to outer space – whether to groups or a complete permanent loss of global access. These are genuine risks which need to be considered by decision-makers. This paper acknowledges the generalisations of sustainability explored to find the intersection between space and sustainability, with the chance that there could be groups of people whose voices are inevitably lost in broad discussions.

The paper challenges key sector actors to consider that different values and perspectives can play a crucial role. The work presented here can identify and challenge biases and assumptions that might otherwise go unnoticed, test boundaries of innovation, and significantly help identify risks and opportunities. This is highlighted by Professor Moriba Jah advocating for cultural competence that contributes toward the long-term sustainability of space activities and responsible behaviour by all space actors [15].

Aotearoa New Zealand is in an excellent position to provide insight from different values and perspectives because it is a bi-cultural country with shared and different cultures, histories, languages, and worldviews [16]. These differences come from Western societal values, culture and language, and the Indigenous Māori and wider Pacific culture and language influence modern Aotearoa New Zealand. There is an opportunity for co-development with Indigenous partners to build genuine, non-transactional partnerships that promote the long-term wellbeing of the space environment [17].

The nascent nature of Aotearoa New Zealand's commercially driven space sector also presents an opportunity to explore how government institutions can foster a sustainable market-driven space economy. The New Zealand Space Agency (a sub-division of MBIE) was established in 2016 following Rocket Lab's proposal to commence commercial space launches [18]. Since then, MBIE has marketed New Zealand as "business-friendly" and an ideal location for small operators to set up themselves [19,20]. The Government is simultaneously building the technical expertise and regulatory capability to manage these growth policy challenges [7]. Therefore, to explore the sustainability paradigms and how they influence the sustainable development of the space sector, a literature review was used as evidence and context for the study. The review considers an international and national perspective of sustainability and sustainable development that will outline the recommendations for future research relevant to the space sector in Aotearoa New Zealand.

1.1. *Definitional conflict - sustainability*

Definitional conflict, or a lack of consensus around definitions, can be seen as a hurdle or a sign that problems exist within a field. However, rather than being an indication that something is wrong in a discipline, providing definitional clarity is part of a process that is necessary, particularly when there is agreement that a research or policy problem exists [21].

A lack of definitional consensus can result in problems where there is an assumption this already exists. These assumptions invalidate bodies

[3] Largely referring to countries, and societies that have had a dominating influence on art, culture, literature, and ideas [153].

of knowledge because of beliefs regarding conceptual similarities [22]. Specifically, in areas of space research, the James Webb Space Telescope almost did not proceed because of conflicts around the definitions of its role [23]. Definitional conflicts also arise in areas where policy work and research are more explicitly connected. For example, harassment in the workplace [24] and what counts as 'white collar' crime [25], are both societal problems that have yet to be solved partly because of definitional conflict. Thus, definitional clarity is not a matter of semantics, as vagueness generates confusion in research and policy [26], particularly in broad interdisciplinary fields, like sustainability. Such 'Wicked Problems' in society tend to lead to definitional vagueness [27], especially where different knowledge systems and perspectives are valid [26]. This matters in research and policy because this vagueness impacts what is seen as the nature of the problem; what is to be studied and addressed. It results not just in poor and inconsistent research but also ineffectual policy. However, within policy discussions, the issue definition stage is essential at the outset [28], setting the boundary for what solutions might be discussed, how success is evaluated, and what options might be presented. It presents research with focus and definitional clarity that then simplifies the processes by which scientific judgements are made [29].

The idea of sustainability itself is a site of definitional conflict [30]. Given its considerable interdisciplinarity as a term and field, this is inevitable, and since different knowledge systems contribute to its understanding, it is often political (ibid.). Addressing the lack of consensus is crucial; however, to reduce the chance of multiple definitions of the term, a "disciplinary norm" (ibid., p.36) is required so that research is not stymied. This paper is an effort toward the very 'wicked problem' and shows how a disciplinary norm can be worked on collaboratively.

1.2. Paper outline

This introductory paper outlines the paradigms of sustainability and the implications for Aotearoa New Zealand's space sector through a meta-synthesis of sustainability concepts found in the literature. The aim of the review is to also:

- Present the opportunity to explore Indigenous knowledges in our understanding of space as an environment
- Identify key challenges, tensions and biases
- Make recommendations to address these challenges

Section 1.3 provides a brief overview of the Aotearoa New Zealand context concerning the Indigenous Māori. The rest of the paper is divided into the following three sections.

Section Two outlines the methodology applied to explore the various paradigms of sustainability.

Section Three is a literature review of the terms: sustainability, sustainable development, and space sustainability, as well as the drivers that influenced their definitional evolution.

Section Four is a six-part discussion as follows:

1. The definitional frame that will inform the values and scale of space sustainability initiatives (subsection 4.1)
2. How Indigenous knowledges can enable the sector to rethink their sustainable development approach (sub-sections 4.1 and 4.2)
3. How space-enabled data can be used for terrestrial sustainability (subsection 4.3)
4. The role of Earth in the sustainability (preservation and utilisation) of the space environment (subsection 4.4)
5. Policy design that promotes the sustainability of the Aotearoa New Zealand space sector (subsection 4.5)
6. A discussion on tensions and government interventions relating to the sustainable growth of the Aotearoa New Zealand space sector (subsection 4.6)

Section Five establishes considerations and recommendations for policy makers and other key actors shaping Aotearoa New Zealand's space sector.

1.3. Aotearoa New Zealand's history

Māori are Tangata Whenua (the people of the land), the Indigenous peoples of Aotearoa New Zealand. Māori had long undisturbed occupation of Aotearoa and developed an intimate understanding of the environment over generations. As Tangata Whenua, Māori established a unique culture intrinsically linked to land and developed a 'strict system designed to regulate human activity with respect to nature' [31]. All lands, waterways (lakes, harbours, open sea) and resources below and above Aotearoa were governed according to Māori customary law and collectively managed by groups of hapū (the primary political unit in traditional Māori society). As Indigenous peoples, Māori approaches to managing the environment and interactions between humans and the natural world were based on traditional knowledge, worldviews, and values. Interactions with the natural world are closely bound to the physical and metaphysical dimensions inherent in Te Ao Māori (a Māori worldview) [32].

1.3.1. The bi-cultural constitutional framework

The eighteenth century was a period of transition to colonialism in Aotearoa New Zealand [33]. The colonial discourse of Aotearoa New Zealand is founded on negotiated treaties and agreements made between nations of hapū and the British Crown [34]. There are two sets of founding documents which were written in both English and Māori (but not an exact translation of each other), entitled He Whakaputanga o te Rangatiratanga o Niu Tireni/The Declaration of Independence New Zealand (1835) and Te Tiriti o Waitangi and the Treaty of Waitangi (1840) [1]. Each agreement reaffirmed the continued authority of Māori tribes over their tribal territories and legitimised a form of colonial authority over new settlers [34]. The terms set out in the founding documents provided a bi-cultural vision and framework for the co-existence of two distinct authorities and evolvement of a bi-cultural society.

With the increased arrival of new settlers determined to acquire lands, a settler government was established to enact legislation as a self-governing Crown colony [1]. A colonial settler parliament was opened in 1854 and began a revamp of Māori customary laws and replaced it with British concepts, including individualised title and property ownership [35]. Despite the Treaty agreements which reaffirmed Māori independence and their authority over their tribal territory, a plethora of legislation was enacted which breached the treaties [36]. Between 1840's and 1870's, British colonial forces fought to wrestle land away from tribes to open up land for new settlers. The New Zealand wars began between the colonial settler government and Māori. A Māori resistance tradition opposing colonisation began (ibid.).

By 1900, tribal land estates dwindled from 29,880,000 ha to 3,200,000 ha through land confiscations and this displacement had a profound impact on Māori economic welfare [37]. The Crown took no account of aboriginal title and ignored Māori Treaty rights in determining national and local regulations, policies, and plans. The Tohunga Suppression Act 1908 coupled with land alienation had a detrimental impact on the ability of Māori to continue to exercise their responsibilities and obligations of kaitiakitanga, a Māori cultural expression which relates to western forms of sustainability [38].

1.3.2. Te Ao Māori (Māori worldview)

Te Ao Māori considers land, resources, knowledge and tikanga (customs) as taonga or treasures that require kaitiakitanga (guardianship) or protectors [39]. The Māori view of the world is inherently interconnected, intergenerational, and sacredly holistic, where the health of the natural world and its resources are connected to their wellbeing spiritually and physically [40–44]. The environment's mauri (life force) is central to understanding the importance of the relationships, their genealogy from Ranginui and Papatūānuku, and the spiritual connection that binds them [43]. The Rauora framework, commissioned by the Ministry for the environment, acknowledges that the Māori knowledge system is not based on the minimum optimal level of operation needed for survival. The framework defines relationships through a lens of abundance, how wellbeing contributes to identity and a premise that the colonial mindset is grounded in consumerism and exploitation, leading to an extractive economy [40].

The dominance of the Western perspective in Aotearoa New Zealand reflects the effects of marginalisation that have made it difficult for Māori to thrive economically, socially, politically, and culturally [42, 45]. The Māori population declined dramatically after the Treaty's signing, and the British Crown had acquired 80% of the land by the 1900s [1]. The effects of colonisation have removed Māori authority to exercise control over their land and natural resources. Moewaka Barnes et al. [46] expressed that Māori had to fight being alienated from the land and the resources, as well as the intergenerational roles and responsibilities that uphold the dignity of their ancestors. The unequal power and economic balances highlight the competing values between Māori and the governmental institutions.

Interventions such as the Waitangi Tribunal were established in 1975 to make legal cases for Māori based on historical illegal confiscations of land and resources for fair settlements as reparations [1,47]. The Foreshore and Seabed Act (2004) is one example of tensions between the Crown and Māori regarding how resources should be owned and used. Exploiting the foreshore and seabed exhibits Government agendas around privatisation, commercialisation, and using market levers to determine policies [48]. The desire for tino rangatiratanga started a movement to push the Government into reforming and adapting policies that breach the promises set by Te Tiriti O Waitangi [16]

The activism and movement for tino rangatiratanga have also materialised in frameworks and research published about Te Ao and tikanga Māori (Māori customs). Examples include:

I. Decolonising methodologies by Linda Tuhiwai Smith [49] on the challenges and significance of indigenous knowledge and research from a Māori perspective.
II. Mauri-o-meter by Kepa Morgan [43] for evaluating the impact of activities on well-being (refer to The Mauri Model, in section 4.1).
III. He Awa Whiria, by Angus MacFarlane, Sonja MacFarlane, and Gail Gillon [50] as the braided rivers approach to collaborate between different knowledge systems.
IV. He ara Waiora [51] developed for the New Zealand Tax Working Group as a starting point for a tikanga based framework.
V. The Rauora Indigenous Worldview Framework by Ihirangi [52] for Aotearoa New Zealand's first climate adaptation plan.

There is evidence that mātauranga (knowledge) and tikanga practices in these frameworks have been adopted into national and local plans, such as Te Tāruke-ā-Tāwhiri: Auckland's Climate Plan [53] which models how the principles of Te Tiriti O Waitangi are used in local governance. The goal of the climate plan was to incorporate mātauranga Māori and Te Ao Māori principles to respond to climate change and the city's sustainability. For example, the method uses an Indigenous framework based on the four pou (posts or support) that acknowledge interdependent relationships with nature: whare (housing), wai (water), whenua (land or ground), kai (sustenance such as food or water). Harmsworth et al. [54] has also published an extensive list of various Māori-based frameworks, assessment and evaluation tools, and collaborative processes used for freshwater management across the country. The authors model for an international audience that successful collaboration with Indigenous peoples from the outset will build capacity for both the local group and the government and lead to successful collaboration provided that it is adequately resourced and evaluated over a long time (>~3 years).

In summary, even though the bicultural identity is emerging within Aotearoa New Zealand policies and political discourse, care is needed to ensure that the integrity of Indigenous knowledge is not distorted through superficial or tokenistic use [55–57]. Involvement of iwi (tribe), hapū (subtribe), and whānau (family) in policy design, decision, and delivery process are critical for tino rangatiratanga [58].

2. Methodology

A meta-synthesis was undertaken to explore the concept of sustainability and sustainable development within the space sector. To ensure a wide range of factors were captured, a conceptual framework was used to facilitate a global literature review where key phrases such as "space and sustainability" were used in conjunction with the six PESTLE categories, as shown in Fig. 1.

PESTLE (also known as PEST or PESTEL) is an acronym for a conceptual framing commonly used in foresight work to categorise macro-environmental factors. Searches are done within six domains – Political, Economic, Social, Technological, Legal and Environmental. There are variations of this framework to include other categories e.g., STEEPLE which in addition includes Ethics as separate category. In all cases, the value of these frameworks is that they can help discover factors in areas that would not ordinarily be considered.

As such, PESTLE has been used in wide range of sustainability studies as an analytical framework or as a comprehensive way of understanding various perspectives across different domains for an issue [59–61].

The scope of literature searches within each of the PESTLE categories for this paper are summarised below:

3. Literature review

This paper focuses on the key issues related to space and sustainability for Aotearoa New Zealand, guided by understanding the emergence of the term *sustainability* and the drivers that influenced its evolution. These understandings were then applied to the Aotearoa New Zealand space sector to highlight the tensions and tradeoffs that key actors might need to consider for sustainability strategies.

3.1. Origins of modern-day environmental and sustainability movements

The second half of the 20th Century, post-World War II, saw the rise of economic development and growth as a policy goal [9]. It promoted optimism as progress raised living standards and affluence, but also a realisation of the wealth gap between developed and developing nations. There was a growing recognition and concern about the damage scientific and technological progress and industrial expansion was having on the natural environment by the 1960s [62]. Concerns related to threats from rapid population growth, pollution and resource depletion. It is highlighted in published books like Rachael Carson's 'Silent Spring' (1962), Paul R. Ehrlich's 'The Population Bomb' (1968) and work by Gareth Hardin (1968) in which the Tragedy of the Commons is discussed. From this period, we see the growth of the environmental and green movements, the rise in ecological crises related to film, media and pop music, and the establishment of non-governmental environmental groups such as Greenpeace and Friends of the Earth.

Environmental concerns grew more acute because of fear that economic growth might endanger the survival of the human race and the planet. Most notably, "The Limits to Growth (LTG)" was published by The Club of Rome in 1972 [9,63,64]. The LTG modelled the interdependency of the economy and the environment and identified the collapse of civilisation. The rapid collapse scenarios could be mitigated if technological advances and social changes could be made early enough [65]. The LTG model ran counter to an expansionist vision of space encapsulated in Nikolai Kardashev's three stages of evolution: 1. use of an entire planet's energy; 2. use of an entire solar system's energy; and 3. use of an entire galaxy's energy. The Kardashev scale [66] was

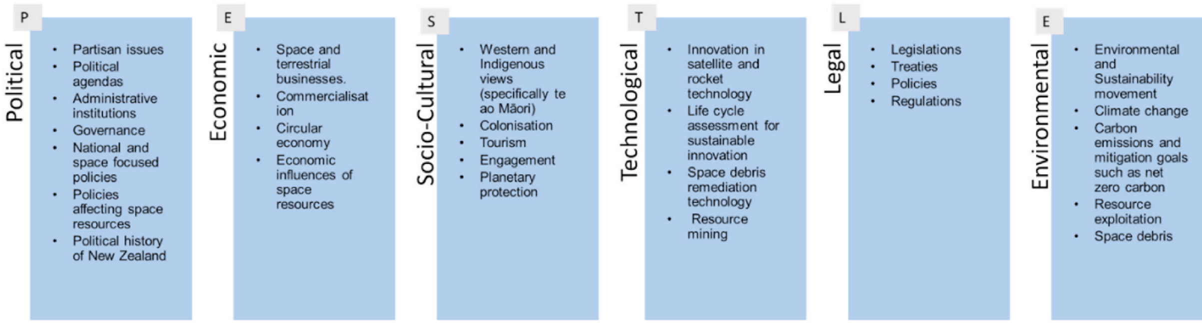


Fig. 1. PESTLE categories and the relevant search terms.

widely taken up in the science and science fiction communities. It presumed that because solar energy was limitless, so too could the growth of human economies.

At the same time, other authors had a more optimistic outlook for the future. Barbara Ward [67] prompted readers to consider the planet as 'Spaceship Earth' from a preservationist perspective. Survivability depends on considering all societies as one system acting on the principle of collective self-interest, a holistic earth system that is a self-regulating and self-preserving closed-loop system known as Gaia [68]. These perspectives of a preservationist approach to sustainability are essential to understanding the values driving the sustainability movement. The term sustainability was also then used by the International Union of Conservation of Nature (IUCN), the United Nations Environment Programme (UNEP), and the formerly known Worldwide Fund (WWF) by the 1980s [9].

Kuhlman & Farrington [63] suggested that The United Nations responded to the LTG report by establishing the Brundtland Commission in 1982 and the 'Our Common Future" report in 1987. The purpose of the Brundtland Commission report was to propose strategies that would encourage international cooperation to bring about change and sustainable development [2]. The report highlights the frustration amongst the international community about environmental degradation and the associated economic and social issues. The Brundtland Commission report was widely credited with showing that resources could be managed to bring about intergenerational equity [9,63]. It defined sustainability as,

> "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [2].

Since the 1980s, the issues that sparked debate and public attention about sustainability continued through to the UN Conference of Environment and Development (UNCED) in 1992, otherwise known as The Earth Summit [64,69]. The Brundtland Commission report [2] identified that sustainability was not limited to just environmental issues but would be a compromise between the environment and development (ambitions, actions and needs) that would improve the status quo. Decisions for sustainability would be a compromise; more often not, economic and politically powerful countries would hold that responsibility. The term was a tradeoff between environmental preservation and economic development, understanding that an anthropocentric view was imperative for growth [62]. One argument was that the issue with the commons was driven by the western values of political and economic capitalism [70] and that the idea of sustainable development is an oxymoron that market economics imposed on the global environment [71,72]. Consequently, some limitations bound economic development when environmental protection is also an objective [73], and raises the question: how important is the natural environment?

3.2. Intersection of space and sustainability

3.2.1. Geopolitical drivers for space and sustainability

Sustainability in the context of space could be argued to have started with the launch of the Soviet Union's Satellite Sputnik in 1957, in the middle of the Cold War. Due to the political and military tensions of the period, the launch spurred the UN to form the Committee on the Peaceful Uses of Outer Space (COPUOS) in 1958 to facilitate international cooperation in outer space [74].

Following the launch, space issues primarily focused on safe and open access to space for much of the twentieth Century through international treaties and principles:

1. The Outer Space Treaty (1967): Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies
2. The Rescue Treaty (1968): Agreement on the Rescue of Astronauts, the Return of Astronauts, and the Return of Objects Launched into Outer Space
3. The Liability Treaty (1972): Convention on International Liability for Damage Caused by Space Objects
4. The Registration Convention (1975): convention on Registration of Objects Launched into Outer Space
5. The Moon Agreement (1984): Agreement Governing the Activities of States on the Moon and Other Celestial Bodies [75].

An ongoing challenge for any international treaty or legislation, and crucially for understanding sustainability in the context of space, is that no globally accepted boundary separates a country's airspace from outer space. There are several arguments that make it a complicated geopolitical issue for international lawyers to determine where national exclusivity of space ends [76]. Lal and Nightingale's [3] review of internationally used boundaries places 80 km above mean sea level as the lowest altitude used by NASA and the US Military. McDowell [4] agrees that the delineation of space starts nearer to 80 km above the Earth rather than the Karman line at 100 km. These arguments expand on why space needs to be demarcated in Table 1.

An example of geopolitical challenges comes from the international community's failure to recognise the Bogotá Declaration[4] of 1976, where the equatorial countries of Brazil, Colombia, Congo, Ecuador, Indonesia, Kenya, Uganda, and Zaire claimed sovereignty over the GEO territories above their countries' marked airspace [77]. The most considerable contention to the Bogotá Declaration was from the western industrial powers of the 1970s and demonstrates how space powers and dominating actors influence space law [76].

Aotearoa New Zealand's approach to defining outer space is not necessarily straightforward as legislation for *space* activities are enacted at altitudes above flight level 600 (approximately 18,288 m) and above the upper limit of controlled airspace [78,79]. However, the Outer Space and High-altitudes Activity Act 2017 does not define outer space as it

[4] The 1976 Bogotá Declaration was signed by seven equatorial countries to extend their territorial airspace into geosynchronous orbit. The Bogotá Declaration has been seen as contradicting the 'non-appropriation' aspect of the Outer Space Treaty [2].

does for high-altitude activities [78]. Operating in the New Space environment requires boundaries for space sustainability activities (local, national, global, solar system) to inform key decision makers nationally about the values and geopolitical tensions that need to be considered for national space sustainability strategies. Therefore, solving the demarcation issue requisites a transdisciplinary approach by actors within space policy, politics, law, science, and technology. The need for boundaries might only heighten as national sovereignty is threatened as the space sector grows [80].

3.3.2. Environmental drivers for space and sustainability

Broader sustainability concerns for the space environment emerged around the same time as the concept of terrestrial sustainability was growing. Donald J. Kessler and Burton G. Cour-Palais published an article in 1978 warning about the effects of the satellite environment and the effects of space debris. Earth orbits populated with space debris over time, and the risk of cascading collision between existing debris leads to a situation known as the Kessler Syndrome. Even though space debris was communicated as an issue in 1988 by the Brundtland Report [2], debris mitigation guidelines did not start to develop till 1993 [81]. However, as discussed by the UN report above, space debris is only one aspect of the space sustainability conversation. Simpson et al. [64] argued that sustainability varies universally; therefore, there is no universally accepted definition of "Space Sustainability" due to cultural, conceptual, linguistic and developmental differences. Thus, the UN COPOUS has a broad definition that they have adopted and established the Long-Term Sustainability (LTS) to provide some international voluntary guidelines.

> *"[…] the ability to maintain the conduct of space activities indefinitely into the future in a manner that realises the objectives of equitable access to the benefits of the exploration and use of outer space for peaceful purposes, in order to meet the needs of the present generations while preserving the outer space environment for future generations."* [82]

A recent UN report on 50 international stakeholders summarised space sustainability and the issues for the future as:

- Environmental sustainability
- Sustainability of near-earth environments
- Sustainability of celestial bodies
- Sustainability of socio-economic growth
- Economic sustainability of outer space
  - o Cost of entry into the market
  - o Lack of capacity-building options for an emerging sector
  - o Economic self-sustaining sectors for emerging nations
- Political sustainability of outer space
- Global political climates
- Space safety and security [83].

The OECD paper on Space Sustainability [8] acknowledged that "space sustainability" has a much broader scope than the definition provided by the UN COPOUS. This could include environmental, social, employment, and economic dimensions. It highlights why a transdisciplinary approach to exploring sustainability and sustainable development of the space sector is needed to identify a range of issues, risks and opportunities. It is a starting point to develop a definitional frame of reference.

3.2.3. Cultural drivers for space and sustainability

Commercial risks have already been clearly identified, but many more aspects must be considered. Culturally, for example, many Indigenous groups, including Māori, consider the sky a sacred place [17]. Those values and world views can be adversely impacted by the increase in the number of satellites, accumulation of space debris and light pollution [84]. Furthermore, the environmental geopolitics of outer space requires conversations about territories, power imbalances, and how knowledge is utilised [85] There are also strong tensions between the importance of the values that drive decisions and if priorities are not explicitly discussed, it leads to more significant misunderstandings and conflicts [86]. Aotearoa New Zealand's push for increasing launch capacity comes when per capita greenhouse gas emissions are amongst the highest in the OECD [18].

Suppose the space sector prioritises economic gain and capitalistic values as primary importance. In that case, it fails to realise the value in wellbeing, natural resources, and living systems [46]. The perspectives and knowledge systems of Māori can be brought into the process through taking a meaningful partnership approach, which means working together to determine issues and develop solutions. This is to honour Treaty obligations but also to ensure that the integrity of Māori knowledge is not distorted. This approach is important as it helps build consensus on the issues, risks and uncertainties and develop shared visions of a preferable future. A common goal relevant key actors are working towards can empower people as they have a voice in making decisions. The success of a Māori-informed design process in Aotearoa New Zealand should safeguard that engagement is not just for consultation but partnership [58]. Therefore, the decision-making power for the growth of the space sector should see that Māori are also actively part of the process for its long-term sustainability. The approach also shows that it is possible to involve key actors from different epistemologies that co-generate a valid sustainable development strategy. In practice, the involvement of Māori needs to extend from consultation to partnered experimentation [87].

The most privileged countries and commercial industries have emerged as spacefaring nations racing to occupy space [88]. Therefore, how do these institutions and key actors ensure that Indigenous and disenfranchised groups of people that find outer space sacred are not adversely impacted by colonisation and exploitation of space as is the goal of many Western-led space initiatives. The widespread failure to honour colonial treaties perpetuates the scarcity-based mindset pushing for a first come - first claim strategy [84]. The lack of genuine dialogue and meaningful engagement translates into a western perspective in policies and decisions domineering for the space sector.

While Indigenous people are often framed as the beneficiaries of satellite technologies, typically telecommunications and Earth observation, the rarely articulated assumption that satellite services provide solutions to inequalities created by colonial processes ignores the fact that Indigenous groups are largely absent from decision-making about space resources. This has been reported on by an Independent Group of Working Astronomers [89] and by Neilson and Ćirković [90] in response to the Canadian Space Agency's space exploration strategy. Therefore, space faring nations and private actors occupying space need to consider which paradigm is more acceptable to address the sustainable development of space [11]?

4. Discussion

Acknowledging the prevailing tension concerning power dynamics when contrasting or integrating knowledge systems is imperative. This is because, often, one system is dominant, and the other is marginalised. Treating both knowledge systems as equal in terms of credibility would overlook the inherent complexities at their nexus. This tension is often described as an 'inclusion' vs 'decentring' problem, where the latter considers the power inequalities in any relationship, while the former does not.

As such, any reader needs to consider such power dynamics when interpreting the discussion below. Additionally, it is acknowledged that this review suggests a course of action, focused more on decentring, to understand and compensate for the dominant Western knowledge systems in place. The recommendations made in this review are explicit: refusing to move from hegemonic approaches not only continues the marginalisation of other voices and frameworks but denies the possibility of better outcomes.

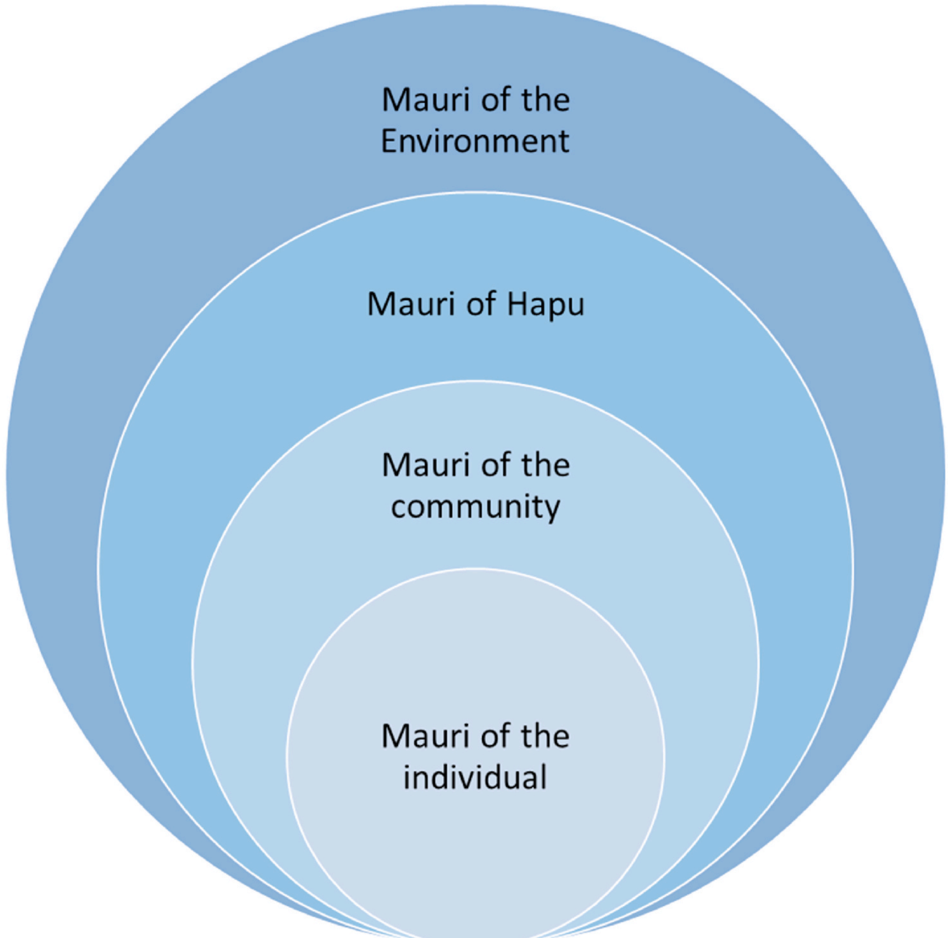


Fig. 2. The Mauri Model of sustainable development [43].

4.1. Paradigms of sustainability

Sustainable space sector development requires collaboration across many disciplines and knowledge systems to recognise relevant problems and design effective solutions [91]. One objective is to accommodate the different ways of conceptualising sustainability driven by differences in values, e.g., political, economic, ethical, and philosophical. It is important to consider those differences and identify and explore their assumptions because they influence what society values and ultimately will have consequences for the health and wellbeing of the environment and people. This informs the space sector whether certain actions are sustainable for the long-term use of space.

Another objective would be to determine the scale of sustainability as Aotearoa New Zealand's space sector must reconcile sustainable development concerning its local, regional, national, and bicultural obligations whilst also meeting international treaty requirements[5] [92]. For example, the scale of sustainability will require defined boundaries before future challenges like mining asteroids confront sustainability debates [18].

In the sustainable development discussion, the environment and commonly available natural resources are expressed as markets and prices [71]. However, there are disciplinary differences in the interpretations of sustainability and conceptual disagreements due to the models relevant for exploring sustainability and the philosophical and ethical values that guide the interpretations [73]. One example is the categorisation of weak and strong sustainability measured using the idea of capital, assets, or wealth [63,73,93].

Weak sustainability is based on economic value principles, where natural capital is not important as it can be substituted with human-made capital or rely on technological advancements to mitigate negative impacts. In such a system, consumption must be constant over time, so the sum of natural and human-made capital must remain intact. Strong sustainability, however, is based on ecological principles that emphasise the environment and natural capital. For sustainable development for the next generation, natural and man-made capital must remain intact [63,73,93]. Ang and Van Passel [93] highlighted the limitations of the weak-strong sustainability argument with the use of the term capital and the capitalistic view of nature brought on by a needs-based perspective. A generation's needs can change, influencing economic markets; however, Redclift [71] argued that sustainable development discussions have shifted from addressing the needs of a generation to the rights of a generation.

The discourse about sustainability is about power, distribution of wealth, and equity. These interpretations show that the difference in opinion determines the value of what a sustainable space sector could and should look like. This paper proposes strong and weak sustainability as a starting point for discussions about space sustainability.

Sustainability can be described as an 'ultimate' societal value, where species and environmental protection are the most important [11]. For example, individual wants and needs are influenced by the economic structures and processes they experience. They can be different to the values that count in society to preserve ecosystems and biodiversity. These tensions make it challenging to live in societies where competing values force decisions between limited resources; the tradeoffs between environmental protection and economic prosperity can often seem

[5] See section 3.2 for a list of international treaties.

Table 1
Arguments for and against the demarcation of space [3,76].

Space should be demarcated	Space does not need demarcation
• The altitude limit for sovereignty • Increased traffic from spacecraft launches • Understanding innocent passage limitations from countries that are not peaceful with each other	• It is scientifically challenging to define a precise altitude • The growth of space activities has not been affected by a lack of definition • The current space treaties in play do not clarify the boundary at which they apply

conflicting [86]. One example of value-driven sustainability plans on the global stage was the Millennium Development Goals (MDG). At the start of the Millennium, the United Nations set eight international MDGs, including several targets to reduce or eradicate extreme poverty and its effects – ensuring environmental sustainability. The General Assembly established these goals on values such as freedom, equality, solidarity, tolerance, respect for nature, and shared responsibility [86]. The MDGs have since been updated to the Sustainable Development Goals (SDGs) with 17 new United Nations approved goals between 2015 and 2030 [94]. It is interesting to note that the sustainability of the space sector has not been an issue that has captured the attention of policymakers at this level. While the space sector is considered critical to achieving the SDGs [95], it has not been the subject of similar scrutiny.

Sustainable development has been operationalised in many ways, one example being the three interdependent 'pillars' or 'domains' [9,63] – see Table 2. It is the intersection between social, economic, and environmental tradeoffs. Other similar models also include cultural and political (or governance) pillars that could aid in understanding sustainability as a measure of the wellbeing of future generations [63,96]. In Aotearoa New Zealand, cultural wellbeing is tied to the Crown's treaty obligations. It can explain behaviour, what they find desirable, and how people derive meaning from their place in their environment [97]. Watene and Yap [42] emphasised that sustainable development often excludes culture and its value for Indigenous peoples and their survival. This contrasts with the value of culture, which is often seen as a commodity and measured by profitability in aspects like tourism, cultural performances, and art [46].

Fig. 2 visualises the Mauri Model developed by Kepa Morgan for the region of Tauranga, Aotearoa New Zealand and uses the region's values for water management [43]. The model informs an evaluation tool to assess how actions impact the mauri of each domain to determine if a rāhui (prohibition) is placed on an area or a resource that is under threat. This is an example of a strong sustainability model that the space sector could use to explore the sustainable development narrative [98].

One difference between the three pillars of sustainability commonly used in the western narrative (refer to Table 2), is that the mauri model considers the wellbeing of the various aspects and embeds the value of culture. The mauri of the environment is prioritised over the hapū, community or the individual, demonstrating the relationship with the environment due to its mana (prestige) [43]. The second difference is a definitional conflict between the nature of sustainability and sustainable development. Ruwhiu et al. [45] argued that the western view of sustainability is anthropocentric at its core and will still allow exploitation for economic gain. Economic growth highlights sustainable development, whereas a Māori perspective considers the effect on the interdependent human nature of relationships. The absence of economic advantage with the mauri model creates tension for Aotearoa New Zealand's space sector, given that it is commercially focused.

It can be inferred from Fig. 2 that when natural resources and the environment are not looked after, their mauri is weakened. This directly impacts cultural wellbeing, mental health, and wellbeing, ultimately affecting economic wellbeing, and in this case, a healthy space sector. The interconnectedness of the domains of wellbeing represents a holistic systems approach and highlights the broader impacts of our activities. There are noticeable differences between two models shown in Table 2 and serves as a reminder that our understanding of sustainability is based on our understanding of terrestrial environments. The diagram reinforces the need for transdisciplinary systems thinking, cultural perspectives, and expertise to propose a better model. If a strong sustainability approach is required, the mauri model prompts key actors to consider if Aotearoa New Zealand is prepared to prioritise the mauri of the space environment over the mauri of the various communities that interact within it.

Sustainability and sustainable development are complex, but the definitional frame, driving values, and scale of sustainability can establish how we conceptualise and operationalise it. Barnes et al. [100] emphasises that such complexity requires respectful integrative teams and the investment of time and resources to explore such issues.

4.2. The role of the transdisciplinary approach to sustainable development challenges in the space sector

Since key actors will need to accommodate the scale and the values driving sustainable development, the ideal vision of sustainability could shift over time to reflect any changes to the values or the boundaries of space. In this scenario, sustainable development is not an end goal of a fixed state but rather a dynamic trajectory, where the edge of a sustainable space ecosystem continues to evolve as information, and technological changes are acquired [101]. A transdisciplinary approach to sustainable development empowers experts of various knowledge systems to bring relevant information and technological changes to the decision-making process.

A recent Finnish-based study on the sustainable use of space highlighted the lack of transdisciplinary perspectives to address the challenges within the space sustainability discourse [102]. This is despite sustainability literature showing that there is a need for a transdisciplinary and systems-based strategy to shed light on the issues, the values driving change and propose action to address these issues [87,91,98,96,100,102,103]. A transdisciplinary approach to outer space challenges allows for Indigenous knowledge systems to be integrated [100] and promotes reflection to see realities from various perspectives [96]. Integration of critical arguments and perspectives from multiple knowledge systems will add to the complexity of outer space discourse, but its synthesis will allow for a continuous process of transforming behaviour, policy, relationships, and the identification of limitations [98,103]. An indigenous epistemology provides a framework for collaborating across disciplines because its practice is embedded in intergenerational self-determination and interconnections between the people, environment, and the larger community [100].

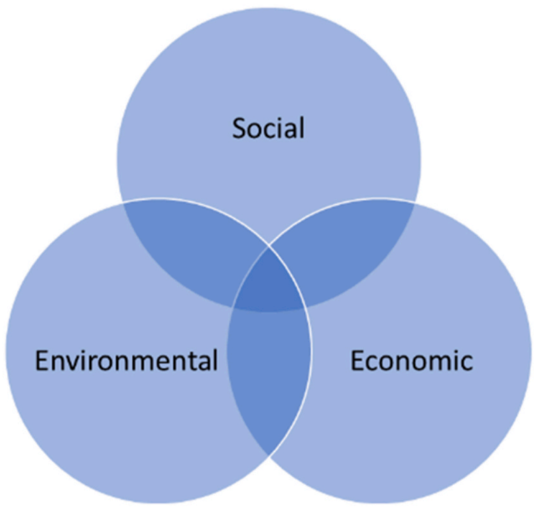
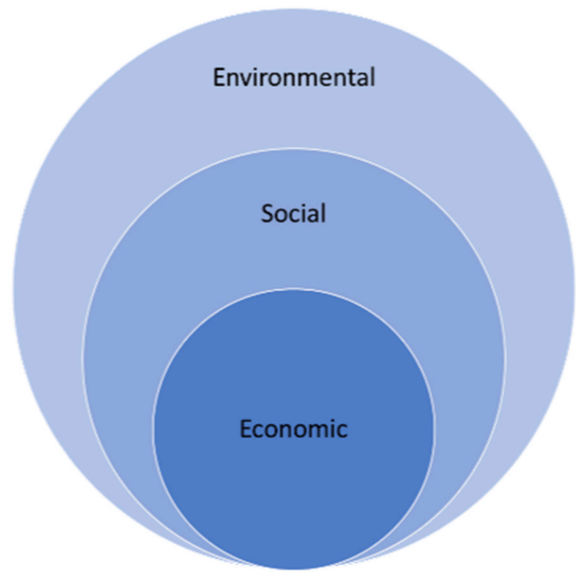
4.3. Space for terrestrial sustainability

One of the common areas of discussion around sustainability in space is how space can be used to promote terrestrial sustainability. In this argument for sustainability, outer space use will be utilitarian to an extent, and it would be challenging to consider any policy or strategies for a sustainable space sector as entirely anthropocentric or eco-centric [104].

The need for terrestrial sustainability, inspired by the start of the space exploration age, led to the first images of Earth as a floating speck in space. Klinger [85] describes the emergence of 'Spaceship Earth' post the Cold War era as the start of environmental geopolitics. The image *Earthrise* was taken in 1968, and *The Blue Marble* was shot in 1972, perhaps also playing a role in influencing the environmental movement. The image serves as an icon for preservationist environmentalism and challenges the ideas of sustainability in terms of boundaries and the need for balance [92] Images like Figs. 3 and 4 also initiated dialogue about the vulnerability of Earth to anthropogenic activity and the investment required to manage the changing climate [85].

Using outer space for Earth observation has become a vehicle to manage terrestrial sustainability. Satellite use reduces the need for

Table 2
Models of sustainability from a terrestrial perspective, including some considerations for how those might be understood and framed from a space environment perspective.

	Weak Sustainability	Strong Sustainability
Key idea [63,73, 93]	Natural capital and other types of capital (manufactured etc.) are perfectly substitutable	The substitutability of natural capital by other types of capital is severely limited
Key concept	Optimal allocation of scarce resources	Critical natural capital
Sustainability issue [98]	The total value of the aggregate capital stock should be at least maintained or increased for future generations.	Conserving the irreplaceable "stocks" of critical natural capital for the sake of future generations.
	Economy, environment and social themes have equal weighting. A balance is sought between the three. The economy can exist outside of environmental and social constraints	Economy, environment and social themes are given different weightings. The environment is given the greatest weighting, indicating that nothing can develop outside of the biosphere.
Examples of sustainability models [98]		
Definitions of thresholds and environmental norms	Technical/scientific approach for determining thresholds and norms (instrumental rationality)	Scientific knowledge as input for public deliberation (procedural rationality)
Who would provide definitions of thresholds and environmental norms for the space environment	Stakeholders who are directly or indirectly supporting the space sector, such as those defined by Deloitte's 2019 report on the New Zealand space economy – space manufacturing, space operations, space applications, ancillary services, research & development, Government	A broad range of transdisciplinary stakeholders – from different industry sectors, universities, public sector, independent regulatory bodies, e.g., Privacy Commission, Indigenous experts, and non-space sectors
Location of space environment	Any activities on planetary bodies and their surfaces, subsurfaces, atmospheres orbital environments including Lagrange points, comets and asteroids, and transit routes between space destinations[a]	

[a] This has been based and modified from the Artemis Accords – Principles for cooperation in the civil exploration and use of the Moon, Mars, comets, and asteroids for peaceful purposes [99].

infrastructure on Earth and provides cost-effective options for increased global connectivity and accurate monitoring services [14]. Trends in the Earth observation global markets show that defence and intelligence-based markets are driving the need for high-resolution data [14]. The derived data is becoming increasingly important for managing natural resources, informing industries like the agricultural sector in the face of climate-related challenges, and monitoring environmental policy compliance [14,107]. This includes weather monitoring, climate disasters, warning systems and rapid response capabilities to environmental and social challenges, and telecommunication, broadcasting, and navigation [14,108]. For example, Aotearoa New Zealand's first Government funded space mission, MethaneSAT, is part of a global collaboration detecting methane emissions [109]. Additionally, the UN COPUOS has also established expert groups to provide guidelines on how space can be utilised sustainably to support sustainable development on Earth [110].

The increased number of satellites for remote sensing and Earth observations has led to issues such as radio and other spectrum interference, orbital crowding, privacy and surveillance, and competition with established space operators [108].

4.4. *Terrestrial sustainability: an Aotearoa New Zealand perspective*

A conceptual paper by Kennedy et al. [44] on the sustainability paradigms showed that in Te Ao Māori, the idea of sustainability is not a process rooted in an extractive economy, as also described in the Ihirangi report [40]. Kennedy et al. [44] explained the differences in the definition of Māori and the western view; it is the way of being that promotes intergeneration equity, enables the survival of Te Ao Māori, and is passed down through their tikanga (practices). The Brundtland report [2], representing the western perspective, on the other hand, states that, "Sustainability ensures that social and natural environments are protected or improved to provide intergenerational equity at the very least."

Aotearoa New Zealand was also a part of the Rio Earth Summit of

Fig. 3. Earth Rise image taken on the Apollo 8 Mission in 1968 [105].

Fig. 4. The Blue Marble image taken on the Apollo 17 Mission in 1972 [106] (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

1992, where the principles of 'Agenda 21'[6] were developed as a part of a formal acceptance of sustainable development. The country adopted Agenda 21; however, the Parliamentary Commissioner for the environment [111] reported that the effort to meet the commitments before the 2000s was weak. The same report identified sustainable development barriers to the progress of sustainable development, which included:

I) Resources
II) lack of understanding
III) unwillingness to commit to long-term plans
IV) other priorities

These barriers present a point of tension for sustainable development as environmental preservation in Aotearoa New Zealand has economic value. The Ministry for the Environment commissioned a report in 2001 [112] that showed that the dairy and agricultural exports earned NZD 5 billion in 2000 due to Aotearoa New Zealand's reputation for being environmentally unpolluted. This reputation portrays strong environmental values, a place with no environmental degradation, and high environmental quality.

In 2017, the OECD still identified New Zealand's natural environment as an economic asset associated with good quality of life and low pollution levels. Aotearoa New Zealand has presented itself as a 'clean and green' nation, which has been vital in marketing its environmental image to the international world [112]. In 2009, the country introduced a '100% PURE NEW ZEALAND' brand strategy to promote the 'clean and green' image internationally for foreign investors and export markets [18]. This might have been credible in the 1990s; however, there have been more reports of polluted waterways, farming lobbyists interference with governments, nitrate runoff, and increasing greenhouse gas emissions since then [18]. Aotearoa New Zealand's foremost environmental challenges are climate change and managing greenhouse gas (GHG) emissions, air quality, waste management, and biodiversity conservation [113,114].

The Resource Management Act – RMA (1991) was Aotearoa New Zealand's earliest response to sustainable development [115]. The legislation intended to manage the environment and resources: land, water, and airspace, even over coastal and marine areas [116]. *Airspace* over the areas, however, is not defined as a certain altitude. The Act's purpose was to ensure that the development of resources in Aotearoa New Zealand was sustainable and protected for future generations (ibid.). The RMA was a vital tool for implementing sustainable development in Aotearoa New Zealand. Some key actors, however, saw it as a hurdle or a learning curve to introducing sustainability concepts [111]. Former Prime Minister for New Zealand, Geoffrey Palmer [116] observed that the central Government failed to implement effective legislation due to policy negligence, leaving environmental issues to be resolved by market powers and the political influence of well-resourced lobby groups. It calls to attention the struggle Aotearoa New Zealand already must reconcile economic growth and environmental preservation and, therefore, evident that a value-based hierarchy determines drivers and behaviours for economic development [11].

The Government also published the Programme of Action report in 2003 [117] to highlight the institution's role in Aotearoa New Zealand's sustainable development and positive policy outcomes over the long term.

An early New Zealand definition for sustainable development includes:

- management of natural and physical resources
- safeguarding the life-supporting capacities of the environment
- taking account of the social, economic, and cultural wellbeing of communities
- accounting for the needs of future generations (Parliamentary Commissioner for the Environment, 2002)

The OECD reminded New Zealand that their recommendations from the 2007 Environment Performance Review remained unaddressed, per the 2017 report [113]. These areas included hazardous waste management, compliance assurance, and liability for environmental damage.

The Ministry for the Environment announced that the RMA is to be replaced with three pieces of legislation Natural and Built Environments Act (NBA), the Strategic Planning Act (SPA), and Climate Adaptation Act (CAA). The new legislation would be a better system as it would reduce costs, time, and complexity of managing resources for future generations [118].

4.4.1. *The business sustainability movement*

The economy plays a crucial role in managing sustainability

[6] Agenda 21 is a non-binding plan adopted by 178 governments to meet the challenges of sustainable development [154].

objectives. Since the NZSA is a subdivision of MBIE, there is a strong business case for the development of the space economy. If business and the private market are driving the space economy, the question is if Aotearoa New Zealand's businesses have a track record for sustainable development. Is there enough dissatisfaction amongst the Government and private companies with the status quo to warrant a shift to a sustainable future?

An occasional paper by MBIE in 2021 showed a growing interest for the Government to spearhead mandatory sustainability reporting regimes to demonstrate the link between strategy and commitment toward a sustainable economy [119]. The paper highlighted that Māori trusts and businesses already reported how sustainable management of resources economically benefits the community. However, this reporting standard has not been replicated across the country's economy.

Aotearoa New Zealand's political system adopts free-market values and generally avoids government intervention to foster a competitive space market [120]. As the NZSA is a division within MBIE, the Government signals a strong business case for the space sector. A 2019 review on New Zealand's Space Economy, commissioned by MBIE, reported that even though the sector was at the early stages of development, it generated NZD 1.75 billion per year in revenue (2019 value), representing 0.5% of the economy and 0.27% of the global space economy [19]. Growth is expected to continue if the Government continues to incentivise and enable growth through regulations, funding, and infrastructure support [121]. The space sector operating in a free-market environment can simultaneously accomplish sustainable development according to an international Harvard study conducted in 2004 on sustainability values, attitudes, and behaviour. The study indicated that sustainable development must be achieved within a free market economic system [86].

Aotearoa New Zealand's businesses can communicate about sustainability in a few different ways, such as the Fairtrade mark, B-Corp or Toitū certification [119]. For example, The B-Corp sustainable business certification started in 2006 and has gained prominence as the movement that rates companies based on social and environmental performance, accountability, and transparency [122]. Certified companies are models that meet the highest standards of corporate responsibility. However, a consistent sustainability strategy could strengthen the commitment to sustainable development across many Government institutions and not be restricted to a siloed approach for just the space sector. Giovannoni and Fabietti [123] explained that sustainability in the business sector is not an individualistic goal based on one-off actions but an integrated effort across social, environmental, and financial factors. A unified strategy across institutions presents an opportunity to manage compliance and monitoring of sustainable development goals that might be outside the boundary of the aerospace sector in Aotearoa New Zealand.

Sustainable reporting is one tool that encompasses all businesses that participate in the financial market [119]. Internationally, the need for reporting has been driven by laws, regulations, and growing pressures in the business sector about considering sustainability or Environmental, Social and Governance (ESG) performance [124]. Reporting is in the company's best interest and can influence investors when there is evidence of SDGs to increase revenue or better their supply chain and talent pool [125]. However, sustainability and business strategies need to be integrated for a sustainable business model that is effective [123]. A KPMG survey [124] showed that reporting about sustainability issues (ESG) is a global norm and signals responsible behaviour to the consumer and the rest of society. The report sampled the top 100 companies operating in various countries and compared reporting behaviour. Only 69% of New Zealand's companies had a sustainability reporting system, lower than the global average. It is vastly different compared to countries like Australia (92%), the United Kingdom (94%) and Canada (92%).

It should be noted that MBIE reported in 2020, 97% of the firms operating in New Zealand were small or micro businesses with 0–20 employees [126]. The country has no mandated reporting requirements for ESG factors; however, the public sector will now be required to report emission reduction targets publicly and plans to make government initiatives carbon neutral by 2025 [119]. The Government was already aware that the business sector had not adopted sustainable business practices seen internationally as early as the 2000s [117]. Therefore, the KPMG survey [124] highlights that nearly 20 years later, New Zealand businesses are not keeping pace with the rest of the world on practices that would improve sustainable development. The emerging nature of Aotearoa New Zealand's space sector provides an opportunity to include consistent sustainability reporting measures that align with the strategic goal of sustainable development.

4.5. Sustainability of space

Newman and Williamson's [127] analysis of space sustainability shows that *sustainability* evolved as different drivers acted in the space sector. It shifted from hardware reliability at the start of the space race to managing funding streams following the peak of lunar explorations. Current sustainability issues concerning the space sector include:

- More intensive use of certain earth orbits (Movement of telecommunications satellites from GEO to LEO)
- Growing demand for radio frequency spectrum and the increased risk of interference
- Accumulation of orbital debris [8].

The most common space sustainability aspect seen in literature is space debris [8,128–132]. The Inter-Agency Space Debris Coordination Committee (IADC) defined *space debris* as artificial objects that are no longer functional [133]. Non-functional objects include fragments and elements of rocket launches, de-orbiting activities, the break-up of satellites, and collisions between existing debris. Continued accumulation of debris can result in the Kessler Syndrome [134], where the space debris population is dense enough that cascading collisions could make parts of or all of Earth's orbital environment unusable [8,135]. LEOs are 1000 km above the surface and are commonly used for satellite imaging and by the International Space Station [136]. They are the most vulnerable type of orbit, and the sustainability of this orbit has been linked to space debris in several studies [128–132]. LEOs are also where many satellites work together in combinations known as constellations. Thousands more satellites are predicted to be launched as constellations by private actors like SpaceX, OneWeb, and Amazon [84]. With the rise in satellite constellations, academic literature is calling to consider the sustainability of space activity, the possible long-term effects of anthropogenic activity, and the risk of collisions [8,84,137–139].

The general guidance for space operators by the IADC is to have a management plan for space debris, including an assessment of risks, debris minimisation strategies, and end-of-mission disposal plans [133]. Long-term sustainability has gained international awareness, but Hutchison et al. [7] reported that it takes time for governments to manage and legislate space activities due to innovative changes in space technology.

A growing number of papers show that current space sustainability pressures are with space debris hindering the access and use of various Earth orbits, shown in Fig. 5.

A search performed on the Web of Science database in July 2022 using the terms "space", "sustainability" and "space debris" displayed more than 8000 publications over the eleven-year period of 2010–2021. The total number of publications in these areas has more than tripled since 2010. The top ten categories used by Web of Science to categorise publications are displayed in Fig. 5, with the top category being "Aerospace Engineering", followed by "Electrical and Electronic Engineering".

Key events also drive how *space sustainability* is perceived. For example, the launch of the Chinese Anti-satellite test used a ballistic

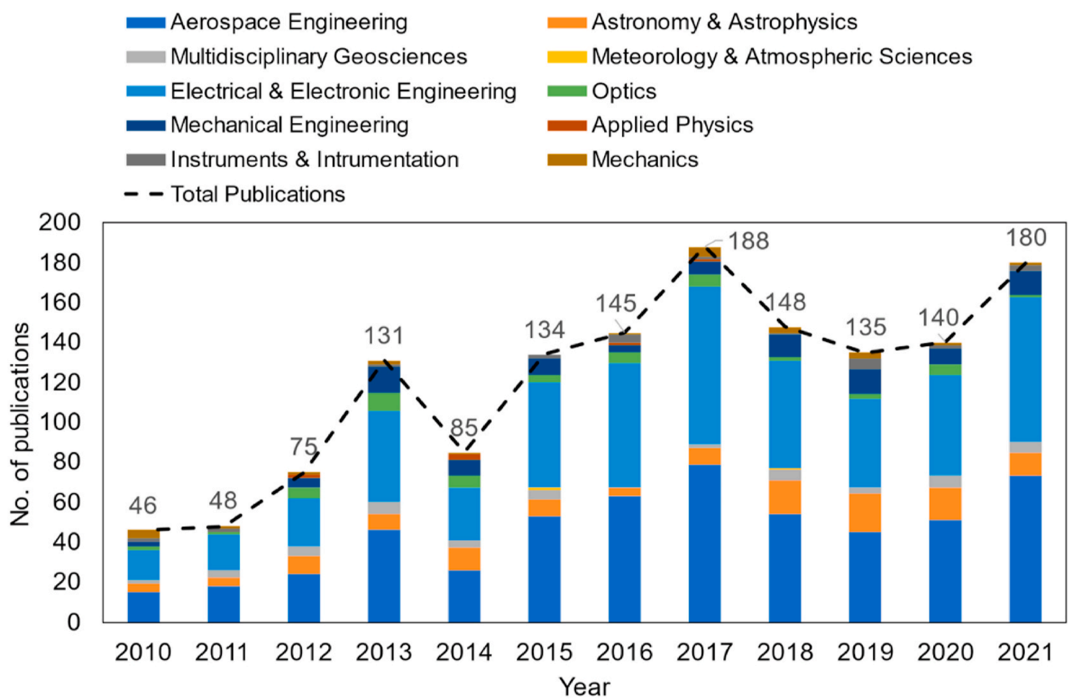


Fig. 5. Publications by year grouped by Web of Science categories, using search terms “space”, “sustainability”, and “space debris”.

missile, which generated more than 3000 pieces of debris [140]—followed by the satellite collision between Russian Cosmos 2251 and Iridium 33 in 2009. This collision created about 1300 pieces of space debris and prompted calls for the mandatory disposal of defunct satellites [8].

Given the large number of debris caused by these events, it has not slowed down the launch of satellites. New Space has increased in commercial value as it has become more accessible as launch costs have been declining by 40%, and satellite advancements can produce high-resolution data with a capacity increase of 1000 times per second [14]. As of late 2021, SpaceX had already launched around 1900 Starlink satellites as a part of its mega constellation [141]. A commentary by Neilson and Ćirković to the Canadian Space Agency defended that the light pollution from mega satellite constellations can be considered an erasure of Indigenous knowledges [90]. These launches increase the risk of damaging the space environment, especially when there is hardly any internationally coordinated regulation or ethical consideration of the future of space, with the rush to occupy and pollute these orbits [84]. The commercialisation of space will only benefit a set of wealthy entrepreneurs who want to monetise outer space or use it purely for extractive purposes [121]. Policymakers and governments would soon need to intervene to manage space commercial, civic, and military activity [138] as growing space activity highlights the parallels between exploration and colonisation of outer space to what we have seen terrestrially [121].

A recent collaboration between the World Economic Forum, the Massachusetts Institute of Technology Space Enabled Research Group, the University of Texas at Austin, the European Space Agency (ESA), and Bryce Space and Technology have proposed a Space Sustainability Rating (SSR) to be issued from 2022. SSR measures collision avoidance capabilities, trackability, and future serviceability while in orbit [131, 142]. Active debris removal (ADR) is also being explored so that existing debris can be removed, or future debris is consistently being removed [8, 142]. This could include space recycling [129] and, more specifically, a closed system [143]. ADR is currently being tested, such as Northrop Grumman's Mission Extension Vehicle-1 (MEV-1), the Japanese company Astroscale's ELSA-d project [142], and the European RemoveDEBRIS mission [142,144]. It is identified as a measure that will preserve the orbital environment, with many methods of ADR being tested on the ground [145]. Future interventions like the SSR certification and ADR technology would complement any policy intervention to slow down and reduce the amount of space debris being produced.

The priority of space debris as a sustainability challenge masks the other interrelated domains of sustainability. For example, the disregard for sustainability or Indigenous perspectives is exemplified in the launch of the 'Humanity Star'[7] by Rocket Lab from Aotearoa New Zealand or the red Tesla roadster launched by Space X, with no scientific purpose. Gorman [146] described both launches as open to interpretation; the Tesla launch could be considered Elon Musk's mid-life crisis, whereas the short-lived Humanity Star - is an artistic piece. Shammas and Holen [121] viewed the Humanity Star as a marketing stunt by a capitalist with the goal that everyone should be able to see it in the night sky. However, both launches would not be considered sustainable as defined by the Brundtland report, as there is no evidence that they have improved intergenerational equity or ensured the protection of the natural environment. Venkatesan et al. [84] and Neilson and Ćirković [90] described this type of space occupation as colonial behaviour.

Addressing space debris is a critical issue, however, a sole focus on space debris fails to bring an understanding of how it is connected to a wider space system, or even to other aspects of environmental sustainability, for e.g., launch and life-cycle emissions [147,148]. There is a need for a transdisciplinary systems-thinking approach to sustainability so that the long-term use and access of space is governed and managed responsibly.

4.6. Sustainable growth of the Aotearoa New Zealand space sector

The Treaty of Waitangi reminds the Government about the role of Māori partnerships in the decision-making process, especially when faced with such a wicked problem as the comprehension of sustainability around the space environment. It requires transformative solutions at the intersection of Indigenous knowledge, the common western

[7] The Humanity Star is a 1-m reflective satellite launched in 2018. It was in orbit for a few months and burned up on re-entry [18].

understanding of space sustainability issues, and conceptualising factors such as definitional conflicts, paradigms of sustainability, and terrestrial preservation. To avoid a situation where mātauranga Māori is retrofitted for planning and policy decisions in growing the space sector, Harmsworth and Awatere [41] visualised a Treaty-based Planning Framework (Fig. 6) for resource management.

Such a framework allows actors to weigh both Māori and western approaches equally to inform planning and policy, for e.g., of eco-system services. It is a model for key actors within the space sector that enables the shared aspects of kaitiakitanga and stewardship or sustainability. Using such a planning framework from the outset facilitates working together in a co-planning approach, acknowledging that there are also differences in the approach, and a step towards acknowledging the agreement of the Treaty [38].

The Ihirangi report [37] cautions that applying an Indigenous lens requires understanding the entire customary system rather than appropriating the most desirable values, such as kaitiakitanga, into Government policy. At the time of writing, there are no published examples of a Treaty-based planning framework in the context of the Aotearoa New Zealand space sector development. While efforts are underway to begin the discourse, such as the Tāwhaki Joint Venture [149]these are not the norm within the space industry, nor reflect a consistent approach across the NZSA or MBIE's space activities. This reveals a gap in the sector's development, where there is a critical need for a Treaty-based planning framework that enables tino rangatiratanga, for Māori to exercise their obligations towards culture, customs, and beliefs, including kaitiakitanga.

Once the framework for the sector's growth has been defined, the space sector would also look to the economic benefits it brings to the country (see Section 4.4.1). Lisk and de Zwart [20] compared Australian and New Zealand space sectors and showed that both countries are staying "on-trend"; by fostering the commercial space services sector. However, each country has different approaches to supporting new business models, keeping up with evolving technology, and costs imposed on the operators. Aotearoa New Zealand is an example of where New Space is heading and creates an entryway for private actors to commercialise the space sector. As there is a strong focus on commercialising the space sector, sustainable development extends to space manufacturing, applications, research, and development. The economic landscape is changing as more private actors enter space-based activities. Therefore, another aspect of sustainability to consider is the long-term viability of the space industry. The NZSA acts as a purely regulatory body and prefers large, competitive, and established companies that are likely to succeed when launched from Aotearoa New Zealand [120]. The current capacity of the sector to only accommodate established companies could also double as a limiting factor, which could pose a threat to the sustainable development of the space sector.

Aotearoa New Zealand is establishing its niche within the industry by capitalising on the growth of the space sector whilst also managing its national goals. The development of space services and innovations has made the satellite industry invaluable for telecommunication, navigation, remote sensing, and national security [7]. Operators like Rocket Lab have offered low-cost launch services for national and international markets, pushing Aotearoa New Zealand into the commercial space sector [7,20]. Rocket Lab is currently permitted to launch every 72 h with a total launch rate of 120 flights per year from its private launch site in Māhia [150]. This is, however, just the start of a new era. Technological advancements will see the number of competitor companies growing and the number of launches from Aotearoa New Zealand also increasing. Rapid growth can also foster consequences with widespread systemic impacts; for example, space debris pollution is not just commercial or environmental but also cultural and social.

Scott [18] provides a brief overview of the consequences that must be considered with establishing New Zealand as a launch site. The "100% PURE" brand for New Zealand is at risk of further public scrutiny as emissions impact carbon footprint. The rapid approval, development,

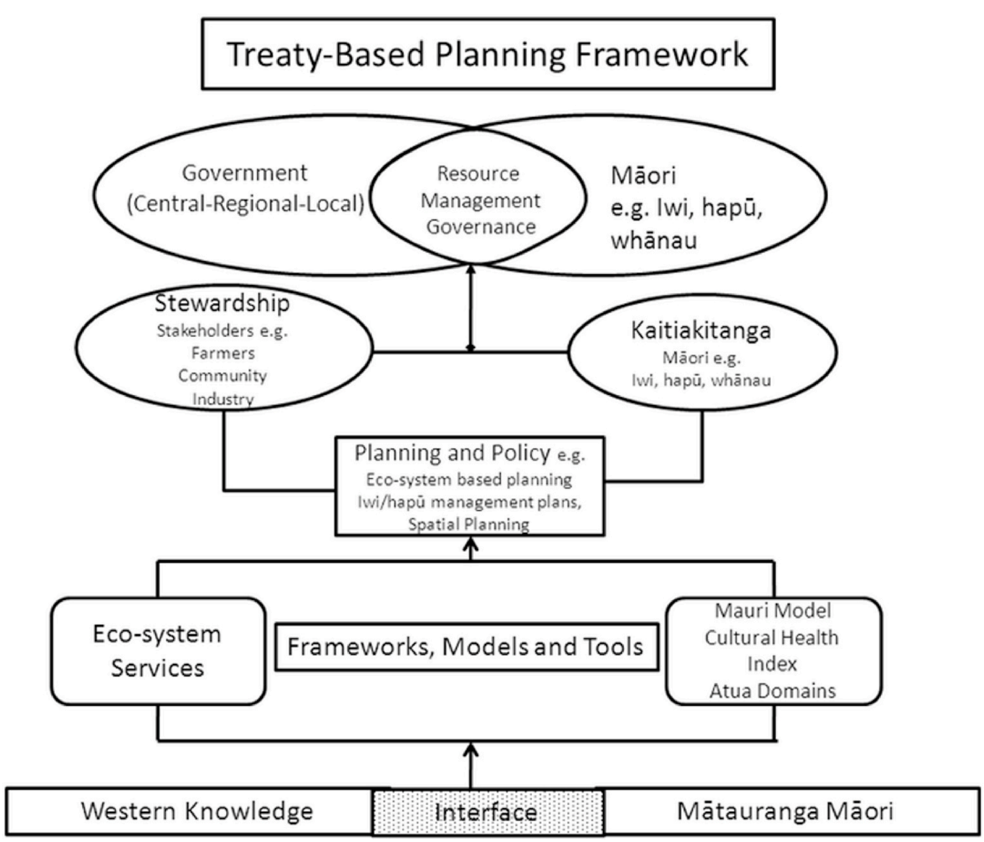


Fig. 6. A planning framework based on the Treaty of Waitangi Principles [41].

and implementation of space regulations may affect geopolitical and reputational relationships. Especially with the risks associated with the relationships with Lockheed Martin and DARPA, increasing security and intelligence activities, and the possibilities of militaristic involvement. Current market forces continue the technological shift towards defence and possibly weapons testing, with Rocket Lab as an example because of its ability to quickly change Aotearoa New Zealand's space industry involvement [151]. The launch of United States defence payloads reinforced the theme that there is a co-dependency between military and private companies in the current space industry. Furthermore, the OECD [8] described that there are already issues with space debris management for compliance on an international level. Therefore, voluntary compliance with international guidelines is not a sustainable stand-alone long-term strategy for the Aotearoa New Zealand space sector.

Any policies implemented for Aotearoa New Zealand based launches need to balance out private and international interests for the sustainable growth of the space sector. Operating from Aotearoa New Zealand should be advantageous for national and international market participants while simultaneously being environmentally responsible and addressing the tension for a bicultural approach. Referring to Section 1.3.2, the infancy of the space sector provides room for co-governance, co-planning, and co-management of the space sector to reach these desired outcomes [54]. A market-driven space sector already demands adaptive governance and a management structure that balances the priorities of various political and private actors [152]. Therefore, it falls to the Government to intervene and implement policy actions to manage these tensions through various political levers that benefit Aotearoa New Zealand's objectives and purpose for the space sector. If international cooperation could lead to future new treaties, then the regulations such as SSR, insurance to cover ADR, launch fees, and values that ensure Indigenous-led action could be considered a part of a long-term strategy to grow a sustainable space sector.

Focusing on the economic aspect, government interventions such as subsidies could be favourable for private companies wanting to invest in the space industry to grow the space economy. The most effective tool reported to change behaviour is the implementation of taxes and charges [8]. The report also warns that taxes and charges rarely work as a standalone policy response, leading to competition and future trade issues. If taxes and charges for space activity are too high, this may cause competition between countries. Private companies may look to other countries and potentially cause trade-based issues with countries that might not have the same debris mitigation strategy [135]. These would reduce Aotearoa New Zealand's revenue from the space industry.

There is a need for the Government to leverage the market interest and build the capability to manage future growth in conjunction with reliable policies. The development of commercial demand also means a lower cost to access the market, with associated sub-sectors projected to grow the space economy simultaneously. Integrating these sub-sectors into Aotearoa New Zealand's economy would improve services that utilise satellite data critical for land management, communication, navigation, and safety [19]. The ideal situation would be to promote early, voluntary behaviour change, and co-governance frameworks and structures that would influence sustainable space sector development while simultaneously implementing effective policy designs and including incentives for R&D that will lead to the holistic wellbeing of the space sector.

5. Conclusion: sustainability for the Aotearoa New Zealand space sector

There have been some clear drivers of change which have led to our contemporary views of sustainability. Those drivers initially arose from an awareness during the environmental movement of specific issues caused by human activities, such as pollution, which further developed into an understanding that whole planetary systems were in fact being impacted, particularly because of our rapidly growing economies. These systems-level impacts, like climate change, are complex challenges that have many interdependencies, and affect all aspects of environment, society and economy.

Responses to such systems-level impacts were initially focused on growth, for example sustainable development concepts. These responses have since matured into a broader, more holistic view of sustainability, which involves recognising and understanding the connections between the needs of society, economy, and our different cultures, as well as the terrestrial and space environment which frames the limits to which we can live and operate in. Hence, there is a need to take transdisciplinary approaches to address systems-level challenges, not only in developing solutions but also in understanding the issues that we are trying to address, which can lead to strong sustainability approaches.

Arguably, the intersection of space and sustainability is at a similar stage as the environmental movement, where the focus is on specific critical issues, most notably orbital space debris. But as we have experienced on Earth, increased activities in space will result in increased impacts on its varying environments. We currently have a unique opportunity to think ahead about potential impacts and how we might mitigate those before they become issues, particularly at systems-levels, which could adversely affect the long-term commercial, scientific and cultural value of space.

> The space sector may need to consider a sustainable trajectory over a sustainable state [98] or consider if a weak or strong sustainability model would align with the sector's long-term sustainability. Would Aotearoa New Zealand need to consider space environmentalism for the long-term sustainability of outer space and its use? These questions posit that space sustainability is complex and goes beyond the issues brought on by space debris and the overcrowding of usable orbital space.
>
> The Aotearoa New Zealand space sector could consider:

- The definitional frame that will inform the values and scale of space sustainability initiatives (Section 4.1)
- How Indigenous knowledges can enable the sector to rethink their sustainable development approach (sub-Sections 4.1 and 4.2) and implement a bi-cultural strategy that honours the constitutional framework (sub-Section 1.3.1 and 4.6).
- How space-enabled data can be used for terrestrial sustainability (Section 4.3)
- The role of Earth in the sustainability (preservation and utilisation) of the space environment (subsection 4.4)
- Policy design that promotes the sustainability of the Aotearoa New Zealand space sector (Section 4.5 and 4.6)

These considerations determine how Aotearoa New Zealand's space policies evolve; therefore, the sector must develop, implement, and adapt its sustainability strategy to attract and retain actors to operate in the country. Even though sustainability is an intention by key actors and the Government, it will first require a transdisciplinary approach to acknowledge and accept the complexities of various knowledge systems. This paper highlights the opportunity for Aotearoa New Zealand's space policy arena to grow and operate within a business development model sustainably.

Recommendations

It is recommended that a cross-sector and bi-cultural consensus of a preferred future for a sustainable space sector be achieved. Future actions include:

- Developing genuine, non-transactional, ongoing partnerships and processes for Māori participation, including the expression of tino rangatiratanga and kaitiakitanga.

- Policymakers interacting with stakeholders to influence the pathway of sustainable development.
- Engaging with experts that shape the bi-cultural space sector landscape.
- Establish clear sustainable development strategies that are visible for all stakeholders.
- Establish consistent sustainability reporting measures for the space sector.

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Declaration of competing interest

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

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