75th International Astronautical Congress (IAC), Milan, Italy, 14-18 October 2024.

IAC-24,81840

Rocket Realities: Navigating Social and Ecological Trials in the New Space Era

Casey M. Domingo [a]*, Harriet M. Hurley [b]
[a] *(Un)Common Cosmos,* c.domingo@live.com.au
[b] *(Un)Common Cosmos,* hmhurley9@gmail.com
* Corresponding Author

Abstract

Rockets are the bread and butter of the space industry. Our lives would be vastly different without them, all known benefits of space simply science fiction. Their iconic aesthetic and purpose are recognized around the globe, holding a cultural significance that instills a sense of comradery amongst those passionate about such. The rocket is a pervasive symbol, one that glorifies triumphant achievements of human endeavors.

As we sit perched on the precipice of a New Space Age, we are witnessing space-related activities becoming cheaper, faster and better. This results in rocket launches occurring more frequently than ever seen before. However, is our cultural and technological reliance on space blinding us from their social, environmental and ethical pitfalls?

A 2022 paper authored by Loïs Miraux showed that space commercialization is currently and will continue to remarkably proliferate environmental degradation. Whilst equally creating firm obstacles for future space activities and therefore all space actors. The commercial sector of space is not only expanding but diversifying from traditional space ventures. As these advancements occur, they come with oversights about how increased rocket production and launching pose challenges to Earth's ecology and long-term economic models. Launches have been shown to cause ozone depletion, air acidification, climate change exacerbation, and more. We are seeing unparalleled expansion with New Space and therefore must deepen our understanding of the space sector’s influence.

Alongside this, is a myriad of social concerns relating to the establishment of launch sites on lands with a recent history of colonization or military activity. This is known to be culturally destructive against First Nations and local populations, a topic often neglected within industry discourse. Ecological and social repercussions of rocket activities should be known, as impacts can be avoided and amended through a thorough evaluation of potential and existing risks. Creating better long-term ethical models for the industry.

However, the current literature and research taking place in this regard is scarce. This paper underscores the need to amplify these insights, whilst directing further resources and funding into these areas.

Humans have been spacefaring for two generations, thanks to incredible technological mutations in the name of space exploration. Despite this, the global space sector remains in its infancy. Therein lies an opportunity, not simply for innovation and growth, but to set precedence as an industry that foresees its faults before they become consequences, and to build a space culture truly worthy of human presence.

1. Introduction

Much of humanity, both ancient and modern, has dreamt of travel amongst the stars. It's a connection we've long been enamored by and one that will continue well into the future. Today's population are living through a remarkable time for space. Witnessing the formative years of what may one day be the genesis story of our interplanetary presence.

1.1 Rationale

The world is currently facing a profound environmental crisis, marked by widespread climate change, land degradation, biodiversity loss, food insecurity and more. Rising global temperatures have led to an increased frequency of extreme weather events such as storms, floods, and droughts, impacting communities worldwide [1]. The Amazon rainforest, often referred to as the "lungs of the Earth," continues to suffer from deforestation at an alarming rate, while coral reefs, vital for marine biodiversity, are rapidly dying due to ocean acidification and warming waters. In addition, pollution, particularly plastic waste, has infiltrated oceans and ecosystems, threatening wildlife and contaminating food chains.

In response, there have been concerted global efforts to address and rectify the anthropogenic damage done to the environment. International agreements such as the Paris Climate Accord aim to limit global warming to below 2°C, with nations committing to reduce greenhouse gas emissions and adopt sustainable energy practices. Conservation programs, like the reforestation of degraded landscapes in countries such as Brazil and Kenya, are actively working to restore ecosystems. Furthermore, the development of renewable energy sources, including wind, solar, and hydroelectric power, represents a major shift towards reducing the world's dependency on fossil fuels, aiming to mitigate further environmental harm.

Parallel to this, there is a growing recognition of social justice issues. In particular, the concerns of marginalized communities who have historically borne the brunt of environmental and social degradation. In recent years, movements such as Black Lives Matter in the United States and Indigenous rights movements in Canada and Australia have gained momentum, demanding justice and equality for historically oppressed groups. Western societies are increasingly working towards diversity and inclusivity, with policies aimed at addressing economic disparities, protecting civil rights, and seeking reparations for past injustices. This shift towards justice reflects a broader societal need and commitment to not only protecting the environment but also ensuring equity and fairness.

The space sector has played a pivotal role in advancing sustainability and equity efforts. Developing groundbreaking innovations like satellite-based climate monitoring, disaster management, and remote internet connectivity [2]. However, the excitement surrounding these capabilities and achievements may inadvertently overshadow the sector's own environmental and social footprint. It is then the responsibility of public and private actors within the sector to become aware of these footprints. Then to uphold the evolving standards of environmental and social responsibility.

1.2 A Surge in the Sector

Currently, the space sector is experiencing an unprecedented boom, capturing the imagination of the public and driving a new paradigm of space-related activities. This 'boom' can largely be attributed to the advent of "New Space", a term denoting the transition from government-dominated space initiatives to a more dynamic, diversified and competitive environment where private enterprises are increasingly influential. Unlike the traditional space race, dominated by national governments, New Space is characterized by the active participation of private companies. These companies are pushing technological boundaries and making space activities more accessible and cost-effective. Many privately owned space technology companies, and public-private partnerships are at the forefront of this paradigm shift, contributing to an increase in activities that surpasses historical precedents. However, as the space sector expands, it must ensure alignment with society's growing expectations for sustainable and ethical practices.

This paradigm shift implies a significant escalation in the number of space missions and launches.

Currently the commercial component of space makes up 78% of the global space economy. An economy which is projected to increase by 9% per annum by 2035, reaching 1.8 Trillian by 2035 [3]. With that in mind, it's clear that New Space is undeniably here. The scope of ongoing, planned and proposed projects is considerable, including megaconstellations, space tourism, point-to-point (Earth-to-Earth) space flight, space based solar power, moon missions, and mars and asteroid missions [4]. Therefore, the frequency of orbital launches has surged in recent years, with projections indicating a continued upward trajectory. Insights predict that the number of rocket launches will increase dramatically in the coming years. In 2023 we saw a staggering 223 orbital launch attempts, 37 more than 2022 and more than double the amount (102) in 2019 [5]. For 2024 we have had 155 launches up until the end of August. That's roughly one launch every two days. This increase is depicted in figure 1.

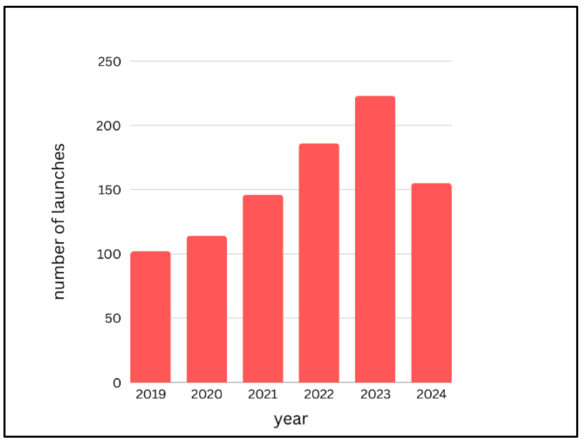

Fig. 1 The number of launches attempted and successful from 2019 to August 31st, 2024. Source: [6]; [5]

This rapid expansion inevitably raises a multitude of questions and challenges that necessitate careful consideration. The accelerated development within the space sector suggests that numerous challenges and implications are likely to emerge, with both predictable and unforeseen consequences for the environment and society. Even if the more ambitious activities don't see the light of day, the current surge of activities and launches still pose a need for thorough environmental and social assessment. While this period of growth is undeniably exhilarating and marks a historical moment for humankind, it is also accompanied by significant risks that must be judiciously managed. Lessons from other industries—such as the mining, forestry and energy sector, which have encountered substantial criticism for its environmental and socio-cultural impact—offer critical insights. These lessons not only serve as cautionary tales but also offer unique opportunities for the space sector to set precedent as an industry capable of competent and sustainable practices.

1.3 Scope

This paper will address the challenges associated with the primary artery of the space industry: rockets. As the fundamental enablers of all space activities, rockets play a pivotal role, making their impacts an essential area of inquiry.

We take a literature review approach in our investigation. Consolidating academic research, government and commercial reports, media articles and community field work to examine ecological and sociocultural concerns. In exploring the social trials, we address rocket infrastructure through a First Nations lens. However, in all cases we acknowledge that environmental and social domains are inextricably linked and want to emphasize that impacts on the environment rarely happen in isolation and without societal effect. However, for the purpose and scope of this paper, we have decided to separate these into distinct categories. Similarly, the scope has been intentionally limited to address key concerns and constraints, prioritizing breadth over depth. Each subject area could, or has, warranted extensive individual research beyond the coverage provided in this paper.

In Section 1, we offer an overview of relevant environmental studies and assessments. Investigations are centered around the ecological damages, known and postulated, from both rocket activities and their related infrastructure. Extending to suborbital and orbital launches, spaceports, and test ranges.

Section 2 specifically addresses the establishment of rocket-related facilities on Indigenous lands. The broader context of land dispossession and First Nations land use is discussed, examining two current examples of this. Although rocket infrastructure impacts non-indigenous populations as well, we prioritize the First Nations context. We believe this approach is justified, as the sociocultural implications discussed in Section 2 have not received sufficient focus in current space industry discourse.

1.4 Aims and Objectives

Our objective is to highlight and address critical issues that demand greater attention in the context of the rapidly expanding space industry. To achieve this there are three main aims of this research:

1. To consolidate existing research on the environmental and sociocultural impacts of rocket related activities, within the scope.
2. Assess the gap in literature whilst exploring the reasons behind this deficiency and emphasizing the urgency of addressing it.
3. Briefly explore current methodologies used to assess and regulate impacts and challenges.

1.5 Literature gaps

There is a notable gap in the literature regarding the topics mentioned. This is primarily due to the rapid pace of industry advancements that exceeds the capacity for comprehensive scientific research and assessment. This discrepancy has raised concerns among scientists about the growing need to understand the range and extent of impacts, as technology progresses rapidly without adequate awareness of potential flow on effects. The lack of literature possibly demonstrates the key priorities within the space sector, as economic and technological reports and assessments are kept both up to date and preemptive of future conditions. Whereas academic literature, both natural and social sciences, as well as government requested assessments can be both lesser in numbers and limited in scope. This may be attributed to the under-resourcing and under-funding of research to be conducted. Particularly, in the current and projected rocket activity framework.

It's worth noting that the literature volume for ecological impacts of rocket activities varies drastically depending on discipline and hazard. However, academic literature on infrastructure established on colonized lands is either nonexistent for specific cases, or significantly scarce.

2. Environmental Challenges and Sustainability Concerns

While there is a recognition that rockets have an impact on the environment, the depth and complexity of these impacts remain underexplored, particularly within the context of the rapid expansion of space activities. The need for further research has become urgent as the space sector grows in tandem with ongoing ecological crises like climate change, environmental degradation and biodiversity loss. A study presently under review proposes that rocket activities could jeopardize global conservation efforts [7]. It is essential to assess how and to what extent this assertion may be accurate. To ensure that we can effectively regulate, mitigate, and avoid exacerbating global environmental challenges.

The main environmental impacts of rocket activities identified are:

- **Chemical Pollution:** Byproducts of rockets fuels due to the combustion process and rocket material burning up during re-entry.
- **Acoustic Noise**: Pressure waves permeating through mediums in close proximity to launches, including shock waves.
- **Physical impact:** debris from liftoff or multistage release.

Not discussed in this paper are the concerns associated with rocket manufacturing, resource accruement and supply chains and waste disposal. Nonetheless, concerns here can drastically impact sustainability measures.

These environmental impacts listed above are investigated over three ecosystems atmospheric, marine and terrestrial. Importantly, we reiterate that these environments are not isolated, and there is no clear-cut boundary that separates these ecologies and the impacts on them.

2.1 Atmospheric Environments

The atmospheric impact of rocket launches has become an increasingly well-researched topic. This is partly due to the established research area on emissions pollution. Within the space sector, substantial research has been conducted on the pollutants associated with rocket propellant. However, this research area also encompasses the pollutants related to the re-entry of stages in multi-stage launches. Our primary focus in this sub-section will be on the former.

2.1.1 Pollutants in the Upper Atmosphere from re-entry

The atmospheric impacts from rocket stages burning up during re-entry are a developing area of concern in space and environmental sciences. As these stages disintegrate, they release particulate matter and gases into the upper atmosphere (50km and above), influencing atmospheric composition. Nitrogen Oxide gases are one byproduct of this that causes concern due to ozone depletion factors. However, there is much uncertainty regarding the amount produced and the magnitude of impact. Results will vary based on the spacecraft's specific aero-thermodynamic properties [4] and the parameters of re-entry [8].

2.1.2 Rocket propellant and their byproducts

The propellant used to launch rockets release various pollutants, with hydrazine and kerosene being amongst the most harmful [9][10]. While there are a range of fuels with varying degrees of sustainability, their byproducts include water vapor, carbon dioxide, chlorine compounds, nitrogen oxides, ammonia, and black carbon particles (soot). Each emission product with its own distinct impact on the atmosphere. Comparatively rocketry doesn't make a huge impact on the troposphere and lower-level atmosphere. Soot emission contributions from the rocket industry made up 0.01% of total soot emission globally in 2019 [11].

To understand the gravity of rocket fuels, it is necessary to examine higher atmospheric layers, such as the stratosphere. Above 20km (about twice the cruising altitude of a commercial jet), human activities are the only source of atmospheric pollution. Addressing pollution in the stratosphere is more challenging compared to ground-level pollution, which can be mitigated through regulatory measures. Emissions in the Troposphere disperse within days to weeks. However, in the Stratosphere pollution can persist for 2-3 years, potentially causing more harm despite being present in smaller quantities.

2.1.3 Adverse effects in the Stratosphere.

Each propulsion fuel contributes distinct pollutants to the stratosphere, each with unique hazards. The primary concerns for the stratosphere include radiative forcing, ozone depletion and air acidification.

In this context, radiative forcing refers to the absorption of solar radiation by gases and particles in the stratosphere. This has a warming effect and exacerbates climate change. Black carbon particles are highly effective at absorbing radiation. Accumulating in the stratosphere over time. It is estimated that, from this single pollutant alone, rocket activities could contribute to radiative forcing nearly 500 times more than surface aviation sources if the space industry expands as anticipated [11]. This is leading scientists to identify space activities as an additional contributor to climate change.

Ozone depletion is another significant impact, especially considering the ongoing recovery of the ozone layer. Chlorine compounds and nitrogen oxides are major contributors to ozone depletion, reacting with the ozone layer to diminish its protective capacity. Currently, ozone depletion is estimated to be between 0.01% and 0.1%. For comparison, it was 3% when the Montreal Protocol was implemented to ban ozone-depleting substances [12]. However, projections based on space industry growth suggest that this figure could rise and potentially exceed the levels observed before the protocol.

Additional concerns include air acidification. Fuels that release hydrochloric acid and other acidic chemicals contribute to atmospheric acidification, resulting in acid rain. See Marine and Terrestrial Environments for more on this.

2.1.4 'Green' Fuels

In response to these concerns, there have been substantial efforts to develop alternative, more environmentally friendly rocket fuels. Some companies, such as Blue Origin, are making strides by using liquid oxygen and liquid hydrogen, which produce only water vapor when combusted. Though Ross shows water vapor in the stratosphere could still contribute 2% to global radiative forcing [13]. Other innovative fuels, like the paraffin-based propellant used by start-ups like HyImpulse offer cleaner alternatives with fewer harmful emissions. These developments signal a positive shift in the space industry, as they work toward reducing the environmental footprint of rocket launches.

Nevertheless, to ensure that these alternatives are truly eco-friendly, it is crucial to adopt a comprehensive approach that considers the entire life cycle of rocket fuel production and operation. This involves not only reducing emissions during launch but also evaluating the environmental costs of fuel production, transportation, and disposal. Without this broader lens, even "clean" fuels may have hidden consequences that negate their intended benefits. As the space industry continues to grow, the development of sustainable rocket fuels will be crucial in balancing technological advancement with environmental responsibility

Table 1: A summary of common propellant types and their emission products, atmospheric effect and examples of rockets using that propellant. BC = Black Carbon, GHG = Green House Gases. Sources:[9][8][14]

Propellant Type	Emission Products	Atmospheric Effect	Rocket Examples
Solid	Carbon Dioxide, Water vapor, Nitrogen Oxides, BC, Alumina, Hydrochloric Acid	**Large environmental Impact** Ozone depletion Radiative Forcing from BC, GHG & water vapor Acid rain	NASA - Space Shuttle ESA - Ariane V Lockheed Martin - Atlas
Hybrid (cryogenic)	Water Vapor, Nitrogen Oxides, Hydrogen Gas	Minor radiative forcing from water vapor	NASA - Space Shuttle NASA - Space Launch System Blue Origin - New Shepard
Hypergolic (Hydrazine)	CO2, Water vapor, Nitrogen Oxides, BC	**Extremely toxic** Radiative forcing from BC and GHG significant safety concerns	ROSCOSMOS - Proton
Kerosene	CO2, Water vapor, Nitrogen Oxides, BC, Alumina,	Ozone depletion Radiative forcing from BC, GHG & water vapor Air Acidification	SpaceX - Kerosene ROSCOSMOS - Soyuz

2.2 Terrestrial Environments

Terrestrial environments affected by rocket activity are incredibly diverse, both in terms of their ecological vulnerability and their specific characteristics. Launching is an extreme activity contributing chemical pollution, physical disturbance and acoustic harm to surrounding areas. The significance of such impacts is not fully understood under a new space regime.

Current literature on terrestrial fallout primarily focuses on wildlife and protected species, alongside broader effects on biodiversity, particularly disruptions to nearby soil and vegetation. One study on geophysical impacts has also been identified. The diverse insight brought from varied environmental fields underscores the value and necessity for interdisciplinary research.

2.2.1 Local Wildlife and Protected Species

This section conveys wildlife impacts as a critical area of environmental concern, with disruptions affecting a wide range of species across the animal kingdom. A biological assessment conducted by the FAA at the Boca Chica site identified several key issues, including rocket launch noise, heat plumes, light pollution, hazardous materials, ground vibrations, increased traffic and human activity, tall structures, habitat loss, and the introduction of invasive species [15]. Among these, the most extensively studied factor is the impact of noise on wildlife.

2.2.1.1 Noise as a threat to wildlife

Large acoustic sounds waves permeate through the ground and air during rocket liftoff. This can deafen wildlife, cause psychological distress, drive away from habitats, harm the young, and in extreme cases cause mortality. Long-term exposure can change animal behavior, the consequences of this being uncertain.

A 2023 assessment conducted by the American Bird Conservancy conveys how rocket launches, specifically from SpaceX's Starship, could negatively impact endangered bird species in South Texas, particularly the piping plover [16]. Starship's powerful takeoffs generate noise levels that can disturb nesting sites reducing their chances of survival. Conservation groups have urged SpaceX to relocate operations to minimize harm.

Similar concerns have been raised regarding the Vandenberg Space Force Base in Central California. An area home to 17 endangered plant and animal species. A research team made up of wildlife biologists and acousticians investigated the influences of launches on local endangered species [17]. Research in the same vein can be extrapolated to highlight potential risks for launch sites worldwide and encourage conservation efforts. including the Southern Emu-wren at Whalers Way [18], the Kemp's Ridley Sea Turtle at Cape Canaveral, and the Ocelot at the Boca Chica launch site [15], among others. Evidence indicates that these insights and concerns predominantly originate from environmental protection organizations, rather than from stakeholders within the space industry.

2.2.2 Soil, vegetation and biodiversity

Reducing or endangering wildlife also impacts biodiversity, which is crucial for a healthy ecosystem in which we depend on. The exhaust clouds disperse low atmosphere regions, polluting from the ground cloud and exhaust contrail cloud [14]. The main areas of concern are overall ecosystem toxicity, contamination of vegetation, soil, air quality, and water ways. As a result, huge biodiversity loss in areas near to launch sites, believed to impact human health too.

Moreover, insects that habitat in local vegetation near launch sites can incur negative impact. In 2021 Wenchang Satellite Launch Center in Southern China was shown to have biodiversity impact on both vegetation and insect species [19]. Showing a reduction in abundance and diversity of insects and reduction of forest diversity. Other studies conducted in Central Kazakhstan also specifically demonstrated a loss in vegetation cover and biodiversity from fuel pollutants and first stage rocket debris [20]. Interestingly the paper states that vegetation recovery is faster after winter launches compared to spring and summer.

2.2.3 Acidification

Furthermore, acid rains have been documented to have killed local plants within 2500 feet (about 762 m) of the Kennedy Space Centre [21]. Studies have also shown that soil acidification increases near launch sites, changing the composition of the soil [22]. Albeit the extent and nature of impacts on local ecology is not detailed. Interdisciplinary insights from adjacent fields could potentially aid in understanding the impacts of soil acidification on biodiversity. Stevens 2024 highlights that there's not enough understanding of acidification to know the consequences, however qualitative research can be conducted [23]. This follows on from their development of a model for predicting soil acidification from solid rocket fuels containing Hydrochloric acid.

2.2.4 Geophysical

One relevant study addresses the geophysical disturbances associated with launch noise, specifically focusing on the Kennedy Space Center and utilizing data from previous launches [24]. This research examines how acoustic waves from launches can affect the geophysical structure of the ground, including bedrock and sedimentary formations, with particular concern for the erosional susceptibility of coastal features. The study demonstrated that the methodology used could detect changes in geophysical structures. However, it also emphasized the need for additional data to better understand environmental impacts in detail, highlighting the importance of comprehensive monitoring to ensure the sustainability of coastal environments.

2.2.5 *Environmental Compliance of Spaceports*

Orbital rockets exhibit extreme characteristics and outputs during liftoff. Without a comprehensive understanding of the full scope and magnitude of their impact on surrounding ecosystems, the industry cannot credibly claim to be environmentally conscious. This lack of eco-awareness has not gone unnoticed, as demonstrated by the coalition of environmental groups currently suing the U.S. Federal Aviation Administration for conducting a negligent environmental assessment [25]. The complexity of terrestrial environments requires a holistic approach to understanding these interactions, recognizing that different habitats respond uniquely to the stressors imposed by space-related activities. These concerns add to broader discussions about balancing space exploration with environmental stewardship.

A review conducted by Dallas et. al. in 2020 produced a useful summary of environmental studies on space-related activities [14]. However, to reiterate, there is a lot more research that needs to occur to confidently understand the rocket industry's impact on terrestrial environments.

2.3 Marine Environments

Marine environments are highly sensitive and play a critical role in maintaining the balance of global systems. The health of marine ecosystems is crucial not only for the biodiversity they support but also for the livelihoods and well-being of human populations worldwide, who rely on these systems for resources, climate regulation, and economic activities. This section of research focuses on the impacts to marine ecologies near launch sites and the effects of rocket debris falling into bodies of water, examining how such factors can disrupt these delicate systems.

2.3.1 Acid Rain to Ocean Acidification

Another concern tied to previously discussed air acidification and acid rain is ocean acidification. While acid rain's impacts are well-understood in relation to fossil fuel emissions, its connection to rocket launches is less explored. Historically, rockets using solid propellants, which release chlorine and nitrogen oxides, have been documented to increase water acidity near launch sites [26]. For example, a study conducted in 1992 mentioned that acid rain caused by rocket emissions led to the mortality of small fish within a 2,500-foot radius of a Kennedy Space Center, as well as plant mortality mentioned previously [21]. Given the rise in rocket launch frequency since then, the potential scale of this impact is probable to have increased.

Studies from other environmental fields show that acid rain harms marine ecosystems [27], reducing coral reef growth, decreasing species diversity, and posing indirect risks to human health. The severity of this has been explored in many studies. Although direct evidence linking modern rocket emissions to ocean acidification is limited, the potential for large-scale rocket activity to induce similar effects remains a significant concern. Given these uncertainties, the need for targeted research on the environmental effects of acid rain from rocket launches has never been more urgent. By further investigating these impacts, we can better understand the magnitude of the risks posed to both marine ecosystems and human communities.

2.3.2 A Comprehensive Marine Environmental Risk Assessment

One notable paper was conducted by the National Institute of Water & Atmospheric Research [28] in Aotearoa/New Zealand, commissioned by the Ministry for the Environment. A panel of experts conducted an environmental risk assessment for northern, eastern, and southern regions of New Zealand, focusing on the potential impacts associated with rocket launches.

The key concerns identified were as follows:

- Direct strike causing mortality
- Noise disturbance
- Toxic contaminants
- Ingestion of debris
- Smothering of seafloor organisms, preventing normal feeding and/or respiration
- Provision of biota attachment site
- Floating Debris

The assessment determined that the overall environmental risk was low to moderate across several risk and confidence categories. Those categories were applied to established marine environment classifications, accounting for the various ecosystem components, i.e. flora and fauna species of each habitat.

This evaluation was largely based on the likelihood of risks materializing. Using their model, the panel determined that 10 launches producing 40 tons of debris each would present only a minor risk. However, with 100 launches, the risks could increase to a moderate level, and at 1,000 launches, marine ecosystems are at high risk. The level of risk also depended on whether repeated launches affect a concentrated area or if debris is more widely scattered within the examined zone.

The most significant risks identified were direct strikes causing mortality and underwater noise disturbance, which are more pervasive across larger areas and were harmful even in low-risk scenarios. The study emphasized the need for more focused monitoring of rocket trajectories and distribution of debris fields. It recommended localized studies to avoid results being diluted by data from a broad range of habitats, which can aid in mitigating.

Cumulative impacts were another key concern. Authors acknowledge that results will change under different stressors. Such as temporal accumulation (how rocket activities change in duration and frequency) and the spatial distributions. Furthermore, this research was conducted in data poor conditions. NIWA published this assessment in 2017, a month prior to Rocket Lab's first launch of Electron. Since then, Electron has been celebrated as the fastest commercial rocket to reach 50 launches [29]. With comments from the CEO claiming that if the demand is there, they expect a decent scale-up in Electron launching.

With the scaling up of rocket activities, the results of this assessment may soon, if not are already, be dated, underscoring the importance of continued research on cumulative impacts at local scales. The report recommended that research move toward a semi-quantitative assessment after 50 launches, which is now pertinent given Rocket Lab has met that marker.

The study also highlights a significant challenge, the need to observe impacts first to then determine whether they occur at a considerable rate or scale. This introduces a delicate balance between proactive environmental protection and post-launch impact assessments.

Moreover, this comprehensive marine ecology assessment acts as a great example for industry actors. Particularly, as some environmental assessments are not extensive enough and err on the assumption of negligible impact [45]. Which stresses the importance of conducting similar examinations in other spacefaring nations, particularly those with higher rocket launch frequencies.

3. Sociocultural Impacts and the Dispossession of Indigenous Lands

The social impacts of the space sector are deeply intertwined with historical and ongoing issues of colonization and land dispossession, particularly concerning the location of launch sites and testing facilities. Space infrastructure is often established in remote areas with favourable launch conditions. Whilst these conditions are important for minimizing risks to human populations, they can be accompanied by residents losing their homes and their way of life. This is particularly relevant for First Nations communities. Populations that hold significant cultural, spiritual, and historical value with land acquired for rocket-related infrastructure. Many communities are continually combatting the challenges of post-colonial legacies, in attempts to continue ways of life that have been violently severed. The sociocultural trials associated with rocket activities extend beyond the scope of this paper. However, we have chosen to focus on this issue due to its pressing relevance and to amplify conversations that are lacking in industry discourse.

3.1 Land Dispossession and Cultural Erasure

Land Dispossession involves the use and exploitation of Indigenous people's land, typically resulting in the environmental destruction of those lands. Large industries have a longstanding history of monetizing First Nations lands, a pattern frequently documented in historical accounts and current media.

The space industry is no exception. The establishment of spaceports and testing facilities on Indigenous lands is a continuation of this pattern of exploitation and displacement.

This not only leads to physical dispossession but also has profound cultural and spiritual impacts. For many Indigenous peoples, the land is not just a physical resource but a central component of their identity, spirituality, and cultural heritage. The disruption of sacred sites, burial grounds, and traditional practices by space-related activities can have devastating effects on the cultural continuity of these communities. It communicates that these cultures are not included in ‘Space for All’ ideologies.

The establishment of space infrastructure on lands traditionally belonging to First Nations peoples perpetuates notions of cultural dominance and superiority. Although consultations are often conducted, they may fail to fully disclose the long-term implications and objectives of these activities. In the current political climate, where companies increasingly prioritize the diversity and inclusion of Indigenous peoples, there is a risk that such efforts become tokenistic, serving only as superficial gestures while enabling further expropriation. This is particularly concerning in the context of constructing launch and testing sites, since as Section 1 details, we are still uncovering the breadth and magnitude of environmental impacts and hazards.

Many Indigenous cultures globally have long practiced sophisticated sustainability and interconnected relating with the environment. The space sector could benefit from bolstering these practices and peoples rather than disrupting them. Particularly as pursuits are made to contribute to the United Nations Sustainable Development Goals.

These types of disruptions are not uncommon to the space sector. In an ethnographic paper exploring the establishment of the launch facility Centre Spatial Guyanais (CSG) in French Guiana, anthropologist Karlijn Korpershoek details how its creation led to the displacement of the Amerindian and Creole civilians living there [30]. The whole area was redesigned in a way that conflicted with the local’s agricultural practices. Indicating a dismissal of the traditional ways of life in Kourou prior to the existence of CSG. Korpershoek states “The case in French Guiana shows that access to outer space required others to reshape their relation to the land, where a practice of resource sharing was complicated by the enforcement of a foreign system on a well-established way of inhabiting the world. It thereby creates a trade-off in which access to one potential global common means the restriction of another.”

Korpershoek provides other examples of similar or adjacent occurances, though importantly disclaims that these aren’t ubiquitous experiences, and each case has its nuances and variation in outlook. The examples have been compiled below along with other sourced examples:

- Woomera, Rocket Testing Facility: Disruption to local First Nations groups who contest the site (Australia)
- Baikonur, ROSCOSMOS Launch site: Deteriorating health and direct impacts from falling space debris on local populations.
- Boca Chica (SpaceX facility): Forced adaptation and/or relocation of residents and local ecosystems.
- Kodiak Island , Alaska Aerospace Corporation Facility (AAC*):* Reports of regulatory evasion from the corporation, opposition from residents due to local economy and ecological disruption. Attempts were made to establish a spaceport by the same corporation in Puna, Hawaii. It didn’t proceed due to strong opposition from the local Hawaiian population and the East Hawaiian state senator [31].

4. Sociocultural Case Studies

We present two detailed case studies that highlight these concerns: Koonibba Test Range on Kokatha Country, South Australia and the planned Biak Spaceport in Biak, West Papua. Both serve as examples of how rocket infrastructure has affected Indigenous lands, cultures, and ecosystems. It is essential to recognize that these cases involve various layers of political, social, and environmental dynamics that cannot be fully explored within the scope of this paper. Much of the insight presented here is drawn from local news and community collaboration, with minimal academic resources. Offering a glimpse into broader issues that demand deeper investigation and continued dialogue.

4.1 Koonibba Test Range on Kokatha Country

Since the colonization of Australia in 1788, Indigenous Australians have been subjected to systemic violence and oppression, including widespread massacres, disenfranchisement, and forced displacement from their traditional lands. Despite ongoing efforts by Indigenous communities to reclaim their sovereign rights, they continue to face significant socioeconomic and political challenges. Approximately a third of all First Nations Australians are living below or near the poverty line [33], with limited access to essential resources such as housing, healthcare, education and internet access [34]. Resources that are readily accessible to the wider population of Australia. These inequalities are further underscored by alarming realities, such as the leading cause of death among Indigenous Australian children being suicide [35]. Furthermore, that First Nation Australians are the most incarcerated population in the world [36].

This context is important when we consider how these conditions may be exploited for industrial gain. Rocket related activities are not the cause of these systemic issues, though they may benefit off these conditions.

The Koonibba Test Range (KTR) on South Australia’s Eyre Peninsula is a key site for space technology testing. Indicating Australia's growing role in the global space industry since its first launch in 2020. As the largest commercial rocket testing site in the Southern Hemisphere, KTR specializes in suborbital launches and returns. However, its location on the traditional lands of the Kokatha people raises concerns about the intersection of space development and Indigenous land rights, especially given Australia’s colonial context.

Southern launch collaborated with the Far West Coast Aboriginal Corporation and the Yumbarra Conservation Park Co-management Board to ensure protection of sacred sites and risks to local flora and fauna are minimized. Additionally ongoing consultation has been conducted with the Koonibba Aboriginal Corporation. Community members have welcomed benefits arising from the consultation package like improved education, Wi-Fi, and essential resources as part of space industry collaborations. However, the prior absence of these resources demonstrates artificial states of poverty. This highlights a key issue, essential services, which should be a right, can instead be used as leverage to secure agreements that further land acquisitions in vulnerable communities. Although Southern Launch has engaged and consulted with local Indigenous groups and received garnered community support, the manner in which these consultations were conducted are being questioned.

Aunty Sue Coleman Haseldine is a Senior Kokatha Elder and a respected advocate for Indigenous and environmental issues. She has received several awards for her leadership and environmental protection efforts, notably the South Australian Premiers award and serving as an Ambassador for ICAN, which was awarded the Nobel Peace Prize in 2017.

As a custodian of Kokatha country, Aunty Sue is responsible for cultural maintenance and spends significant time practicing traditions and caring for the land. This includes cleaning sacred waterholes and rock holes to ensure local wildlife has access to clean drinking water—a practice that has been upheld for generations. She teaches younger community members about their land and traditions, safeguarding the cultural heritage that is deeply tied to the very lands over which rockets now fly. Aunty Sue describes Kokatha country as "… our pharmacy, our school, our church. Our spirituality's out here.".

Aunty Sue is particularly concerned about the potential destruction of cultural sites and the misleading nature of consultations regarding space activities. The consultation package did not mention any connections to defense projects, which she believes were deliberately omitted. That region of Australia has a history of the land being misused for weapons testing, in Emu Fields and Maralinga. Projects here not only contaminated the land but forcibly removed Indigenous people living there and has led to ongoing health complications. Aunty Sue was a child during these tests, and knows first-hand the physical, psychological and spiritual harm such activites on sacred country can cause. Recently, Southern Launch signed a Memorandum of Understanding with Hypersonix. A company planning to build craft for the US Defense Innovation Unit in 2024. This lack of transparency has led Aunty Sue to feel that the consultations are exploitative and indifferent of the historical contexts of Aboriginal Australians.

She fears that the launch activities could threaten Koonibba, not only through environmental impacts but also by attracting unwanted attention and risking the destruction of sacred sites. The launch base is located near a cemetery, raising concerns about disruption to ancestors.

It is essential to recognize that these sacred sites hold immense cultural value, akin to significant monuments and cultural sites in the West. The destruction of these sites could have a devastating psychological impact on the people, causing lasting trauma. Although Southern Launch has committed to surveying the area after the launches to assess any damage, this response comes too late. It has been noted that Southern Launch officials are relying on outdated maps of sacred sites, while recent surveys by World Heritage have identified additional areas of significance. Moreover, Aunty Sue as a senior elder, possesses knowledge of sacred women's sites that may not be documented, and requiring her to share this information would undermine Kokatha culture and law.

4.2 LAPAN Spaceport on Biak Island

4.2.1 Forty years of occupation

In the context of the West Papuan genocide, the planned construction of a spaceport on Biak Island raises serious ethical concerns regarding the ongoing dispossession and exploitation of Indigenous Papuan lands. West Papua, a region that has endured decades of violent repression under Indonesian rule, is home to Indigenous communities who have long resisted the forced occupation of their land. Since Indonesia's annexation of West Papua in 1963, the Indigenous population has faced systemic violence, cultural erasure, and environmental destruction. These abuses, which are part of a broader effort to suppress West Papuan independence movements, have been described as a slow-motion genocide [37]. Biak is an island within this region, one that has gone through one of the most severe massacres perpetrated under Indonesian rule. The establishment of a spaceport on

Biak threatens to further marginalize Indigenous communities already enduring profound injustice.

In 2020 Indonesian President Joko Widodo proposed Biak Island as an equatorial spaceport for SpaceX, marking the latest pressure on the islands Indigenous population for space development. This is not the first time Biak has been considered for such projects. In the 1980s, Indonesia's National Institute of Aeronautics and Space (LAPAN) requested that those residing in the village of Saukobye relinquish 100-hectres of their land for space development. Again, in 2002, plans were advanced for a collaboration with the Russian space agency, ROSCOSMOS, to establish a similar facility on the island.

Recent efforts to progress these plans are intended as a collaboration between the Indonesian government, LAPAN and international space actors, designed to be a major hub for rocket launches [38]. However, the project has been met with strong resistance from the local Biak community. In particular, the Warbon people of Saukobye view the development as yet another form of exploitation of their land and resources [39]. Indigenous leaders have voiced concerns about the environmental impact of the spaceport. Manfun Sroyer a tribal chief on the island, has been quoted stating "This spaceport will cost us our traditional hunting grounds, damaging the nature our way of life depends on. But, if we protest, we'll be arrested immediately" [40]. The construction of this facility not only risks further environmental degradation but also exacerbates the political and social tensions in the region. Saukobye elder and head of the village, Yusup Ampnir, has spoken out in strong disagreement of the proposal which will see Suakobye people displaced. Expressing how it will not only uproot their way of life and destroy the local environments that they depend on for daily life, but it is likely to also cause tensions with neighboring groups.

Given the history of state violence against West Papuans, there is also concern that the spaceport will be used as another tool to suppress dissent, as land grabs and resource extraction have frequently been accompanied by military intervention. In this case, the expansion of the space industry mirrors ongoing colonial practices, reinforcing the subjugation of Indigenous peoples for the sake of technological and economic progress.

4.2.2 Concerning Rhetoric

An Indonesian academic paper on the international relations benefits of the Biak spaceport project reveals a troubling perspective on the broader geopolitical aims tied to its development. The paper states, *"By forging international partnerships with those interested in spaceport services in Southeast Asia and outside the region, Indonesia could gain soft power and be seen as a benevolent hegemony." [41].* This language not only glosses over the severe impact on the local Biak population but also reinforces imperialist narratives, framing the expansion of state control and influence over Indigenous lands as a benevolent or positive force. The idea of Indonesia gaining "soft power" through international collaboration actively ignores the voices of Biak's Indigenous communities, whose lands and lives are being compromised for global ambitions. The portrayal of Indonesia as a "benevolent hegemony" sanitizes the state's oppressive actions, effectively legitimizing the further marginalization of the Biak people while dismissing their resistance as an impediment to progress.

This rhetoric reflects a larger pattern in the coverage of the Biak spaceport, where both academic literature and discourse on the resistance of the Biak community is scarce. Instead, much of the available information centers on the economic and strategic advantages of the spaceport, employing language that prioritizes national growth and technological progress [42][43][44]. The near absence of critical engagement with the perspectives of the Biak people in these discussions perpetuates a narrative that erases local voices. A pattern familiar for First Nations populations. This silencing of Indigenous resistance not only undermines their struggle for land rights but also obscures the broader implications of environmental degradation and cultural destruction that such projects bring.

5. Pathways Forward

5.1 Assessments and Competency Tools

Tools such as Environmental Impact Assessments (EIA) and Life Cycle Assessments (LCA) are essential for quantitatively and qualitatively evaluating the consequences of projects from inception to completion. These assessments are critical not only for determining the feasibility of plans but also for ensuring compliance with stringent environmental and social constraints.

To effectively address potential harm to the environment and First Nations communities, it is imperative that these assessments adopt an interdisciplinary approach, integrating insights from both natural and social sciences. Neglecting this broader perspective risks damaging public perception of the space sector and undermining its long-term economic viability.

While social and cultural competency metrics can provide thorough initial insights into the cultural impacts of practices, more proactive measures are often necessary. Engaging marginalized voices is crucial for a deeper understanding of these impacts, as exemplified by initiatives like Indigenous led science and space conferences, which aims to elevate the perspectives of elders and experts in the field.

5.2 Advancing Funding and Policy

Increased funding for research into the social, environmental, and ethical implications of rocket activities is essential for mitigating potential hazards before they escalate into significant issues.

As an increasing number of nations engage in spacefaring ventures, it is imperative to enhance regulations and policies governing these activities to ensure responsible practices. The United Kingdom's *Space Industry Act (2018)* and the draft *Space Industry Regulations* establish clear guidelines for assessing the environmental impacts of space-related activities. These regulations require that entities engaging in spaceflight operations must evaluate “the potential direct and indirect significant effects of the proposed spaceflight activities”[45].

These include population and human health, biodiversity (such as the local ecology, flora, and fauna), air quality, noise and vibration levels, water resources, the marine environment, climate impacts (including greenhouse gas emissions), land and soil quality, as well as the landscape and visual impacts. Additionally, the regulations mandate consideration of material assets and cultural heritage, including architectural and archaeological aspects, ensuring a comprehensive approach to understanding environmental and cultural consequences.

A rigorous assessment framework backed by international and domestic policy should be established for space faring nations. Thus equipping industry actors with the necessary tools to conduct legitimate and thorough self-evaluations. By promoting a culture of accountability and proactive risk management, we can better navigate the complexities of the New Space Age.

6. Conclusion

Investment in research and the establishment of robust policy and regulatory frameworks are vital for navigating the intersection of environmental sustainability and social equity. As we face the pressing realities of climate change and environmental degradation, the space sector has a unique opportunity to set a precedent for sustainable and inclusive business models. By embracing this responsibility, it can align commercialization and technological advancement with the stewardship of Earth’s precious and fragile environment. Failure to do so will have far-reaching consequences for all humanity, as emphasized by the IPCC's findings (2022). The path forward represents not only an opportunity for innovation but also a moral imperative for the integrity of our planet and its diverse communities.

Acknowledgements

Firstly, I would like to acknowledge the Wurundjeri Woi Wurrung people of the Kulin Nation. Owners of the land on which this paper was written. I pay respects to Elders, past present and emerging, acknowledging that First Nations Australians as the early scientists and first astronomers, with a deep and ongoing connection to Sky Country. I acknowledge that sovereignty on these lands was never ceded.

I also extend gratitude to Harriet Hurley the co-author and co-founder of (Un)Common Cosmos.

References

[1] IPCC, 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001

[2] N. Peter, N. Afrin, G. Goh, E. Chester, Space technology, sustainable development and community applications: Internet as a facilitator, Acta Astronautica, 59, (2006), 445-451, doi: 10.1016/j.actaastro.2006.02.018 .

[3] World Economic Forum, Space: The $1.8 Trillion Opportunity for Global Economic Growth, Insight Report, (2024)

[4] L. Miraux, A.R. Wilson, G.J. Dominguez Calabuig, Environmental limits to the space sector's growth, Science of The Total Environment, 806, (2022),part 4, doi: 10.1016/j.scitotenv.2021.150862

[5] Space Works, Recap of All Global Launches for 2023, www.spaceworks.aero/recap-of-all-global-launches-for-2023/, (accessed 07.22.24)

[6] Gunters Space, Global Launches in 2024, https://space.skyrocket.de/doc_chr/lau2024.htm, (accessed 07.10.24)

[7] L.P. Ang, F. Kong, E. Hernández-Rodríguez et al. Rocket launches threaten global conservation, Research Square, PREPRINT (Version 1), (2024), https://doi.org/10.21203/rs.3.rs-4477063/v1

[8] T. F. M. Brown, M. T. Bannister, L. E. Revell, Envisioning a sustainable future for space launches: a review of current research and policy, Journal of the Royal Society of New Zealand, 54(3), (2023), 273–289, doi: 10.1080/03036758.2022.2152467

[9] Space Generation Advisory Council, Environmental Impacts of Rocket Fuel, U.S. Task Force, Space Generation Advocacy & Policy Platform, 2023

[10] C.M. Maloney, R.W. Portmann, M.N. Ross, K.H. Rosenlof, The climate and ozone impacts of black carbon emissions from global rocket launches, Journal of Geophysical Research: Atmospheres, 127, (2022), e2021JD036373, doi: 10.1029/2021JD036373

[11] R. G. Ryan, E. A. Marais, C. J. Balhatchet, S. D. Eastham, Impact of rocket launch and space debris air pollutant emissions on stratospheric ozone and global climate, Earth's Future, 10, (2022), e2021EF002612, doi: 10.1029/2021EF002612

[12] L. Miraux, Environmental limits to the space sector's growth, Science of The Total Environment, 806, Part 4, (2022), doi: 10.1016/j.scitotenv.2021.150862 .

[13] M. N. Ross, P. M. Sheaffer, Radiative Forcing caused by rocket engine emissions, Earth's Future, 2, 177-198, (2014), doi:10.1002/2013EF00160.

[14] J. Dallas, S. Raval, J. Alvarez-Gaitan, S. Saydam, A. Dempster, The environmental impact of emissions from space launches: A comprehensive review, Journal of Cleaner Production, 255, (2020), 120209, doi: 10.1016/j.jclepro.2020.120209

[15] Federal Aviation Administration & Office of Commercial Space Transportation, SpaceX Starship/Super Heavy Launch Vehicle Program at the SpaceX Boca Chica Launch Site, Biological Assessment, Texas, 2021

[16] Elizabeth Howell, SpaceX Starship Launch Could Harm South Texas Birds, Advocacy Group Says, Space.com, 18 Apr. 2023, www.space.com/spacex-starship-florida-move-texas-birds-protection, (accessed 07.05.24)

[17] L. K. Hall, et. al., Assessing the influence of rocket launch and landing noise on threatened and endangered species at Vandenberg Space Force Base, J. Acoustical Society of America, 153, (2023), A72, doi: 10.1121/10.0018203

[18] The Nature Conservation Society of South Australia, Eyre Peninsula Southern Emu-wren Distribution Assessment, 2023.

[19] Xue, Y., et al., Rocket launching activities are associated with reduced insect species richness and abundance in two types of tropical plantations around the Wenchang Satellite Launch Center, southern China, Ecological Indicators 127, (2021). doi: 10.1016/j.ecolind.2021.107751

[20] S. Lednev, T. Koroleva, P. Krechetov, A. Sharapova, I. Semenkov, A. Karpachevskiy, Revegetation of areas disturbed by rocket impact in Central Kazakhstan, Écoscience, 25(1), (2017), 25–38, doi: 10.1080/11956860.2017.1396100

[21] Bennet, R.R., J.C. Hinshaw, and M.W. Barnes, *The Effects of Chemical Propulsion on the Environment.* Acta Astronautica, 26(7), (1992),531-541.

[22] G. M. Marion, C. H. Black, P. H. Zedler, The effect of extreme HCL deposition on soil acid neutralization following simulated shuttle rocket launches, Water Air Soil Pollution, An International Journal of Environmental Pollution, 43, (1989), 345-363, doi: 10.1007/BF00279201

[23] M. C. Stevens, A. W. Johnson, M. Z. Li, G. Cinar, O. Jia-Richards, Development of a Qualitative Model for Predicting Soil Acidification Due to Solid Rocket Motor Exhaust, American Institute of Aeronautics and Astronautics (AIAA), AIAA AVIATION FORUM AND ASCEND 27 July, 2024.

[24] H. Byul Woo, et al., Assessing Potential Geophysical and Environmental Impacts from Frequent Rocket Launch Missions at Kennedy Space Center, Geoconvention, Calgary, Canada, 2024.

[25] Mike Wall, Environmental Groups Sue FAA over SpaceX Starship Rocket, Space.com, 1 May 2023,

www.space.com/spacex-starship-rocket-environmental-groups-sue-faa, (accessed 07.20.24)

[26] Final Environmental Assessment for Multi-Use of Launch Complexes 39A and 39B John F. Kennedy Space Center, FL, NASA, 2013

[27] A. Singh, M. Agrawal, Acid rain and its ecological consequences, Journal of Environmental Biology, 29(1), (2008), 15–24

[28] Lamarche, G., et al., Ecological Risk Assessment of the impact of debris from space launches on the marine environment, National Institute of Water & Atmospheric Research Ltd (NIWA), New Zealand, 2017

[29] Tim Fernholz, Nifty Fifty: How Rocket Lab's Electron Set a New Speed Record, Payload, 20 June 2024, payloadspace.com/nifty-fifty-how-rocket-labs-electron-set-a-new-speed-record/, (accessed 07.25.24)

[30] K. Korpershoek, Accessibility to Space Infrastructures and Outer Space: Anthropological Insights from Europe's Spaceport, International Journal of the Commons, 17(1), (2023), 481–491. DOI: https://doi.org/10.5334/ijc.1284

[31] Alaska Residents Urge Caution to Hawai'i Officials Considering Spaceport, Hawai'i Public Radio, HAWAII, 13 Feb. 2019, www.hawaiipublicradio.org/local-news/2019-02-13/alaska-residents-urge-caution-to-hawai-i-officials-considering-spaceport. (accessed 07.15. 24)

[32] Alutiiq People//Sugpiaq People, Alutiiq Museum and Archaeological Repository, alutiiqmuseum.org/alutiiq-people/. (accessed 06.15.24)

[33] Parliament of Australia, Chapter 13 - Indigenous Australians, 2024, www.aph.gov.au/Parliamentary_Business/Committees/Senate/Community_Affairs/Completed_inquiries/2002-04/poverty/report/c13, (accessed 07.30.24).

[34] Australian Human Rights Commission, Statistics about Aboriginal and Torres Strait Islander People | Australian Human Rights Commission, 2024, humanrights.gov.au/our-work/education/statistics-about-aboriginal-and-torres-strait-islander-people, (accessed 07.18.24)

[35] Esse Deves, et al., Calls for Support as Suicide Revealed as Leading Cause of Death for Indigenous Children, ABC News, 10 Oct. 2023, www.abc.net.au/news/2023-10-10/calls-for-help-as-indigenous-child-suicide-rate-rises/102949238, (accessed 07.12.24)

[36] United Nations Association of Australia, Australia's First Nations Incarceration Epidemic: Origins of Overrepresentation and a Path Forward, UNAA, 18 Mar. 2021, www.unaa.org.au/2021/03/18/australias-first-nations-incarceration-epidemic-origins-of-overrepresentation-and-a-path-forward/, (accessed 07.04.24)

[37] J. Elmslie, C. Webb-Gannon, A slow-motion genocide: Indonesian rule in West Papua, Griffith Journal of Law and Human Dignity, 1(2), (2013), 142-166

[38] Luthfi T. Dzulfikar, Indonesia's First Spaceport in Biak, Papua, Set to Become First Equatorial Launching Site in the Pacific, The Conversation, 22 Nov. 2019, theconversation.com/indonesias-first-spaceport-in-biak-papua-set-to-become-first-equatorial-launching-site-in-the-pacific-127499, (accessed 07.28.24)

[39] Permata Adinda, "Are You Rebels?": Biak Spaceport's Land Acquisition Carries Dark Past, Project Multatuli, 4 Apr. 2022, projectmultatuli.org/en/are-you-rebels-biak-spaceports-land-acquisition-carries-dark-past/, (accessed 07.15.24)

[40] Rory James, Anger after Indonesia Offers Elon Musk Papuan Island for SpaceX Launchpad, The Guardian, 9 Mar. 2021, www.theguardian.com/world/2021/mar/10/anger-after-indonesia-offers-elon-musk-papuan-island-for-spacex-launchpad, (accessed 07.29.24)

[41] Korwa, J.R.V., et al., Indonesia's First Spaceport Plan in Biak Island: A View from International Relations, Jurnal Hubungan Internasional, 12(2), (2023), 33-44.

[42] Diana, S.R., F. Farida, and I. Musdafia, Selection of Spaceport Site in Indonesia: Good Economic Efficiency and Contribution to Local Economic Development. Researchers World: Journal of Arts, Science & Commerce, ,4, (2018), 65

[43] Perwitasari, S. Anggina, A. N. Hakim, Risk Management of Spaceport in Indonesia: Vulnerability Level of Biak Spaceport, Singapore, Springer Nature Singapore, (2022)

[44] D. Susanti, A. Rafikasari, Indonesian Spaceport Development: Defense and Security Perspectives, Astropolitics, 21(2–3), (2023), 150–163, doi: 10.1080/14777622.2023.2274918

[45] J.A. Lonsdale, C. Phillips, Space launches and the UK marine environment, Marine Policy, 129, (2021)