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Assessing benefits and risks between the space economies and the sustainable development goals

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As humanity's presence in space continues to advance, it is important to consider the positive and negative effects of space activities on sustainable development. This paper presents the findings from an expert elicitation process to assess the benefits and risks of the Earth-for-space, space-for-Earth, and space-for-space economies for the United Nations' Sustainable Development Goals (SDGs). Significant benefits and risks exist, with SDGs 6, 9, 12, 14, and 16 exhibiting numerous benefits, and SDGs 6, 8, 11, and 15 exhibiting various risks from activities across the space economies. Multi-sectoral, multi-disciplinary experts have identified benefits including space as a means to facilitate international agreement and cooperation, insights from space-based Earth observation, and advances in economic and technological development. Conversely, they identified risks of space advancement resulting in inequality, overexploitation of space resources, and the increase of global geopolitical tensions. These findings were used to suggest an SDG 18 for space, consisting of seven targets that address the concerns raised in the process.

KEYWORDS

space economy, sustainable development goals, space activity, sustainability, sustainable development, space resources

1 Introduction

Humanity's presence in space has grown rapidly and can be divided into three interconnected space economies – the "Earth-for-space," "space-for-Earth," and "space-for-space" economies (Richards et al., 2023). The development of each of these economies has far reaching implications for life on Earth, and the implementation of the United Nations (UN) Sustainable Development Goals (SDGs), refer Table 1.

The Earth-for-space economy consists of Earth infrastructure and activities that enable humanity to access or observe, and understand space, including launch pads, telescopes,

TABLE 1 UN SDGs.

SDG	Name	Description (from United Nations, 2023)
1	No Poverty	End poverty in all its forms everywhere
2	Zero Hunger	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
3	Good Health and Well-Being	Ensure healthy lives and promote wellbeing for all at all ages
4	Quality Education	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
5	Gender Equality	Achieve gender equality and empower all women and girls
6	Clean Water and Sanitation	Ensure availability and sustainable management of water and sanitation for all
7	Affordable and Clean Energy	Ensure access to affordable, reliable, sustainable and modern energy for all
8	Decent Work and Economic Growth	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
9	Industry, Innovation and Infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
10	Reduced Inequalities	Reduce inequality within and amongst countries
11	Sustainable Cities and Communities	Make cities and human settlements inclusive, safe, resilient and sustainable
12	Responsible Consumption and Production	Ensure sustainable consumption and production patterns
13	Climate Action	Take urgent action to combat climate change and its impacts
14	Life Below Water	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
15	Life on Land	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
16	Peace, Justice and Strong Institutions	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable and inclusive institutions at all levels
17	Partnerships for the Goals	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

and large antenna arrays. The space-for-Earth economy encompasses space-based infrastructure that provides benefits here on Earth, such as telecommunications and position, navigation, and timing (PNT) satellites. Finally, the space-for-space economy consists of infrastructure and activities that facilitate humanity's self-sustaining presence in space, such as *in-situ* resource utilisation, space agriculture, and in-space refuelling (Richards et al., 2023). Whilst, the Earth-for-space economy has been developed by humanity over centuries from use of stars for navigation to the invention of the first telescopes, the space-for-Earth and space-for-space economies have only emerged in recent decades.

Development across the space economies has taken place against the backdrop of a worsening climate emergency and sustainability crisis (Steffen et al., 2015; World Meteorological Organization, 2023), and increasing geopolitical tensions due to great power competition and dynamics (Mazarr, 2022). The complexity of the climate crisis has been highlighted through the interconnected Planetary Boundaries which illustrate that factors beyond emissions, such as biodiversity and ocean health, need to be addressed for humanity to mitigate the climate crisis and achieve a sustainable future (Rockstrom et al., 2009; Steffen et al., 2015; Rockstrom et al., 2023).

The space sector has played a vital role in better understanding climate change through monitoring Earth's land surface temperature, ocean temperature, ozone, sea level, sea ice, and soil moisture (ESA, 2023). Satellite communication technologies may support more equal access to knowledge and education, as well as to facilitate civilian and non-civilian (i.e., military) security activities (Ince, 2012; Maral et al., 2020).

Recently, scholars have called for an integrative approach to understanding earth-bound and space-based sustainability challenges given their interdependencies (Galli and Losch, 2019; Aglietti, 2020; Yap and Truffer, 2022; Yap and Kim, 2023). This perspective seeks to contribute in this direction by presenting how space activities may impact environmental, social and economic sustainability on Earth positively and negatively, and *vice versa*. It does so by systematically mapping and assessing benefits and risks that the three space economies pose to the implementation of the SDGs, and their respective targets. Based on an expert elicitation exercise, the results show that each of the different space economies has positive and negative impacts across the SDGs. This raises questions about whether existing space policy and governance are fit for addressing interrelated sustainability challenges, including the need for a more integrative approach to manage the synergies or trade-offs between the different sustainability considerations (Yap and Kim, 2023).

The SDGs have been chosen as the framework against which the impact of the three space economies is assessed because they cover, but are not limited to, the themes of people, planet, prosperity, and peace. The SDGs consist of 169 targets spread across 17 goals, with the overall aims of increasing sustainability and improving livelihoods for all, and have an implementation timeline from 2015–2030 (United Nations, 2023).

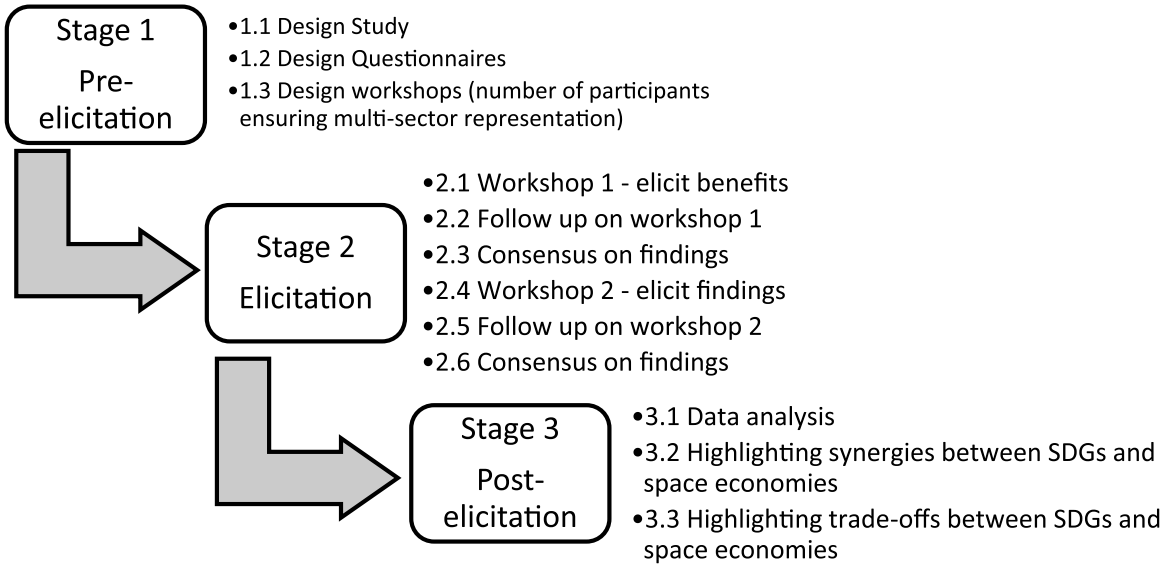

FIGURE 1
Expert elicitation process.

In the following, we describe an expert elicitation process facilitated by the University of Cambridge that was undertaken to explore more varied roles for space in a thriving future for humans, including negative impacts. To do this systematically, benefits and risks that the three space economies pose to the implementation of the SDGs, and their respective targets were assessed one by one. During the process, held under Chatham House Rule, experts from the fields of space and sustainability collaborated in hybrid (online/offline) and synchronic/a-synchronic manner and were assigned a series of SDGs and their subsequent targets. In the first gathering (a workshop to elicit and quantify expert opinion), participants were asked to assess the benefits of the three space economies on the implementation of the SDGs, and in the second workshop they were asked to assess the risks. Workshop time was also provided for participants to discuss any other aspects of the interaction between the space economies and the SDGs that had not been otherwise covered. Participants were asked to provide insight as to what a "Space SDG" might include in the event that one be developed. Results were recorded and combined in spreadsheets for further circulation and analysis, the results of which are detailed in this Perspective. In this Perspective, benefits and risks of a particular space economy that are associated with a particular SDG are referenced in brackets.

2 Methods

Results were captured through a three-stage expert elicitation process, refer Figure 1. Stage 1 of the process involved designing the study, the questionnaires, and the workshops. The expert participants were chosen due to their expertise in the areas of space and sustainability, and to reflect global diversity thus ensuring multi-sector representation. The selection criteria for participants was: demonstrated expertise in space and sustainability activities (policy, academic, or technical), affiliation with an organisation that undertakes space related research or work, and geographical location (with an aim to achieve global diversity in the workshops). In total, 21 participants accepted the invitation to be involved in the workshops, with attendance at workshops varying due to participants' pre-existing commitments. The work backgrounds of participants who accepted the invitation included: international policy organisations, universities, think-tanks, and an international engineering company.

The primary objectives of the two workshops were to identify:

- benefits of the space economies for the SDGs, and
- risks of the space economies for the SDGs.

The secondary objectives of the two workshops were to consider:

- What other benefits and risks are there from the space economies, and
- If a "Space SDG" were to be created what should it include?

Stage 2 of the elicitation process involved the workshops, and follow ups in order to have consensus on the findings once the spreadsheets across the SDGs and their targets were combined. In the workshops, participants were divided into four groups that were assigned SDGs: 1–4, 5–8, 9–12, and 13–17, and corresponding targets, and placed into online breakout rooms. The groups of participants were assigned the same SDGs for the two workshops. Each online breakout room had a session leader who was responsible for guiding the discussion and recording the findings in a spreadsheet. The first workshop investigated the benefits of the space economies for the SDGs, and the second workshop investigated the risks, with time provided to discuss the secondary objectives (listed above). All discussion in the workshops was recorded in spreadsheets that were created in Stage 1. Each workshop included time for introduction as a

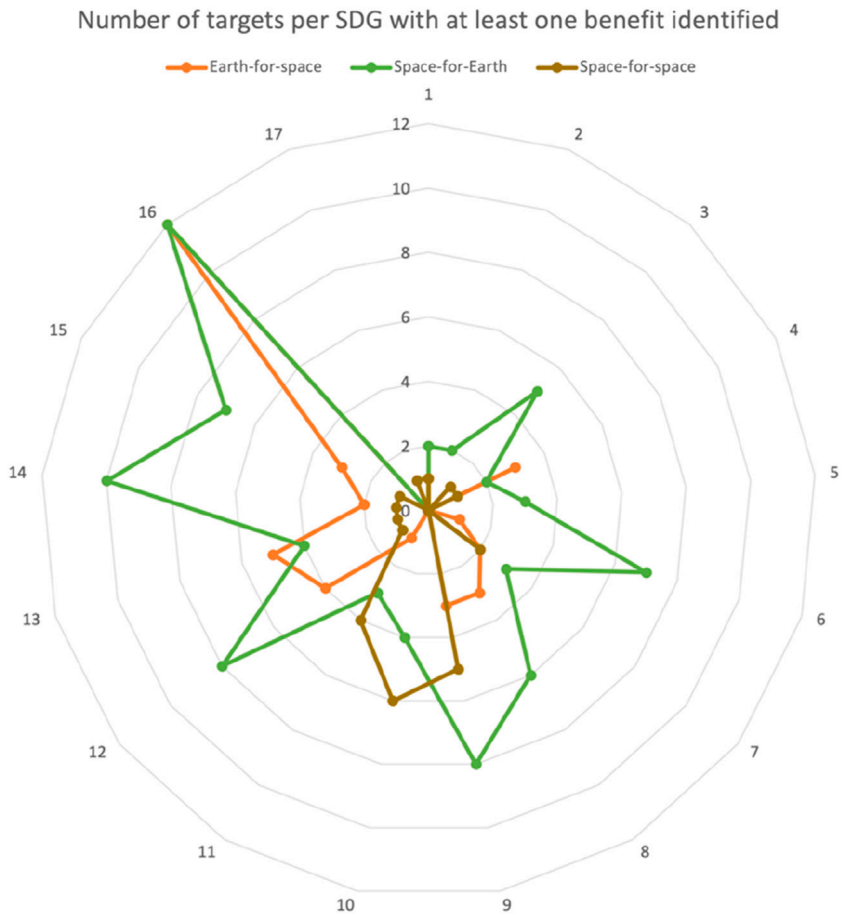

FIGURE 2
Identified benefits for the SDGs from the space economies.

group and to conclude at the end of the session. Qualitative discussion points from the workshops have been incorporated throughout this perspective.

Stage 3 of the elicitation process involved data analysis, and the highlighting of synergies and trade-offs between the SDGs and the space economies. In the data analysis, the benefit or risk number for a given SDG was determined by summing the number of targets in an SDG for which at least one risk or benefit was recorded in the workshop. This approach was chosen to account for the different amounts of time that were spent, and hence discussion that occurred, for different SDG targets in the workshops, and to ensure consistency in what a benefit or risk is across the workshop groups. This analysis enabled for the identification of critical SDGs, that is SDG areas for which governance should be prioritised.

3 Results

3.1 Identifying and capitalising on benefits early

Understanding how different space economies benefit the SDGs and their targets can help humanity to grow these economies safely and sustainably into the future, and do so in a way that benefits humanity in general. Through identifying these benefits early, particularly in the space-for-space economy, it is possible to develop and implement governance that ensures these benefits are promoted. Figure 2 illustrates the findings of the benefits of the three space economies on the implementation of the SDGs, and helps to identify *accelerated SDGs*, whose progress is accelerated by the space economies, including SDGs 6, 9, 12, 14, and 16.

3.1.1 Benefits from the Earth-for-space economy

Numerous benefits were highlighted by the participants for the SDGs and their targets, as well as broader benefits not specifically attributable to one SDG that stemmed from development of the Earth-for-space economy. Significant benefits for all SDGs from the development of the Earth-for-space economy have been identified, with many associated with the theme of a developed Earth-for-space economy providing a means to facilitate international agreement and cooperation (SDGs 4, 8, 9, 12, and 16). Furthermore, participants identified that the Earth-for-space economy has the potential to accelerate progress towards education and skills training (SDG 4), development of workers' rights, gender equality (SDG 8), and safeguarding of our skies from light pollution for astronomy and public benefit (SDG 11).

Participants identified that the development of Earth based space infrastructure can accelerate entrepreneurship (SDG 8), and can help society move away from highly toxic chemicals, e.g., in rocket fuels (SDG 12), due to pressure from operators and regulators that want to undertake responsible launch and hence increase sustainability (SDG 13). Benefits were identified through the inclusion of communities in decisions and development programmes (SDG 14), space companies investing in communities (SDG 15), and space companies asking how they can help charitable entities (SDG 13).

3.1.2 Benefits from the space-for-Earth economy

Similar to the benefits identified from the development of the Earth-for-space economy, benefits were identified that stem from the development of the Space-for-Earth economy. These benefits were primarily associated with space-based observation, whether that be through visual or more advanced instrumentation observations, and that data if open-source can boost monitoring and connectivity (SDG 1).

Participants identified benefits of a developed space-for-Earth economy through observation for weather (SDG 1), crop monitoring (SDG 2), agricultural moisture levels (SDG 2), harvest progress (SDG 2), environmental change (SDG 3, and 6), drought (SDG 3, and 6), and space-based observation for conflict resolution (SDG 9) and resilience building (SDG 9). Furthermore, space-based observation can support inspections and monitoring related to water and sanitation (SDG 4), monitoring of the drug trade (SDG 3), and contribute to the improvement of resource use and efficiencies (SDG 7, and 9) whilst also facilitating disaster preparedness (SDG 11) and climate resilience (SDG 13).

A developed space-for-Earth economy provides increased connectivity that can in turn facilitate telehealth services (SDG 3) and educational services (SDG 4, and 5) to remote locations, drive growth in the financial sector (SDG 8), and reduce inequality through access to data (SDG 10). In addition to observational and connectivity benefits, a developed space-for-Earth economy provides numerous opportunities for the transfer and impact of advanced technology throughout society, such as: space-based solar power as a new source of energy (SDG 7), advanced optics and propulsion technology (SDG 9), and new industrial sectors from the creation of in-orbit infrastructure (SDG 9).

3.1.3 Benefits from the space-for-space economy

Benefits for the SDGs from developing the space-for-space economy were associated with advanced technological developments, technology transfer, increasing global cohesiveness, and inspiring humanity. Furthermore, it was identified that if a more redistributive economic model can be developed and implemented, then the benefits of a space-for-space economy could be experienced across humanity (SDG 1).

Amongst possible technological developments identified as beneficial to the SDGs was that space medicine research (SDG 3), particularly in the field of cancer research, has the potential to accelerate progress towards health-related SDGs. These benefits are not limited to the space-for-space economy, and may be realised through space-for-Earth activities. Benefits are likely to be expected from space resource development and use, including asteroid mining (SDG 9), and the possibilities of space-based power as a new means of power generation, storage, and transmission (SDG 13). Technology transfer possibilities were identified for space resources, space bases, closed-loop life support, solar panel manufacturing, and materials research and development (SDG 9, and 11). It was identified that extensive development of the space-for-space economy resulting in human bases in space will help humanity to mitigate many of the risks that are associated with being a one-planetary species. Despite these potential benefits, the development and use of space resources can bring undesirable risks, which is examined in the following subsection.

3.2 Identifying and mitigating risks early

Understanding the impacts of the space economies on the SDGs, is a complex and extensive task. To develop a comprehensive understanding, the risks posed by each space economy to each of the SDGs and their associated targets were examined. Figure 3 illustrates the findings from the workshops of the risks of the space economies on the implementation of the SDGs, and helps identify threatened SDGs that are put at risk by the development of the space economies, including SDGs 6, 8, 11, and 15.

3.2.1 Risks from the Earth-for-space economy

Risks associated with the Earth-for-space economy identified in the workshops were associated with the limitations and challenges experienced by developing nations and their access to space, regulations and licensing, and the environmental effects of Earth-for-space activities. Differential development of the space industry was highlighted as a risk potentially leading to a lack of inclusivity (SDG 9), which may in turn lead to concentration of skills into a minority of states that have the education and capacity to invest in space technology (SDG 10), and inequitable access to the Earth-for-space economy benefits (SDG 11).

Risks associated with regulations and licensing regarding the Earth-for-space economy were primarily associated with the relative advantages of technological development possessed by certain nations providing them with speed of deployment in the competition to reach and occupy space. Competition from states, or private companies, to participate in the space economy may lead to risky investments (SDG 9), and may result in loss of life as emerging space powers develop launch capabilities (SDG 9). Similarly, a "race to the bottom" of approving space activity licences may occur with potentially adverse impacts for both the environment (SDG 13), and human life, as well as the potential for corruption to exist (SDG 16).

Environmental risks are widespread, with emerging powers potentially launching with less sustainable technology (SDG 9), whereby sea launches/returns can be detrimental to marine life (SDG 14), and contribute to supply chain emissions and pollution (SDG 13, and 15). Due to the limited frameworks in place, there is also the risk of not recognising the wider space economy as a natural resource, thereby leading to resource overexploitation (SDG 12). Mitigation of these Earth-for-space related risks is threatened by lobbying from companies, that may

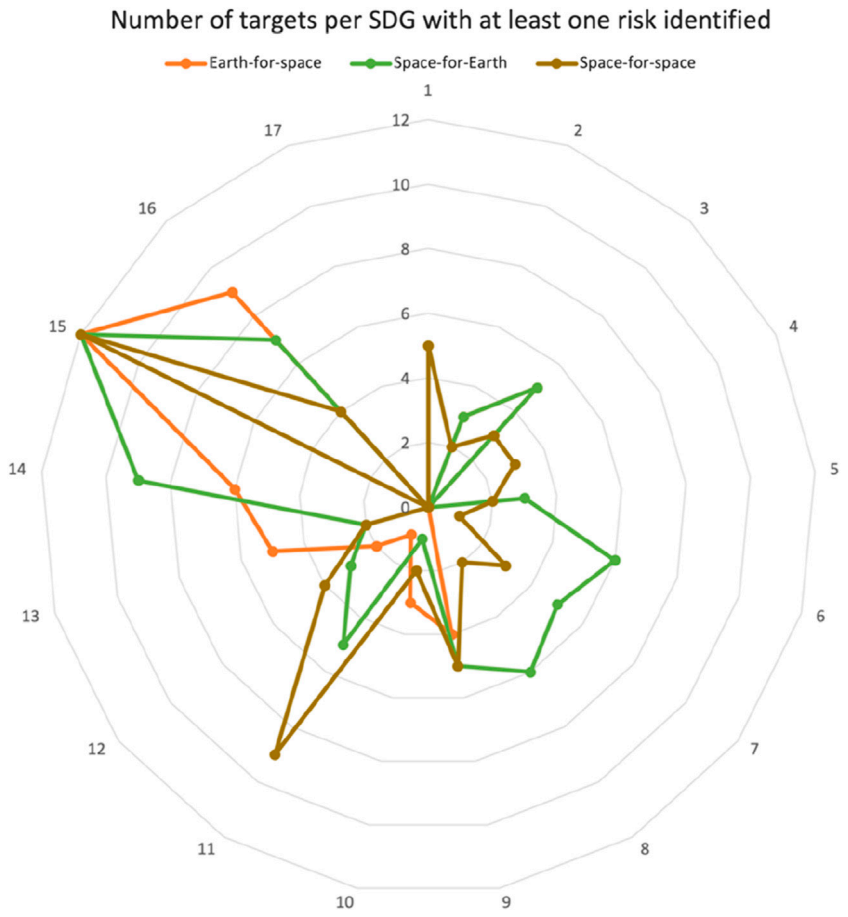

FIGURE 3
Identified risks for the SDGs from the space economies.

undermine climate and sustainability policies and targets (SDG 13).

3.2.2 Risks from the space-for-Earth economy

Identified risks to the SDGs from the space-for-Earth economy were across three areas: equitable access to data, space debris, and competition leading to increased geopolitical tensions. Whilst space observation data associated with developments in the space-for-Earth economy has already demonstrated benefits, there is a risk that this data may not be widely accessible, such as small holders not having access to agricultural data (SDG 2). There are other risks associated with space observation and data, such as the potential for it to restrict civil liberties and privacy if used in the monitoring of behaviour (SDG 3), for it to inhibit the green transition (SDG 7) if used to find new mineral sites, or for it to be used by authoritarian states to discriminate or suppress dissent (SDG 10). There is generally a risk of uneven access to space data (SDG 11). It was also highlighted that spectrum access is difficult and as such needs to be treated as a resource (SDG 13). Furthermore, whilst space data and communication has been touted as a solution for education in remote communities, there is a risk that teleschool by itself is not sufficient in satisfying educational needs (SDG 4), and that remote communities may not have all ground infrastructure required to make use of the available space data and communications (SDG 4).

Space debris related risks are extensive and are rapidly increasing as the space-for-Earth economy grows (SDG 5, 6, and 8). Similarly, an increasingly overcrowded Low Earth Orbit (LEO) risks accidents and consequential problems such as LEO becoming uninsurable (SDG 13). This subsequently increases deorbiting pollution (SDG 6), and may render space tourism not sustainable (SDG 8). Action on addressing space debris related risks in the space-for-Earth economy relies on extensive international cooperation, which may be undermined by lobbying from certain states and private actors (SDG 13).

Risks associated with geopolitical competition exist across activities associated with all three space economies. Intensified geopolitical competition has many potential causes including: competition due to space-based engineering or space power technologies (SDG 7), conflict over space resources (SDG 16), and over the impact of space-for-Earth activities on Earth ecosystems (SDG 15). There are also risks posed by potentially malicious activities in space (SDG 16), and the exclusion of developing states from the space-for-Earth economy (SDG 9) may increase geopolitical tensions. Whilst space is inspirational and can encourage people to pursue studies and careers in STEM fields, there is a risk that if the economies are not developed fairly then the workforce will not be representative of humanity, whether that be gender or country (SDG 4).

3.2.3 Risks from the space-for-space economy

Whilst nascent, the space-for-space economy poses numerous risks with respect to the SDGs. These risks are clustered in the areas of conflict and geopolitical tension, inequality, and loss of connection to Earth. Space-for-space economy conflict has many potential causes including from space resource competition (SDG 1, 6, and 7), the deployment of risky technology for competitive advantage that malfunctions (SDG 9), general risk-taking behaviour (SDG 9), malicious activities in space (SDG 16), and a lack of regulation on private actors from States (SDG 12, and 16).

A burgeoning space-for-space economy is likely to involve extensive space resource use, potentially even asteroid mining which could increase inequality as the riches of space resources is concentrated either amongst select private companies, ultra-rich individuals, or nation States, this would in turn have negative impacts for global equality (SDG 1, and 9). The extraction and use of space resources has the potential not only to create inequalities of wealth and access through a first-mover advantage, there is also the potential for degradation of and harm to unique locations such as the surface of the Moon, through mining, and even desecration of historic sites, such as the Apollo landing sites, in accessing resources, such as Helium-3. Proposals also exist for the terraforming of Mars and other locations, destroying their unique attributes and potential evidence of undiscovered lifeforms (Deudney, 2020). Furthermore, an advanced space-for-space economy will have advanced space technology resulting from innovation and R&D. The ownership and usage of this technology could contribute to deepening inequalities between nations (SDG 3). As humanity develops the space-for-space economy and becomes a spacefaring civilisation, there is a risk of loss of connection to humanity's history, culture, and heritage on Earth (SDG 11). As humanity settles different areas of the Solar System, and beyond, conflict may become more likely with the loss of common heritage and the development of technologies with destructive potential (Deudney, 2020). Ways to ensure that humanity's history is not lost need to be explored, and space archaeology will have an important role in this endeavour.

4 Discussion

To safely and sustainably grow the space economies in such a way that the SDGs and hence development on Earth is not risked but is accelerated, the role of the space economies in addressing global challenges and the required governance mechanisms need to be identified.

4.1 Addressing global challenges

The role of the space economies in addressing both current and future global challenges is extensive. Humanity is facing a myriad of problems, including accelerating climate change, regulation of disruptive technology such as artificial intelligence (AI), and rising geopolitical tensions and conflict. Technology and cooperation across the space economies as they develop have the potential to help address and solve these challenges.

Climate related solutions are already under development in the space-for-Earth and space-for-space economies. Space observation capabilities have facilitated the monitoring of Earth's ecosystems including ocean health (EU Science Hub, 2023), biodiversity (Bae et al., 2019), emissions (Liu et al., 2020), and levels of deforestation (Moffette et al., 2021). Continued advancements in space-based observation technology, together with ground and air-based observation tools will be able to provide us with increasingly comprehensive and accurate data on the health of Earth's ecosystems. Importantly, space technology has the potential to play a crucial role in identifying and monitoring environmental tipping points (Setiawan et al., 2022).

Space exploration is a new frontier for cooperation between private companies and nation States, that is public-private partnerships. If humanity wants to become truly spacefaring then this will require extensive collaboration between companies and States to achieve the necessary technological advancements. However, this relies on the creation of effective governance frameworks, communication, and the willingness of companies and States to cooperate. This aspiration for the use of space as a domain for peaceful co-operation was outlined in the Outer Space Treaty, which includes provisions to this effect such as Article 1, which states "The exploration and use of outer space, including the Moon and other celestial bodies, shall be carried on for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind." It requires that outer space "shall be free for exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law" (Outer Space Treaty, 1967). However, subsequent decades have witnessed increasing competition in the space domain and a consequent deterioration in the geopolitical context which has meant that space remains a place for great power and commercial competition.

It is to be hoped that the Artemis Accords, will provide reinforcement to the principles of peaceful and co-operative uses of outer space. The Artemis Accords are expressed to create a "shared vision for principles, grounded in the Outer Space Treaty of 1967, to create a safe and transparent environment which facilitates exploration, science, and commercial activities for all of humanity to enjoy" (NASA, 2020). The Accords include provisions such as peaceful purposes, transparency, interoperability, mitigation of space debris and emergency assistance, but also contain more contentious provisions dealing with extraction and use of space resources and deconfliction of space activities, foreshadowing the development of space "safety zones."

The space economies also have potential in addressing global challenges such as through technological developments in space agriculture and space medicine, which could result in benefits here on Earth for agriculture and medicine for numerous diseases (Mortimer and Gilliham, 2022; Renault, 2022), including possible advances in cancer treatments (Prasanth et al., 2020; Pavez Lorie et al., 2021). Furthermore, the development of the space-for-space economy into one that identifies, processes, and utilises space resources, such as asteroids, could see currently rare and expensive commodities become common and affordable (Butkevičienė and Rabitz, 2022).

4.2 Facilitating strong governance across complex domains

Governance across the space economies needs to be developed through extensive consultation with industry and participation from all nation States, e.g., through the co-ordination efforts of the United Nations Office for Outer Space Affairs (UNOOSA) in order to advance responsible and sustainable uses of space. Governance needs to help shape the future of the space economies into one that is beneficial for humanity and facilitates the achievement of the SDGs but at the same time needs to be non-restrictive and allow for innovation and collaboration. The aims of any governance mechanisms for the space economies should ensure that there is responsible development and use of technology, and that space is identified as a resource that belongs to, and benefits, all. Building upon the framework provided by the Outer Space Treaty and subsequent UN space treaties, future space activities must coordinated and undertaken in such a way that benefits all of humanity. Unfortunately, given current global strategic circumstances, it is unlikely that any further multilateral space treaties will be concluded in the near future. The Outer Space Treaty, regarded as the constitution of outer space, has provided a solid international legal framework for peaceful uses of outer space since 1967. Article VI of the Outer Space Treaty requires States to "bear international responsibility for national activities in outer space" whether such activities are undertaken by government or non-government entities, and states are required to provide authorisation and continuing supervision of such activities. This obligation provides the basis for domestic space laws. Despite this framework, strategic and political rivalries are preventing any progress on matters such as the prohibition of destructive ASAT tests and agreement regarding the prevention of an arms race in outer space. The UN Committee on Peaceful Uses of Outer Space is limited in effect by operating by consensus and deferring matters of arms control to the Committee for Disarmament. Hence matters of governance will need to be explored in other venues, including collaborative contractual partnerships such as the Artemis Accords which, while binding only the partners to such agreements, may in turn shape evolution of customary international law (de Zwart, 2021).

Humanity scans the skies for signals from extraterrestrial intelligence and has sent far-reaching signals and probes into space. The remote risk of signals being received by unfriendly extraterrestrials exists. However, currently the planned and proposed activities of humans in space pose a far greater threat to the peaceful uses of space and possibility of harm on Earth. As humanity returns to the Moon, goes to Mars, and beyond, there will be sample return missions, where soil or other items of interest will be returned to Earth for further analysis. There is a risk of contamination from such sample return missions and governance needs to be further developed to mitigate this risk as we learn more about the environmental conditions of sites to be visited. Work is being undertaken by the International Science Council's Committee on Space Research (COSPAR) which has developed the COSPAR Policy on Planetary Protection. This policy, identifies standards to be applied to scientific space missions to ensure that evidence of life forms at the destination in space is not compromised or destroyed by biological contamination from Earth and that Earth is protected from contamination from a returning space mission (COSPAR, 2021). This Policy is reviewed regularly in light of evolving space technologies and enhanced understanding of the applicable conditions and constraints. But these are voluntary, non-binding guidelines and as space activity increases, more binding rules may be required.

4.3 Charting the path forward with a "space SDG"

Given humanity's future in space and the growing space economies, consideration needs to be given as to how a "Space SDG" could be created, and what it would include. Ideally, a space SDG would be included in the current SDGs as Goal 18. However, inclusion in the post-2030 development goals that may follow on from the UN Summit of the Future, which is scheduled to take place in 2024 and will include an "Outer Space Dialogue," would be more achievable. For the purposes of this discussion, it will be assumed that a space SDG could be included as Goal 18 *Sustainable Space Exploration* in the current SDGs, and consider space to be an integral part of sustainable development (Galli and Losch, 2019; Losch, 2020). Goal 18 would use lessons learned from the existing SDGs, as well as insights from these workshops, to create a goal with effective targets that can ensure that the space economies are developed responsibly and for the benefit of all of humanity.

From the workshop findings, it is evident that there were strong themes associated with the identified benefits and risks. Importantly, the space economies have been identified as being able to contribute towards mitigating climate crisis, developing advances in medicine, and advancing global education and skills training. However, themes of inequality, overexploitation of space resources, and increasing geopolitical tensions were repeatedly raised during the workshop sessions. Any SDG for Space must acknowledge and seek to minimise these risks whilst ensuring that the potential benefits materialise. Goal 18 *Sustainable Space Exploration* needs to ensure that all nations have the opportunity to participate in and have access to the space economies, and needs to identify the Earth's orbit and certain regions of the Moon and Mars as limited resources, whilst calling for the sustainable exploration and use of the space environment.

The proposed goal, refer Section 4.4, consists of seven targets. The first two targets ensure that all countries have the opportunity to participate in the future of the space economies, such that no country is left behind or excluded. The third target seeks to ensure that valuable data from the space-for-Earth economy is not exclusively withheld, and that all nations are equipped with the geospatial infrastructure to process and analyse space data (Kaleagasi et al., 2022). The fourth target addresses a key theme from the workshops of space debris and pollution. The fifth target is concerned with the space-for-space economy, and strives to ensure that both the benefits of space resources are available to all of humanity and that space-for-space economy activity does not increase geopolitical tensions. The final two targets are associated with long-term goals of the space-for-space economy, and by specifying that an international coalition of humans are to land on the Moon and Mars respectively, the targets seek to foster international collaboration and minimise, and potentially reduce,

geopolitical tensions. Concerns from the workshop regarding inequality are addressed by targets 1, 2, 3, and 5. Concerns over the exploitation of space resources are primarily addressed by target 5, and that of global geopolitical tensions is primarily addressed by targets 1 and 2.

4.4 SDG 18: sustainable space exploration

The purpose of, and the targets that constitute the proposed SDG 18: Sustainable Space Exploration are provided below. *Promote the peaceful, inclusive, and sustainable exploration and utilisation of space.*

1. By 2030 ensure that all nations have a national or regional space agency.
2. By 2030 ensure participation and direct representation of all nations in UNOOSA.
3. By 2030 ensure that all nations have access to space data that has been collected of their territory and the geospatial infrastructure to process and utilise that data.
4. By 2030 all objects sent to space from Earth, or constructed in space, must be sustainably disposed of in line with UN Long Term Space Sustainability Guidelines.
5. By 2030 develop an international framework to govern the sustainable extraction, processing, and use of space resources, and promote equitable access and benefits for all nations.
6. By 2030 establish an international coalition of humans on the Moon, with the mission of building the foundations for a sustainable human presence in space.
7. By 2035 establish an international coalition of humans on Mars.

5 Conclusion

Humanity's actions in space and the development of the three space economies have widespread impact on life on Earth, presenting both benefits and risks to the SDGs. The workshops identified benefits including space as a means to facilitate international agreement and cooperation, insights from space-based Earth observation, and advances in economic and technological development, as well as risks of space advancement resulting in inequality, overexploitation of space resources, and the increasing of global geopolitical tensions. As humanity advances all three space economies, it is essential that space activities are guided by sustainable development otherwise humanity's activities in space risk becoming monopolised, inequitable, and may potentially lead to increased geopolitical tensions and conflict, on Earth or in space. A Space SDG would set the foundations for an international framework to mitigate the risks and promote the benefits associated with the space economies, whilst also fostering international collaboration.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study of human participants in accordance with the local legislation and institutional requirements.

Author contributions

TC: Writing–original draft, Writing–review and editing. JB: Writing–original draft, Writing–review and editing. GZ: Writing–original draft, Writing–review and editing. BK: Writing–original draft, Writing–review and editing. MZ: Writing–original draft, Writing–review and editing. AT: Writing–original draft, Writing–review and editing. CR: Writing–original draft, Writing–review and editing. BC: Writing–original draft, Writing–review and editing. BM: Writing–original draft, Writing–review and editing. AA: Writing–original draft, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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