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Four Alternative Scenarios of Commons in Space: Prospects and Challenges

COMMONS IN SPACE (GUEST EDITORS: MARCO A. JANSSEN AND XIAO-SHAN YAP)

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XIAO-SHAN YAP
MARCO A. JANSSEN
TIMIEBI AGANABA
RICHARD TUTTON
KARLIJN KORPERSHOEK
GEORGE PROFITILIOTIS
FLORIAN RABITZ
MAJAL SHINY SUBBIAH
LEON WAGENKNECHT

*Author affiliations can be found in the back matter of this article

ABSTRACT

The rapid expansion of human activities in outer space is likely to bring new economic, social, and political dilemmas in the next 50 to 100 years. Future governance will have to increasingly juggle earth-space social justice, resource trade-offs, and environmental sustainability issues. This poses new challenges to the governance of global commons, i.e. whether existing studies are fit to address commons in a global context and whether the governance of outer space commons (dis)integrates with Earth-bound sustainability governance. To explore these questions, this study uses scenario-building techniques to generate alternative future scenarios via a workshop conducted during the 2022 Commons in Space conference. We derived four future scenarios based on two major contextual conditions: (i) the degree of equity in resource distribution in space, and (ii) the degree of integration with Earth-bound sustainability, more specifically Earth system governance. The four alternative scenarios are (i) Space Cartel in which the use of space resources becomes dominated by the rich and powerful; (ii) Earth-centric Gold Rush in which the current 'business as usual' continues; (iii) Open Space (also Space Utopia) in which open access of space resources leads to thriving developments in space at the expense of sustainability on Earth; and finally, (iv) Earth-Space Sustainability in which challenges on Earth and in space are addressed through an integrative governance model. Based on the challenges identified from these scenarios, we discuss specific as well as cross-cutting implications for policy and governance to better address commons in space in the future.

CORRESPONDING AUTHOR:
Xiao-Shan Yap
EPFL, Switzerland
xiao-shan.yap@epfl.ch
x.s.yap@uu.nl

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1. INTRODUCTION

There have been rapid developments in human activities in space over the last 1.5 decades, ranging from advanced satellite infrastructures especially in low-Earth-orbit to new missions on the Moon and Mars, driven by technological innovations and diversification of actors in the sector (Jakhu et al., 2017). However, these new and innovative activities are rather poorly regulated due to an arguably weak global space governance regime. As a consequence, how space resources will be accessed, used, and distributed in the next five decades is highly uncertain, which can impact sustainability transitions and transformations on Earth in various ways. Against the background of intensifying enclosure tendencies, with both powerful nation-states and large multinational companies vying for access to and control over space resources, such uncertainty leads to challenges in identifying space governance needs and the formulation of appropriate institutional arrangements. To better anticipate future developments, scenario studies have been reckoned as a useful tool to collectively identify informed, plausible futures for identifying the opportunities and challenges of governance. Thus far, a few scenario studies on space developments have been conducted (elaborated in section 2.3), but mainly on how national space agencies and industries could navigate different futures to stay competitive in terms of military or business interests.

Studies on sustainability scenarios can be powerful, such as the "Limits to Growth" report by the Club of Rome (Meadows et al., 1972) which has been instrumental in catalyzing the environmental movement in the 1970s by providing an integrated analysis of alternative development futures based on the availability of physical resources on Earth. Scientists and space activists already engaged with the report at that time through their own ways of futuring, which portrayed outer space as the frontier of opportunities to overcome a future of stagnation (O'Neill, 1974, 1975a, 1975b; Vajk, 1976). Fifty years later, technological advancements and commercialization of space activities reinforce such a future prospect as a solution to manifold sustainability crises on Earth. It is unclear how such a prospect will develop in the future especially when considering the various types of actors involved, each of which may have different vested interests. As a consequence, the kind of environmental and social implications that future space governance has to address becomes extremely vague.

To better anticipate governance needs, this paper scopes alternative futures of commons in space which leads to four different scenarios underpinned by different contextual factors, pointing to different environmental and social consequences. The scenarios were originally workshopped by participants in the 2022 Commons in Space virtual conference and made use of research in the commons studies. The scope of issues related to commons in space (also space commons hereafter) is vast and exploring all issues is beyond the capacity of the current paper. We therefore focus on the physical use of resources, such as the extraction of minerals on celestial bodies and the occupation of physical orbital slots that can also cause the accumulation of space debris. Meanwhile, we table other similarly important issues such as light pollution, planetary protection, and cultural heritage for the moment. Although focusing on the physical use of resources may resonate with the approach of the Limits to Growth report, our exploration of scenarios devotes attention to challenges related to globally uneven development and injustice.

The four alternative scenarios identified in this paper are based on variations in terms of who has access to resources in space and how those resources would be distributed: 1) *Space Cartel,* as the use of space resources becomes dominated by the rich and powerful; 2) *Earth-centric Gold Rush*, as the current 'business as usual' continues in space which leads to unsustainable use of resources especially in the low-Earth-orbit and other celestial bodies that ultimately limits the future access to space; 3) *Open Space (also Space Utopia),* as open access of space resources leads to thriving developments in space at the expense of sustainable development on Earth; and finally, 4) *Earth-Space Sustainability*, where challenges on Earth and in space are addressed simultaneously through an integrative governance model to ensure environmental integrity and justice in a multi-planetary context (Yap and Kim, 2023). Based on these different future scenarios, we discuss their potential implications and strategies to govern the use of common resources in space.

The rest of the paper proceeds as follows. Section 2 provides a literature review of existing studies on the governance of global commons and how they may inform our study, the usefulness of futuring and scenario building but also the limitations in recent applications, and how the concept of sociotechnical imaginaries may help inform the future governance of commons in space. Section 3 elaborates on the methodology and presents the four alternative frames of future scenarios. Section 4 presents the constructed narratives for the four scenarios based on a list of identified contextual conditions. In Section 5, we discuss specific as well as cross-cutting implications for policy and governance drawing on the scenarios we developed. We conclude in Section 6 with a broader generalization of our study with the commons literature and provide suggestions for future research.

2. GLOBAL COMMONS AND FUTURING

This section begins with an elaboration on the limitations of applying existing governance approaches of local commons in the context of global commons, and how studying physical resources in outer space as a case of global commons may inspire the field of commons studies. Additionally, our exploration of space resource governance in the next 50 – 100 years borrows insights from studies on futuring and imaginaries, which offer us a broader set of conceptual tools to re-imagine alternative forms of governing global commons and their respective implications in different future states.

GOVERNANCE OF GLOBAL COMMONS

Global commons resources refer to resources that are shared on a global scale beyond sovereign nations, such as the atmosphere, carbon cycle, high seas, deep seabeds, polar regions, and outer space (Freeman, 2016). The success conditions for governing local commons are generally well-studied (Ostrom, 1990), but such understanding does not exist yet for global commons. For local commons, communities are able to govern their shared resources when, for instance, there are clearly defined boundaries of resources and resource users; resource users participate in creating institutional arrangements; and resources and resource use are monitored while rule infractions are enforced (Ostrom, 1990; Baggio et al., 2016). Such conditions are typically not met at the global level. It is especially difficult to create international treaties with credible enforcement mechanisms. For instance, Hoffman et al. (2022) provide a meta-analysis of international treaties and found that the existence of enforcement mechanisms was one of the few conditions for successful outcomes, but most international treaties have no credible enforcement mechanisms – partly due to the lack of an overarching global authority accepted by most nations. At the local level, the ability to solve disputes and find collective arrangements can be facilitated by social networks and trust relationships. Such relationships are more difficult to develop at the global level and, due to the physical distances, individuals and nations experience different conditions and have very diverse interests that prevent mutual consensus. In recent years, more discussions on the role of polycentric governance in addressing global commons have emerged (Ostrom, 2010; Jordan et al., 2015), including in the context of outer space (Weeden and Chow, 2012). This can be perceived as a response to deadlock in conventional multilateral settings: where centralized inter-state bargaining is prone to least-common denominator outcomes, polycentric governance systems offer ways for ambitious, issue-specific cooperation within smaller club settings. In terms of advantages, polycentric governance systems are typically considered flexible in responding to new governance challenges and as a testbed for governance innovation and experimentation (Jordan et al. 2018). Conversely, polycentrism may suffer from inconsistencies between elemental institutional components, legitimacy challenges, and methodological difficulties in evaluating its aggregate effectiveness (see Keohane and Victor 2011, Kim, 2020). We will return to these issues when discussing the governance implications of our four scenarios in sections 4 and 5.

There are two similar cases of global commons that resemble the challenges in outer space. Cyberspace, a network of networks without national borders, is one example of a global commons that illustrates the difficulties of devising fair and equitable solutions at the international level. The supply of internet services by private actors internalizes many of the costs and benefits of cyberspace (Mueller, 2020). The relative success of cyberspace as a global commons is dependent on the creation and adoption of protocols and standards that enable it to connect various components functionally in cyberspace. Debates over intellectual property and digital rights management, however, consistently indicate the presence of enclosure as a fundamental threat to the cyber commons.

Deep-seabed mining in international waters, which exploits a different type of commons, can be seen as a model of mining in outer space (Feichtner, 2019; Butkevičienė and Rabitz 2022). The ocean floor and its subsoil contain many rare metals that are crucial for diverse renewable energy- and zero-carbon transportation technologies (Levin et al., 2020). Commercial exploitation is still in the planning phase although some companies are operating under exploration contracts and the supervision of the International Seabed Authority (ISA) – an intergovernmental agency created by the United Nations Convention on the Laws of the Sea. For all international waters, the seabed, its subsoil, and the mineral resources constitute the common heritage of humankind and the ISA is mandated to ensure that the benefits arising from exploration and exploitation are shared globally in a fair and equitable manner. However, the current capacity of the ISA for monitoring and enforcement is often considered inadequate (Kim, 2017; Levin et al., 2020). The influence of corporate actors in the governance of the ISA also gives rise to concerns over potential regulatory capture.

Space resources are transnational commons and therefore perceivable as global commons. Their status under international law is complex, with the 1967 Outer Space Treaty precluding "national appropriation by claim of sovereignty, by means of use or occupation, or by any other means" (Article 2), whereas "the exploration and

use of outer space [...] shall be carried out for the benefit and in the interests of all countries [...] and shall be the province of all [hu]mankind" (Article 1). These provisions have increasingly become a matter of contention due to growing political and commercial interest in the exploration and exploitation of various space resources (Goehring, 2021). The United States (US), Japan, Luxembourg, and the United Arab Emirates (UAE) have in recent years all passed domestic legislation that in principle allows property claims over space resources from natural- and legal entities under their respective jurisdictions. The US-led Artemis Accords, a new multilateral instrument with currently 24 parties, similarly broaden the scope for property claims by commercial operators. These developments highlight a distinct tendency towards an enclosure of the space commons. We therefore see a growing urgency to explore alternative scenarios for the space commons that go beyond market-based appropriation by multinational space companies and technologically advanced nation-states.

THE ROLE OF FUTURING AND EXISTING STUDIES ON OUTER SPACE

Our engagement with futures and scenarios on the commons in space draws on perspectives from different fields, such as Futures Studies and Science and Technology Studies. The academic field of Futures Studies comprises systematic and explicit contemplation of alternative futures, on the basis of particular theories, methods, and values to facilitate preparation for the unpredictable. This field aims at demystifying the future, making possibilities for the future more known, and increasing human influence over the future (Bell, 2009). In this field, the term "futures" is conceptualized and used as a plural in order to highlight that approaching the plurality of futures is a democratic process that involves the envisioning, imagination, design, and creation of many plausible futures. In other words, the plurality of futures indicates a strong contrast with other traditional predictive approaches that contribute towards attempts to control a singular future and perpetuate efforts of the dominant power structures (Gidley, 2017). The field of Futures Studies includes but is not limited to forecasting. Indeed, alongside the more quantitative and predictive field of forecasting that focuses on extrapolating the past into time horizons that are yet to come, Futures Studies also include the field of strategic foresight, which is usually qualitative and non-predictive and focuses on producing a variety of alternative futures, oftentimes by means of scenarios (Poli, 2017).

Strategic foresight is "a systematic approach to learning and understanding possible futures and building shared visions and is aimed at guiding and enabling present-day decisions" (Iden, et al., 2017, p. 94). Scenarios have been defined as "an internally consistent view of what the future might turn out to be" (Porter, 1985, p. 63). In a strategic foresight process, scenarios act as mental models that offer a structured and practical avenue for analysis, communication, and learning, as—on the one hand—they reveal alternative possibilities about the future, and—on the other hand—they introduce diverse ways of critical evaluation of the imagined future (Ringland, 2010). Fundamentally, the use of scenarios is a way of navigating times of uncertainty (Bohensky, et al., 2006), especially in proactive policy-making (van Dorsser, et al., 2020), and as a technique to rehearse the futures to enable the experimentation of alternative outcomes of the present (Mallard & Lakoff, 2011). In this sense, scenarios can be important in two ways: they can represent different visions of the future, which elicit a normative response since some of them might be more desirable than others; and they can represent different views on how things might unfold, which call for the description of the different logics and underlying forces that shape them, since these factors provide a foundation for action in the present (van der Heijden, 2005).

In particular, the scenario-building method of the Intuitive Logics school is useful compared to the other alternatives of the Probabilistic Modified Trends school, which produces descriptive quantitative scenarios around a baseline by means of extrapolation, and of the "La prospective" school, which produces descriptive quantitative and qualitative scenarios that could possibly evolve by means of structural analysis and stakeholder interviews (Amer, et al., 2013; Bradfield, et al., 2005). The Intuitive Logics school can have either a narrow or a broader scope and can be used in a range of cases, from making sense of situations and developing strategy in a one-time fashion, to facilitating learning in a continuous fashion. It aims at producing either descriptive or normative qualitative scenarios that are equally plausible, by using intuition, brainstorming techniques, research, and expert opinion to define the logics that underpin the organizing principles pertaining to the matter of interest.

In the context of outer space, scenario planning and foresight (also in the form of serious games and anticipatory simulations) are used for strategic decision-making and to support a variety of stakeholders with differing needs in preparing for alternate futures. These have been developed differently based on intended audiences and the context of the developers. For instance, the business community may rely on such support tools provided by consulting or advisory firms. These include consultancy reports that explicate alternative future scenarios of the space sector based on different levels of commercial value generation

and collaborative governance (see for example, McKinsey & Company, 2022). The scenarios range from an accessible, self-sustaining space economy to a case in which a series of space disasters led governments to eventually reassert primary responsibility for space activities.

In the realm of the military, such as the US Space Command, more than 350 military and civilian experts from 27 agencies around the country and abroad participated in the Schriever War Games in one year to explore multi-domain space operations. As part of the Schriever War Games, the military identifies a scenario that they envision facing a decade in the future and builds toolkits of solutions and capabilities that they can use in those scenarios. The 2020 version of the wargames, led by the US Space Force for the first time, resulted in suggestions to inform the development of a roadmap on space domain alliances (Martin, 2020). Meanwhile, civil space agencies such as the UK Space Agency have carried out their iteration of scenario planning, such as by using the Oxford Scenario Planning Approach (Ramirez and Wilkinson, 2016) from an economic perspective. NASA has also sought foresight services such as from The Aerospace Corporation's Center for Space Policy and Strategy to prepare the space agency for a variety of plausible outcomes in the face of uncertainty.

Additionally, inter-governmental agencies, nonprofits, and academia also use futuring tools in outer space studies, such as for educational purposes (Ramirez, 2015) or to develop response activities for disaster planning. For instance, the UN-endorsed Space Mission Planning Advisory Group (SMPAG) uses scenario building to prepare for an international response to a threat by a near-Earth object through information exchange, development of options for collaborative research and mission opportunities, and threat mitigation planning activities. Programs as such contribute to building capabilities for planetary defense. In academia, scenarios are used in, for instance, the Space Law Moot Court Competition led by the International Institute of Space Law or the space wargaming course at the American Military University. However, the development of scenarios in the abovementioned contexts has mostly been in exclusive silos targeting specific audiences or interests. Building scenarios on fair and equitable resource governance in space has to go beyond the existing approaches applied in the context of outer space in order to identify more transformative forms of futures along with clearer indicators for policy implications.

(RE)IMAGINING THE GOVERNANCE OF SPACE COMMONS

The field of Science and Technology Studies (STS) offers its own set of critical resources for analyzing how futures are envisioned, articulated, and acted upon in contemporary societies, which is particularly useful for this study. From an STS perspective, the scenarios we present and reflect upon in the study are themselves articulations of broader culturally and collectively produced and sustained imaginaries of the future. In the past decade, STS scholars have paid increasing attention to the role of imaginaries to highlight how 'whereas science and technology were formerly generally regarded as the domains of facts and artefacts, they are now also associated with storytelling, imaging, and imagining' (McNeil et al., 2017: 457). As others have shown, through popular films, television, or other media, the possibilities of future technoscience are imagined (see Kirby 2010 for examples related to spaceflight), setting the agenda and shaping popular understandings of what is possible or desirable. Tutton (2021) extends this interest in sociotechnical imaginaries to the likes of SpaceX and how, through science fiction narratives and digital simulations, the desirability of specific human space futures is performed to enroll the public. Most of the time, the best-crafted narratives can engender the most action (Flowers, 2003).

Specifically, the concept of sociotechnical imaginaries is of relevance here, which Jasanoff (2015: 19) defines as '"collectively held and performed visions of desirable futures" (or of resistance against the undesirable), and they are also "animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology". Sociotechnical imaginaries are not only questions of technological capabilities or economic models but also visions of 'social progress' (Jasanoff 2015: 4). Imaginaries concern not only technoscientific achievements but also 'aspirational and normative dimensions of social order' (Jasanoff 2015: 5), therefore considering normative questions about how life ought to be lived. As Jasanoff (2015: 4) remarks, investments in technoscience are typically characterized by 'positive visions of social progress'. However, whose positive visions are being advanced is a critical question and sociotechnical imaginaries are open to resistance and contestation (see Bowman 2015, Felt 2015). Therefore, sociotechnical imaginaries project an image of the kind of society that sociotechnical innovation can bring into being and the kind of society needed for innovation to happen.

This is vividly illustrated through the reference of this paper to the Limits to Growth report and its alternative future to the core political commitment to perpetual economic growth. As Jasanoff (2015: 339) reflects, 'sociotechnical orders are not natural' and 'the seen reality is not the only one about which we can dream'. Therefore, our position is not simply to accept current sociotechnical orders but to create openings for imagining them otherwise, by exploring alternative scenarios. Re-imagining how global commons ought to be governed from the STS

perspective might yield useful conceptual implications. It allows going beyond a predictive mode in constructing future sustainability scenarios to identify alternative and potentially more transformative forms of sociotechnical orders in the future governance of commons in space. In undertaking our work in this paper to map out our alternative scenarios, we kept that wider normative focus in mind. As we elaborate below, some of these scenarios clearly map onto strongly institutionalized imaginaries, while others are less so but are nevertheless critical forms of resistance to these hegemonic ones.

3. METHODOLOGY

In building the scenarios, we applied the deductive method of intuitive logics scenario generation that results in a two-by-two matrix. As reported in the literature, this method appears to be the most frequently used one by scenario practitioners (Ramirez & Wilkinson, 2014). This deductive method involves the identification of critical uncertainties that appear to influence the future development of the matter of interest, that is, the factors that are most important and uncertain and their employment by means of either a single main axis or—usually—two axes that formulate a two-by-two matrix (Schwartz, 1991). These critical uncertainties should be causally independent, should be part of the contextual environment, and should not belong in the sphere of influence of the intended scenario user. In the case where the identified critical uncertainties can be narrowed down to two, they are transformed into two axes forming a two-by-two matrix by assigning them values of ordinal metrics or of polarized extremes: the former case creates a Cartesian grid, while the latter creates a set of four mutually incompatible frames. In any case, the generated two-by-two matrix deductively provides a basis for the intuitive logics scenarios (Ramirez & Wilkinson, 2014). After the scenarios have been framed by means of the two-by-two matrix, they are further scoped by building a set of broad descriptors for them. Finally, based on those descriptors and on their particular framing, the individual scenarios are developed by virtue of narratives that may include actors, behaviors, events, chronological structures, and underlying reasons, with the goal of uncovering how each particular future state of the world may unfold through the underlying causal processes, and of challenging, reframing, and changing the conventional mindsets regarding the future (Wright, et al., 2013).

In this exercise, we base our scenario building on ideal-typical configurations of two key dimensions in which the future of common resources in space will be governed, which results in a two-by-two matrix. As shown in Figure 1, the first dimension which forms the horizontal axis is in terms of *governance of resource access and distribution*.

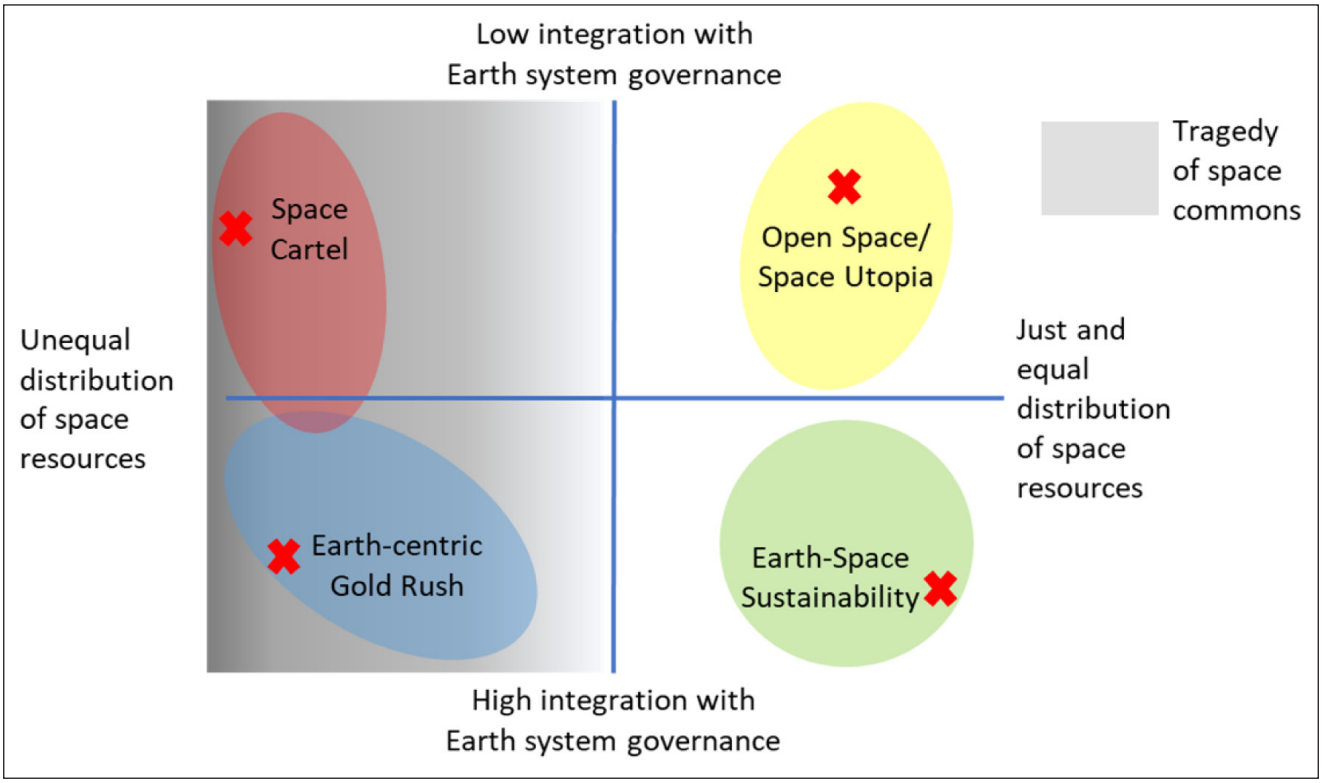

Figure 1 Four alternative scenarios on the future of commons in space.

Source: Authors' illustration.

It entails the rules, norms and principles that determine the conditions under which space resources can be utilized and how the associated burdens and benefits will be distributed, both between immediate stakeholders as well as more broadly between states, societies, or other entitled entities. "Space resources" may include both raw materials, such as lunar ice deposits, as well as abstract goods, such as finite orbital slots for satellite placement. The governance of resource access and distribution is a key element for all resource types. Conceptually, we conceive of this dimension as a gradient running on two endpoints: on one end, space resource governance may enable and facilitate appropriation and control by individual entities, for instance with *res nullius* principles where resources are up for grabs on a first-come, first-serve basis. On the other end, space resource governance can build on the principle of common heritage and seek to ensure a fair and equitable distribution of burdens and benefits between entitled entities. Empirically observable situations are typically hybrids that exist at various points along this gradient, incorporating elements from either extreme (e.g. Andersen 2013; Jaeckel et al. 2017). Meanwhile, scholarly and political debates on the governance of space resources frequently gravitate towards adopting the principles of common heritage and benefit-sharing as priority elements in questions of access and distribution.

The second dimension, which forms the vertical axis, is the degree of *integration of space resource governance with Earth system governance*. Earth system governance is understood here as the collective attempt at bringing societal development in line with the exigencies of Earth system boundaries while meeting the requirements of global justice (Biermann, 2014; Biermann and Kalfagianni, 2020). In the context of our scenario building, a key question is to what extent space resource governance would (mis) align with the dense institutional context rife with norms, principles, and operational rules that could bear immediate or implicit relevance to Earth-bound sustainability governance. On one end, space resource governance can be largely disconnected from and have limited influence and interaction with Earth system governance. On the other end, space resource governance can closely align and interact with Earth system governance in various forms (Yap and Kim, 2023), deriving overarching, shared principles and norms that capture potential synergies at the level of operational rules. In the extant empirical studies on Earth system governance, different issue areas (also known as 'regimes') tend to fall somewhere in between the axis and exhibit different degrees and types of linkage among themselves (Keohane and Victor 2011). While high degrees of integration between issue areas may help enhance consistency in coordination and avoid negative spill-overs (Biermann 2014; Johnson and Urpelainen 2012), lower degrees can provide flexibility and resilience and serve to overcome deadlocks that would be otherwise insurmountable (Keohane and Victor 2011). In the context of this study, however, the implications of high or low (dis)integration between space resource governance and Earth system governance have to be more critically assessed. We focus on how space resource governance would interact with Earth-bound sustainability governance in terms of rising energy demands, sustainability transitions and transformations, geopolitical competition, and developmental gaps. Our exercise therefore identifies whether space resource governance would operate in line with core principles of Earth system governance, or as a distinct and *sui generis* system operating as an isolated governance niche beyond the Earth system.

While both dimensions vary to a different extent, we conceive of their endpoints as ideal types for scenario generation. This leads to four frames of future scenarios as depicted in Figure 1, which is the maximum number for meaningfully engaging in decision-making (van der Heijden, 2005):

> *Scenario I: Space Cartel* is based on a combination of a low integration with Earth system governance, as well as, highly unequal market-based resource appropriation secured by strong private property rights. Affluent private companies or a few powerful state actors self-regulate the use of space resources through advanced technologies, largely unhampered by the pre-existing rules, norms, and principles of global sustainability governance. Due to this disconnect, the rules of space resource governance reflect the commercial- and political interests of the rich and powerful, while reinforcing global distributional injustice on Earth.

> *Scenario II: Earth-centric Gold Rush* is a future in which space resource governance is centered around the unrestricted appropriation of space resources and relatively high integration with Earth-bound sustainability needs. This scenario anticipates a handful of advanced spacefaring nations and high-tech multinational companies exploiting space resources such as minerals for fueling energy transitions, trade purposes, and reasons for resource security in the name of sustainability on Earth. Intense commercial and geopolitical competition also leads to strong distributional injustice on Earth.

> *Scenario III: Open Space (or Space Utopia)* is based on a space governance future largely disconnected from an Earth-centric governance system but with fair and equitable sharing of burdens and benefits

in the outer space environment. Technologies, knowledge, and resources are shared fairly for building infrastructures and settlements in space. Due to a low degree of integration with Earth system governance, this rather 'utopic' future in space comes at the expense of sustainability on Earth, including the asymmetrical distribution of environmental and social impacts stemming from activities in space.

Scenario IV: Earth-Space Sustainability is based on a combination of fair and equitable sharing of burdens and benefits of space resources among actors on Earth and in space, as well as, a high degree of integration with Earth system governance. In this future, Earth-bound and space-based sustainability challenges are governed in an integrative manner to prevent space activities from causing unsustainabilities on Earth, and vice versa (Yap and Truffer, 2022; Yap and Kim, 2023). This requires just and fair use of space resources and infrastructures for tackling sustainability challenges on Earth while maintaining sustainability in space.

As indicated with a grey gradience in Figure 1, Scenario I and II have the highest tendency to lead to 'the tragedy of space commons' in the future. The intense competition among the rich and powerful companies and state actors led to a rapid proliferation of space activities and missions without sufficient environmental governance in space. The resource systems of other celestial bodies (e.g. the Moon, Mars, or asteroids) become exploitation grounds among these actors, leading to severe environmental degradation. Additionally, the increased amount of satellites and space debris limits the use of Earth's orbit and impacts telecommunication, Earth monitoring, as well as military use.

Overall, our scenario building engages in the articulation of what Waskow (1969) calls 'possidictions', the 'author's projection of how certain seeds of change that exist already might be made to flourish given the right political action' (in Bell and Mau 1971: 37). The first two reflect futures that extrapolate and even amplify 'business-as-usual' dynamics, imagining that present-day arrangements continue into the future. The generated narratives for the first two scenarios therefore conform to the principles of plausibility—the need to logically derive scenarios from real-world phenomena. Scenarios III and IV draw more on 'seeds of change' that could develop further given institutional action that counters the dominance of capitalist interests in outer space. The two scenarios rely more on an augmented Intuitive Logics approach in order to be more imaginative in identifying alternative future states, with Scenario IV projecting transformative potentials (Derbyshire and Wright, 2017). All scenarios meet the expectations of consistency – the need to build scenarios on assumptions that are not mutually incompatible, and of relevance – the need to enrich scenarios with sufficiently high-quality information to make them useful for their purpose (van der Heijden, 2005).

The four frames of scenarios were first internally developed and discussed among the organizing team of the 2022 Commons in Space conference. Subsequently, the four frames were presented and discussed at two workshop sessions during the conference, which was held virtually. Participants of the workshop largely came from an academic or industry background across six continents, mostly specialized in the specific fields of outer space. To ensure stakeholder representation, participants in the workshop were divided accordingly into three breakout groups to represent the major actor types, i.e. government actors, rich private actors from leading spacefaring countries, and actors from developing countries, to derive widely shared collective expectations of the four preliminary scenario framings. The timescale for scenario building is set for the next 50—100 years. After the conference, all participants of both workshop sessions received an invitation to join the author team. Those interested in joining were invited to two follow-up sessions conducted online to further specify the scenarios. Finally, the confirmed author team continued with co-developing the narratives for the scenarios in the writing process of the paper.

4. RESULTS: FOUR ALTERNATIVE SCENARIOS OF COMMONS IN SPACE

In this section, we provide the key narratives developed for each scenario based on a set of identified descriptors listed in Table 1. In particular, the narratives for each of the scenarios center around a few major dimensions, including governance characteristics, strategies of the business sector, global competition, and their associated environmental and societal implications.

SCENARIO I: SPACE CARTEL

In the Space Cartel scenario, leading spacefaring nations play a passive role in *space resource governance*. Although decision-making power is likely to still reside with national authorities, the mandate to carry out specific activities in space will be yielded to rich and technologically advanced private actors (Rementeria, 2022). Governments would favor large private or flagship companies due to their potential for innovations and funds to carry out self-organized missions. Therefore, many of the tasks around space exploration traditionally performed by state agencies are expected to be outsourced following the rules

DESCRIPTORS	SPACE CARTEL	EARTH-CENTRIC GOLD RUSH	OPEN SPACE/SPACE UTOPIA	EARTH-SPACE SUSTAINABILITY
Actor composition of governance	Club for the ultra-wealthy and powerful in particular billionaire companies	Leading private actors and advanced spacefaring states	Larger and smaller businesses, states including developing countries	A mixture of state governments, non-state or private actors, and international organizations
Overall governance approach	Privatized or self-governed	Legitimized through Earth-centric sustainability discourse	Inclusive governance in space only	Integrative governance on Earth and in space
Governance characteristics	Issue-specific, self-coordinated arrangements among spacefaring nations tailored to the interests and needs of the Space Cartel	Minilateralism, i.e. international agreements among a subset of countries to achieve specific aims and objectives in space	Multi-level governance and a multiplicity of institutional arrangements; most likely resembling a polycentric system	A mixture of centralized, multilateral agreements and complementary (in)formal institutions coherently aligned with a shared sustainability goal
Strategies of private actors	Self-legitimized activities; benefits are distributed among the rich ones in space	Legitimize their activities based on support from state governments as nation-states compete with each other due to geopolitics	Develop fair incentives and opportunities for all actors in space	Private space activities include considerations for Earth-Space sustainability
Industry structure	Monopolistic or oligopolistic; growth perpetuity	Competition among advanced companies; growth perpetuity	Perfect competition; growth perpetuity	Agnostic to growth perpetuity
Integration with Earth system governance	Disintegrated	Integrated but plays an adaptive role	Disintegrated	Integrated with a more transformative role
Impact on Earth's environment	Severe degradation (emissions and waste from missions)	In line with ongoing sustainability discourse (e.g. energy transition)	Space activities disintegrated from Earth's sustainability leading to severe degradation	Minimal degradation through sustainable management of resources on Earth and in space
Impact on space environment	Severe degradation	Severe degradation	Minimal degradation in space	Minimal degradation in space
Space-based or ground infrastructures	Tragedy of space commons limits access to space infrastructures	Tragedy of space commons leads to the loss of space infrastructures	Unequal distribution and ineffective coordination between in-space and on Earth	Just distribution and effective coordination between in-space and on Earth
Global justice and/or development gap	Widened; highly unjust and unequal	Widened; unjust and unequal	Marginal gap in space, but unjust and unequal between those occupying space and those on Earth	Just and equal between those occupying space and those on Earth
Earth-Space interdependency	Eventually leads to the abandonment of Earth by the rich and powerful.	Earth's sustainability progress becomes highly dependent on space resources	Earth becomes unsustainable and devoid of most resources to meet the requirement of sustainable space settlements	The sustainability of Earth and other celestial bodies is reckoned as highly interdependent

Table 1 Key descriptors of the four scenarios.

Source: Authors.

of neoliberalism (Doboš, 2022). As a result, governments and national agencies heavily rely on private companies to take advantage of available space resources. Governments would be less likely to restrict or interfere with the ambitions of private space actors and more inclined to engage in public-private partnerships (Vernile, 2018). However, due to less state-based enforcement of international space law, an increase in collusive behavior could likely be observed among private space actors, especially in newly emerging space markets (Lucas-Rhimbassen and Rapp, 2021). International coordination among states is likely to be low and fragmented under the prevalence of private actors, causing distributional injustice (Lee, 2000). It is expected that there will be no progress made in negotiating a new treaty on an international level. Rather, we are likely to observe the emergence of issue-specific, self-coordinated arrangements among spacefaring nations tailored to the interests and needs of the Space Cartel, at the expense

of policy priorities of developing countries. This scenario therefore sees a shift in governance towards domestic regimes, which over time crystalize into customs and norms in international domains as actors assert 'best practices'. This leads to legitimacy challenges in the overall global space governance and to the exclusion of principles for global justice and sustainable development.

The *business sector* plays the dominant role in this scenario. Since there are high upfront investment costs involved in accessing space, billionaires will be the first to take commercial advantage of it. Rich private actors rush to occupy and monopolize space resources based on a 'first-come-first-serve' principle. From a business standpoint, space has already been perceived for a long time as the new frontier to be conquered, colonized, and marketed (Goodrich et al., 1987). In this privatized governance mode, the rich prefer to self-regulate the space environment. Moreover, nation-states hosting these spacefaring companies on Earth will be interested in their success as these companies contribute to national supremacy, wealth, and development (Tronchetti, 2015). These companies may receive favorable support, e.g. they are empowered to found self-governing settlements or cities as outposts in space such as on Mars to utilize extraterrestrial resources more effectively. Such colonial communities could exhibit a high degree of independence due to the long spatial distance from Earth. However, challenges arise in relation to the rights and positions of human workers in outer space (Ireland-Piper and Freeland, 2021). In the Space Cartel scenario, workers in space are likely to be suppressed due to the prevalence of artificial intelligence technology, robotics, and rich actor's averseness to unions. Economic actors in this scenario tend to perceive space as limitless (Miraux et al., 2022), which increases the risk of mismanaging space resources leading to severe environmental degradation in space – i.e. the tragedy of the space commons. In the event that negative consequences as a result of the degradation would start to affect financial profits, private actors would prefer some sort of regulative regime.

In terms of *global competition*, states that pursue centralized national space policy might be part of the space cartel in this scenario through their state-led or public-private space missions, e.g. the plans for building Mars settlements led by the UAE and NASA respectively (Aima 2018; Grove 2021). Meanwhile, economic histories have demonstrated that developing countries in general aim for national catching-up or leapfrogging opportunities to reduce their reliance on more advanced countries. In the space sector, emerging nations aim to eventually match the achievements of the globally established nation players (Aganaba-Jeanty, 2016). While the established nations viewed space as an arena for competition over national security during the Cold War, security concerns continue to shape space policymaking in many emerging or developing nations (Harding, 2012). For instance, India's space program has become increasingly ambitious over the past decade (Rajagopalan, 2022). Due to the first-come-first-serve condition in this scenario, large emerging nations such as India would place space as a top priority in the political agenda to gain national security and technology supremacy. Similar to what other Eastern countries such as Japan and China have done in the past, India – as an example – would participate in soft power engagements such as promoting cooperation with developing countries (Space in Africa, 2019). Other developing nations in the present day (and their rich companies) would also find stronger positions in this future scenario, in particular if they have strong national development plans for specific space programs such as the satellite program of Nigeria (CGWIC, 2022). The Space Cartel scenario, therefore, sees some of the developing nations investing in space programs in the present day potentially becoming part of the future 'cartel' through leapfrogging strategies, whether in the form of rich companies pursuing economic profits or powerful states pursuing national supremacy. As a consequence, this leads to new developmental gaps with the rest of the global (and national) society that is not part of this cartel.

SCENARIO II: EARTH-CENTRIC GOLD RUSH

Space resource governance in this scenario enables, in a one-sided way, appropriation of space resources by technologically advanced countries or large multinational corporations. Competition becomes fierce among national governments aiming to grab space resources to alleviate environmental pressures within their national terrestrial territory while continuing a business-as-usual approach. International organizations and space agencies continue to promote space as a frontier of new resources to sustain Earth-bound development, thereby legitimizing the activities of those appropriating space resources. For instance, NASA launched an initiative titled 'Planetary Sustainability' in 2014, and one of the three visions of this initiative is "A multi-planetary society, where the resources of the solar system are available to the people of Earth" (NASA 2014). This framing not only presents space resources as new opportunities for planetary sustainability, it also suggests people on Earth can coexist in harmony by utilizing nearby space resources to sustain themselves (Redwire, 2023).

To legitimize space activities in this scenario, new international institutions would be formulated such as new codes of conduct through international agreements among a subset of nations aiming for space resources. More specifically, nations and companies appropriate the benefits of space resources exclusively for themselves

under minilateral agreements on potential transboundary issues such as environmental impact assessments, the generation of space debris, or liability and redress. Whereas resource appropriation leads to strong distributional injustice, advanced nation-states and large multinational companies mobilize such institutional embeddedness to legitimize their space activities. In the present day, one can relate this to the establishment of the Artemis Accords led by the US for activities on the Moon. Development of this sort also reflects the Outer Space Treaty in the present day, in which principles tend to prioritize Earth-centric benefits whereas the integrity of the outer space environment was considered mostly in the context of preventing the use of weapons of mass destruction. Although these actors face pressure to reduce their environmental footprint in space, private actors overall seek leeway to avoid responsibilities due to factors such as growth imperatives, the enforceability of regulations, and negligence in the early stages of commercial space development (Miraux et al., 2022). Therefore, this scenario is also likely to cause the tragedy of the space commons. Overall, minilateralism in this scenario grants outer space activities a higher degree of legitimacy without, however, overcoming fundamental disparities in the interests of spacefaring and non-spacefaring nations.

In this scenario, *businesses* also require high venture capital and investment costs. These businesses are likely to be high-tech, multinational corporations residing in wealthy nations on Earth. For them, the commercialization of space in this scenario opens up new resources and opportunities to diversify and gain profit (Weinzierl and Acocella, 2017). This resembles strong parallels to the extensive overseas exploration and 'Gold-Rush' mentality during the age of exploration (Pyne, 2016). The emerging commercialization trend will commodify space and its constituents into goods and services that are offered in a market. In terms of *global competition*, there are already national space policies that develop in a direction that supports and complements this trend. For instance, the SPACE (Spurring Private Aerospace Competitiveness and Entrepreneurship) Act of 2015 allows US citizens to utilize and commercially profit from space resources, although not claiming ownership. The Gold Rush mentality of 'go get it as fast as you can' in this scenario therefore leads to state and market competition in securing important resources, such as exploiting new minerals in space to fuel energy transition on Earth. While this opens up a new set of opportunities for those who have investment and technological capabilities, it also leads to new developmental gaps with those on Earth whose joining space activities itself is economically not feasible (Losch, 2019).

An illustrative example is the case of space-based communication systems, which are expected to become increasingly indispensable in the 21st century. Satellite constellations deployed in outer space continue to see a steep upward trend. In the present day, the Starlink project itself aims to build a constellation of 42,000 satellites in low-Earth-orbit (McDowell, 2020). The project is promoted as delivering high-speed, low-latency broadband internet to meet the needs of remote and rural areas worldwide (Starlink, 2023). However, internet satellite constellations like Starlink raise a number of issues including claiming a large number of orbital slots (McDowell, 2020), which leads to an increasingly congested low-Earth-orbit with the accumulation of space debris and probability of collisions (Gangestad, 2017). Furthermore, space-based infrastructures in the hands of monopolies or oligarchs also inflict questions of equity and access. By 'selling connectivity' in a market with low competition, private space actors are likely to have high negotiation power and influence on the socio-technical development of remote areas and the lives of more than 3 billion people who currently still lack access to the internet (Roser et al., 2020). Ultimately, Earth-centric Gold Rush would not only degrade the environmental conditions in space but also impose dependencies of the low-income on those services.

In this future scenario, nation-states and commercial actors build space-based solar power stations to provide energy supply through solar power satellites and wireless power transmissions. The cost for space-based solar power satellites would have become feasible and in some instances, they become an important alternative for non-renewable energy sources like fossil fuels on Earth. However, harnessing solar energy to its maximum potential requires constellations of solar power satellites in Earth's orbit (Hsu, 2021). This further increases the risk of Kessler Syndrome – a phenomenon in which the collisions between space objects in Earth's orbit lead to a cascade of more future collisions (Kessler and Cour-Palais, 1978). Geopolitical interests and the intense pursuit of national energy security on Earth lead states to compete among each other for installing the solar power constellations on a first-come, first-served basis under weak global space governance. Hence, space-based solar power stations become sources to perpetuate developments on Earth at the expense of space sustainability (Pawel, 2020) as well as international cooperation.

SCENARIO III: OPEN SPACE (ALSO SPACE UTOPIA)

The Open Space scenario operates in a *governance model* attentive to multi-level governance in space, focusing on power dynamics and actor interactions (Salmeri, 2023). In this context, actors inform governance at all four levels: global, regional, national, and local (ASU, 2023), and the scenario most likely resembles a polycentric mode due to

the multiplicity of institutional arrangements (Tepper, 2019; Morin and Richard, 2021; Kuhn et al., 2022). Governance in this scenario, therefore, might observe multiple institutional settings or even polities in space. In line with debates in environmental governance which emphasizes decentralization as well as experimentation and localization across jurisdiction (Dunoff, 2007), space actors establish different space polities in this scenario depending on the environmental conditions on those celestial bodies or in specific space regions, the patterns of resource use and economic development, varied environmental values, and specific knowledge base. However, the governance system in this scenario bears the risk of inconsistencies between elemental institutions: in the absence of an overarching governance framework, the rule systems that different coalitions of states put in place for dealing with different aspects of space governance might inadvertently lead to disruptive interactions with negative impacts on governance effectiveness. The fragmentation of space governance across diverse international forums, moreover, incurs legitimacy costs relative to integrated and centralized forms of interstate bargaining. In this rather utopian scenario, these challenges related to polycentricity or multi-level governance would have been largely overcome.

The Open Space scenario contains a mixture of larger and smaller *business* ventures. Examples in the present day have shown large fragmentation between levels of governance with differing and/or double regulatory requirements hindering innovation and commercialization. Polycentric governance in this scenario resolves political conflicts and the so-called 'scale-shopping' or forum shopping, where groups dissatisfied with politics at one scale simply approach a more favorable political venue in which to frame their interests. Here, cross-scale communication among space actors is a priority, with a collective front where every level of governance works together to foster a competitive and sustainable economic environment in space. Guided by market logic, it is a rational choice for commercial space actors to avoid the tragedy of the commons in space to ensure the longevity of their space operations.

In terms of *global competition*, a utopian development in space allows fair access to space resources among all countries and businesses, who have the resources to participate, therefore leaving almost no developmental gap among actors in space beyond the terrestrial bounds of Earth. International institutions in this scenario are designed to ensure low costs and technological barriers for less advanced countries to take up leading roles in space missions. However, the development of these activities and structures in space are largely disconnected from Earth-bound sustainability considerations. Developments in space in this scenario therefore come at the expense of sustainability imperatives on Earth, including the depletion of Earth-bound resources for building space settlements and conducting space missions, socio-economic disruptions as a consequence of supply shocks from space mining or space-based solar power stations, atmospheric pollution from rocket launches, and unjust distribution of space benefits to those on Earth.

SCENARIO IV: EARTH-SPACE SUSTAINABILITY

In the Earth-Space Sustainability scenario, the international space community (e.g. governments of spacefaring nations, private actors, and international organizations) is willing to practice international collective action to achieve a shared sustainability goal. In this scenario, Earth-bound and space-based sustainability challenges are considered and addressed in an integrative way to meet the environmental integrity and justice of those on Earth and other celestial bodies (Yap and Kim, 2023; see also Galli and Losch, 2019; Losch, 2020). As such, the 'earth-space *governance* model' particularly focuses on strengthening the complex alignments between space resource governance and Earth system governance in a multi-planetary context, and takes into explicit consideration that Earth is no longer a closed, isolated system (Yap and Kim, 2023). On one hand, strong governance integration may facilitate centralized, multilateral bargaining scoring high on both legitimacy and effectiveness. On the other hand, there might be a mixture of other (in)formal institutional arrangements that serve to complement the overarching governance framework.

The *business sector* in this scenario experienced a shift in value from a pure market logic towards a global community logic. Similar to other sectors in the present day, large private companies in space play the role of philanthropies as they channel benefits from space for global society across regions on Earth. Space resources are co-managed effectively to ensure space-based infrastructures can be fairly accessed among different actor types across countries at different developmental stages, as those infrastructures become integral to global sustainability transitions (Yap and Truffer, 2022). Additionally, sustainability discourses experience a shift from a planetary towards a multi-planetary context. Earth-bound and space-based sociotechnical or infrastructure systems become closely intertwined with effective coordination in order to ensure just and fair access to services such as energy and water in a multi-planetary context. In the present day, we see policy initiatives emerging in the direction of ensuring earth-space sustainability. For instance, the European Space Agency (ESA) actively promotes the need for environmental impact as well as life cycle assessments for space missions to take into account the pollution and degradation of Earth's natural environment.

In terms of *global competition*, geopolitics in space or 'astropolitics' (Dobos, 2020) are less intense in this scenario,

leading to less competition among states to fuel national development on Earth and more effective coordination among states. This minimizes the developmental gap between advanced and developing nations in the present day due to the provision of equal opportunities to access space resources. Countries that remain 'followers' in this future scenario are guaranteed access to outer space, the means for space activities, and space resources (Deplano, 2023). Importantly, achieving democracy (Dryzek and Pickering, 2019) in agenda-setting or decision-making is of topmost priority in this scenario. For instance, countries in Africa seek space engagement at all levels of governance to meaningfully feed into and impact the wider African Union regional Space Policy and Strategy. By aligning interests at both regional and international levels, these countries find better opportunities to impact space resource governance through a strong African voice. Additionally, Africa also finds a unique position to contribute to the discourse on space sustainability. In fact, the first definition of what is 'sustainable development' and the first Declaration of the Right to Environment can be found in African governance instruments, such as the African Convention on Nature and Natural Resources of 1968, the Algiers Declaration on the Rights of People 1976, and the African Charter on Human and Peoples Rights 1981. This same argument has been made in the context of an argument for Africa to join the G20 where it is argued that African countries are often ahead of others globally on key environmental issues (Ryder, 2022).

In addition, infrastructures on Earth such as launch sites and groundstations are built rapidly in the present day to meet the demand of space activities. However, these developments are often entangled in complex relations with local communities (Maile 2021; Gorman 2007), the environment (Kopack 2019; 2021), and embedded in geopolitical power structures (Gorman 2005; Klinger 2019). Space resource management in this future scenario will consider the alignment and coordination with these infrastructures on Earth. Table 1 summarizes the key descriptors of the four scenarios in this study.

5. DISCUSSION

In reality, the different plausible scenarios will most likely co-develop over time. Policy and governance are confronted with the challenge of navigating these parallel developments and averting alternative futures that cause negative environmental and social consequences. In this section, we discuss three major challenges identified for policy and governance stemming from our study and explore in what ways policy and governance could be adapted, reformed, or transformed to overcome those challenges. The discussion is structured along three dimensions: the politics of sociotechnical imaginaries, increasing interrelations with sustainability on Earth, and the challenge of temporality.

THE POLITICS OF SOCIOTECHNICAL IMAGINARIES

Our exploration of scenarios demarcates four conflicting sociotechnical imaginaries, potentially shaped by different actors and values, each of which consists of different governance approaches. In the capitalist-driven logic of the first three scenarios, space is portrayed as a new frontier to be colonized and exploited through asset-creation or the production of commodities and services. Global capitalism as we know it, more or less continues outwards beyond the atmosphere, overcoming planetary 'limits to growth'. This is a strongly institutionalized sociotechnical imaginary, expressed in the present day by the likes of Elon Musk and Jeff Bezos. The Earth-Space Sustainability scenario borrows from a different set of visions of societal progress that emphasize more the values of justice and equity than profit-seeking and perpetual economic growth.

From a commons governance point of view, a polycentric mode of governing is likely to be present in all scenarios in varying degrees although it most likely finds strong resonance with the Open Space scenario. Insights from the commons literature have demonstrated that polycentric governance can be riddled with the so-called 'collective-action trap', whereby decisions are made based on economic calculations of individual actors to maximize relative gains or to protect themselves from the actions of others (Young, 2021). Based on the study of our scenarios, the challenge for polycentric space governance therefore critically lies in whether the formulation of principles and norms can be oriented towards accounting or adjusting the behaviors of the different actor types while fostering higher-level trust among them in a sector traditionally led by only a few major states.

Otherwise, it could become rather inevitable that future developments – relied on self-coordinated arrangements – fall into the hands of the rich and powerful therefore increasing the plausibility of a Space Cartel or Earth-centric Gold Rush future. To prevent or mitigate negative consequences stemming from the Space Cartel and Earth-centric Gold Rush scenarios, e.g. environmental degradation in space and global injustice (Impey, 2021), new legally binding instruments might be critical here to delimit powerful actors from freely setting the rules of the game that work in favor of their own interest on other celestial bodies. In order to orient these two scenarios toward more just and equitable futures, there is a need to redesign the benefit-sharing regime and differentiate, for instance, access to

the means for space activities, access to outer space, and access to space resources (Deplano, 2023). Furthermore, countries in Africa would have to be implementing an African-led, inward-focused development program. This is crucial to counteract the self-governance of rich companies or the emergence of minilateralisms among interest groups and shape a policy framework that drives leading actors toward sharing benefits with the global community.

INTERRELATIONS WITH EARTH SUSTAINABILITY

In light of rising environmental crises and global inequalities, our scenario building dedicated an explicit consideration for the interrelations between developments in space and environmental and social imperatives on Earth. The Space Cartel and Open Space/Space Utopia scenarios demonstrate two future states in which space developments 'escaped' the bounds of Earth system governance, leading to future space governance that disintegrates from the considerations for sustainability challenges back on Earth. The governance challenge in those two scenarios would therefore be ensuring human space activities progressing in line with the challenges of the Earth system. If operated under a polycentric governance, for instance in the Open Space scenario, the distribution of space resources and benefits has to prevent fragmented or incongruent norms, principles, and actions with Earth system governance.

Meanwhile, the main challenge for Earth system governance in the Earth-centric Gold Rush scenario is about governing consequences related to the use of space resources for fueling terrestrial energy transitions, their associated geopolitical tensions, and societal implications. Earth system governance, therefore, only plays an adaptive role in this context. To prevent the unequal distribution depicted in this scenario, it is critical to specify in policy how relevant activities are organized, how diversified funding sources are, and how benefits from space are embedded in local communities through economic integration back on Earth (Ocasio-Christian, 2020). In addition, if mineral resources in space would be brought to Earth, it would be important to ensure the integration of those minerals into the existing economic trade in a way that protects the position of the African region (Aganaba, 2023).

Earth system governance could play a more transformative role in the Earth-Space Sustainability scenario by explicitly considering how the justice and integrity of the Earth system are increasingly impacted by activities and resources in space, and vice versa (Yap and Kim, 2023). Achieving a future that brings Earth-Space Sustainability requires major governance and societal transformation that goes beyond technological innovation, industrialization, and institutional adaptation. Current policy initiatives addressing space debris (e.g. the Net Zero Space initiative by the Paris Peace Forum and Zero Debris Charter by ESA with ambitious targets by year 2030) have to explicitly integrate considerations for sustainability on Earth. Policy-making for licensing, procurement, and sanctions (Sullivan, 2023) has to be supported with concrete measurements or monitoring such as environmental impact or life cycle assessments of space activities to track negative implications on Earth and in space.

Integrating Earth system and outer space governance also allows for preventing problem-shifting between sustainability challenges on Earth and in space, and trade-offs will be more explicitly considered to ensure environmental integrity and justice including for other celestial bodies. An integrative 'earth-space governance' model (Yap and Kim, 2023) therefore requires understanding the limits of the existing global political order built upon a state-based system, which often asserts that sovereignty is indispensable. Incorporating the principles for environmental integrity and justice of other celestial bodies into existing governance prompts the question of to what extent a terrestrial state-based system is sufficient in the context of governing commons in space, as new rules are made by state and non-state actors pertaining to other celestial worlds beyond the physical reach of many on Earth. Just as the digital revolution giving rise to virtual reality that poses increasing difficulties to a political order based upon territorial terms (DeNardis 2014; Young et al. 2020, Young, 2023), future governance in space will see increasing human and non-human needs entangled in spaces that are non-material or non-physical to many on Earth. Understanding global political orders as social constructs (Young, 2023), the challenge for earth-space governance here is to deal with complexities and governance needs beyond a single planetary scale, which is difficult within the confines of the prevailing global order. A sustained effort is needed in science and policy to search for reformist solutions but also to explore more fundamental alternatives to the current global order.

THE CHALLENGE OF TEMPORALITY

The scenarios also point to the different temporal scales on which stakeholders operate. The narratives constructed for the four scenarios show that actors dominant in the different scenarios operate on various timelines; for example, key stakeholders in the Space Cartel scenario, even though planning on a longer-term future of human settlement elsewhere, are often driven by and reliant on return of investments within particular, shorter term, timeframes (Valentine 2012). There are also clear differences in the discourses put forth by national space agencies, e.g. NASA emphasizes their plans to go to Mars in the 2030s whereas the UAE detailed a timeline for their Mars settlement that runs up until 2117 (Aima 2018; Grove 2021). Just as space policies and actions operate on different time scales, there

are competing understandings of the temporal scale of sustainability among different actors. The growing literature on the conception of sustainability, as well as on the general understanding of futures, has demonstrated significant cultural, social, and political differences. Anthropology studies, for instance, show that indigenous people around the world have a cyclical perception of time, which shapes their approach to the environment with less focus on exponential economic growth and with more emphasis on maintaining ecological continuity (Robyn 2002). A potential problem of these tensions of time scales is that often actors operating on the shorter time scale end up defining the policy conversations, as others have to adapt their strategies depending on the consequences of the actions of the former.

The temporal aspect adds complexity to the challenge of policy and governance, in particular when considering how space activities impact inter-generational equity. In view of emerging policy initiatives that seek to address space debris by 2030 – there is a potential but rapidly narrowing policy window to orient governance of the orbital environment towards Earth-Space Sustainability in the long term (Yap and Truffer, 2022). At the same time, the use of resources on other celestial bodies might first witness the prevalence of an Earth-centric Gold Rush scenario, before progressing to incorporate the interest of the less powerful. To move beyond 'governing the given' and anticipate inter-generational equity, we might need more legally binding instruments to limit the rapid development of activities currently led by a select few seeking to occupy those celestial bodies. Here, science and policy have to explore how to incorporate a more holistic perception of time – perhaps the one informed by indigenous knowledge – to steer toward more equitable futures such as the Earth-Space Sustainability scenario.

6. CONCLUSION

Our paper serves as a precautionary tale of what the futures of commons in space may hold and the associated implications to sustainability, if business-as-usual continues without appropriate governance. Whether or not the future governance of commons in space should unfold in a polycentric mode, a more centralized mode, or a mixture of both, is to be empirically researched and analyzed. Currently, evidence shows that many non-legally binding institutional arrangements are emerging among space actors (Pic et al., 2023) and various policy initiatives are being proposed. As much as diversity and multiplicity allow room for institutional experimentation on a gradual basis, we might not have the luxury of time in view of the exacerbated crisis of global equity. Therefore, space governance is confronted with the challenge of ensuring effective polycentrism that prevents institutional fragmentation (Wolfrum and Matz 2003; Fischer-Lescano and Teubner 2004; van Asselt 2014). Self-coordination among actors and stakeholders has to ensure that the different instruments do not conflict but add to a net positive outcome (Kim, 2020). More often than not, this is only achievable with a shared collective goal on a global level (Galaz et al., 2012), incorporating clear guiding principles for the kind of purposes and outcomes to achieve within dedicated timeframes. This should be high on the agenda of science and policy addressing space commons in the coming years. We hope that our study of the scenarios has provided room to engage with policy and legal imaginaries that open up broader transformative potentials in this process.

For the general scholarship of commons governance, the governance of the global commons on Earth has experienced limited success. The lack of international authority to enforce agreements among sovereign nations makes it challenging to implement effective governance arrangements when actors do not see agreements as in their best interest. This can be demonstrated by the difficulties of decades of negotiations to cope with governance arrangements about the deep seas and climate change. Although new and updated treaties are agreed upon on various global commons on Earth, the typical challenge has been the implementation and enforcement. The scenarios presented in this paper demonstrate some of the consequences of ineffective governance of commons in space; failing governance of commons in space will bring consequences to our planetary or Earth system sustainability. Although commons in space might be seen as science fiction by some, it is urgent that this topic be addressed in more depth by the commons community. Moreover, the commons community needs to engage with the space governance community to learn from the challenges of governance on a global scale. As existing discourses demonstrate, the global commons on Earth is not just a matter among national governments, but also increasingly dominated by non-governmental organizations and industries. This broadening of the stakeholder types is also observable in the space domain; future space resource governance, if operated under a polycentric system, will have to align the complex mix of interests into a coherent whole.

To ensure analytical consistency, our exploration of commons in space has focused only on physical resources available in space, which excludes other commons issues such as light pollution and cultural heritage. In addition, it is beyond the capacity of the present paper to include discussions about more radical approaches to outer space reform, with specific actors calling a complete halt or at

least a drastic reconceptualization of all space actions based on the basis of primarily decolonial action (Smiles 2020) or lifeworlds (Young, 1987; Bawaka et al., 2020). Therefore, our discussions in the present paper hold at least some inherent inequality as opening up outer space for exploration and potential resource exploitation automatically denies those futures where outer space is altogether kept separate from techno-scientific interference. However, following the principle of plausibility and looking at the projected trajectory of the space sector in the next decades (Citi, 2022), it is currently unlikely that all space activities will be halted. We nevertheless encourage follow-up studies to explore these perspectives.

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR AFFILIATIONS

Xiao-Shan Yap orcid.org/0000-0002-6606-4301
EPFL Space Center, Swiss Federal Institute of Technology Lausanne, Switzerland; Copernicus Institute of Sustainable Development, Utrecht University, The Netherlands
Marco A. Janssen orcid.org/0000-0002-1240-9052
School of Sustainability, Arizona State University, USA
Timiebi Aganaba orcid.org/0000-0003-2022-4215
School for the Future of Innovation in Society, Arizona State University, USA
Richard Tutton
Department of Sociology, University of York, UK
Karlijn Korpershoek orcid.org/0009-0000-6644-071X
Jagiellonian University, Poland
George Profitiliotis orcid.org/0000-0002-4636-354X
TU Delft, The Netherlands; Blue Marble Space Institute of Science, USA
Florian Rabitz orcid.org/0000-0002-0041-2094
Kaunas University of Technology, Lithuania
Majal Shiny Subbiah orcid.org/0000-0002-9177-6802
Christ University, India
Leon Wagenknecht
Copernicus Institute of Sustainable Development, Utrecht University, The Netherlands

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