Environmental Innovation and Societal Transitions 44 (2022) 185–193

Contents lists available at ScienceDirect

Environmental Innovation and Societal Transitions

journal homepage: www.elsevier.com/locate/eist

Perspectives

Contouring ‘earth-space sustainability’

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A R T I C L E I N F O

Keywords
Earth-Space
Outer space
Multi-system
Beyond national jurisdiction
Commons
Earth system governance

A B S T R A C T

There have been increasing calls in transition research for a global view of sustainability challenges. We argue that this focus should be expanded from a concentration on the Earth’s surface and stratosphere to include outer space. The substantial growth of the space sector over the past decade has seen huge increases in the number of rocket launches, the diversity of actors, and the availability of new essential services that depend on space-based infrastructure. In particular, the rise of satellite-based infrastructure could drive the need for inter-related multi-system transitions across a wide range of Earth-bound sectors. These developments, however, cause diverse new sustainability pressures, such as atmospheric pollution, increased energy consumption, and the accumulation of space debris. To address these challenges, this article proposes earth-space sustainability as a new frontier for sustainability transition research, requiring the expansion of conceptual and analytical tools at the interface of transition and global governance research.

1. Introduction

Scholars in the field of innovation and transition studies argue that the world is experiencing the emergence of a new techno-economic paradigm, in which new information and communication technologies increasingly combine with global structures and a greater need to manage sustainability challenges (Perez, 2013; Schot and Kanger, 2018). Activities in outer space—or spaces beyond the Kármán line, which begins 100 km above the mean sea level and which represents the attempt to draw a boundary between the Earth and outer space—are having an increasing role in this fundamental transformation process. In recent years, rapid developments in the space sector have led to the “New Space” movement, with multiple private actors venturing into space activities alongside international space agencies (Clormann, 2021; Mazzucato and Robinson, 2018; Robinson and Mazzucato, 2019). Such activities have included private space missions, as well as the launches of new and advanced satellite systems for, among other things, the application of new services to combat climate change, tackle water scarcity, manage natural disasters, and solve other environmental problems. However, beyond these contributions to a potentially more sustainable global future, the rapidly expanding space sector generates new sustainability challenges on Earth and beyond, for instance through the accumulation of space debris, the emergence of space tourism, and unequal access to the benefits of space.

Among these diverse opportunities and challenges, there has been a flurry of technological innovation. Both public and private actors are developing next generation satellite systems, and private companies such as SpaceX and Blue Origin are competing to build new spacecraft and launch systems, such as reusable rockets. Meanwhile, policymakers are urgently calling for new forms of governance to regulate space activities. To understand these inter-related technological and institutional innovations, we must identify

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https://doi.org/10.1016/j.eist.2022.06.004
Received 28 September 2021; Received in revised form 12 June 2022; Accepted 18 June 2022

where and how new socio-technical reconfigurations should be introduced across different Earth-bound and space-based technology and infrastructure systems. To do this, we propose the concept of "earth-space sustainability," which aims to address Earth-bound and space-based sustainability challenges in an integrative manner that prevents space activities from shaping unsustainable development on Earth and vice versa. While the majority of modern society's sustainability concerns stop at the Earth's stratosphere (where the ozone layer is), we propose extending the boundary of these concerns into outer space. More specifically, the concept of earth-space sustainability requires considering spaces beyond the Kármán line, including the Earth's orbits.[1] However, this article does not include discussions on other celestial bodies, such as the Moon, Mars, and asteroids, as it limits itself to analyzing opportunities and challenges related to emerging, satellite-based infrastructure. We outline the most salient developments in the sector and elaborate on promising research directions for addressing the challenges of earth-space sustainability from the perspective of transition research and its interface with global governance literature.

2. Beyond the "Moon versus ghetto" dilemma: emerging earth-space interdependencies

For decades, innovation scholars have asked why modern society is able to land people on the Moon but unable to get the "kid out of the ghetto" (Nelson, 1977, 2011). This topic has been revisited by examining whether and how broader societal challenges can be addressed through major mission-oriented innovation programs (Foray et al., 2012), with calls for moon shot strategies to address problems such as climate change and poverty (Mazzucato, 2021; Nature, 2019). We argue that the rapid expansion of the space sector will play a growing role in the emerging green, techno-economic transformation paradigm (Mathews, 2013; Perez, 2013), as well as in deep transitions (Kanger and Schot, 2019; Schot and Kanger, 2018). To achieve earth-space sustainability, we have to ensure that space activities develop toward sustainability purposes on Earth and that those activities do not challenge space sustainability. An integrated approach will help prevent future space-based and Earth-bound developments from negatively impacting each other.

2.1. *Space-based infrastructure might accelerate sustainability on Earth*

There has been a boom in space activities over the past decade, particularly in the building of new satellite systems. Satellite-based infrastructure has high short- to mid-term transformation potential in industrial and service sectors. Earth observation satellites are contributing to environmental sustainability by massively improving our ability to measure and manage environmental problems on Earth. Indirectly, the ubiquity of space-based communication and navigation systems may also become strong drivers for transition in service sectors across the world.

Earth observation satellites began to gain traction in the late 2000s and became a key space activity of governments in the past several years (see Fig. 1). The European Union's (EU) flagship Earth observation program Copernicus, known as Europe's eyes on Earth, generates precise data of the Earth's surface and climate on an unprecedented scale. This precision allows for a set of new approaches by which to tackle environmentally related challenges. For instance, remote satellite sensing can provide new solutions for water resource management, even in the most remote regions on Earth (Sheffield et al., 2018; UNESCO, 2010). Advanced satellite monitoring technologies, such as interferometric synthetic aperture radar, are filling data gaps on groundwater management; this will become increasingly relevant for agriculture and water utilities in times of extended draught (WIPO, 2020; World Economic Forum, 2018). In addition, Earth observation satellites are increasingly precise in the monitoring of global greenhouse gas emissions, which could support national and international policymaking in tackling climate change (GEO et al., 2021).

Satellite-based infrastructure could also enable radical transformation in a range of industrial and service sectors (Al-Ekabi and Ferretti, 2018; UNOOSA, 2018, 2019). An example is the availability of high-speed 5G internet, which may become ubiquitous (Choudhury, 2019; ITU and UNESCO, 2019; World Bank, 2016). In 2020, most of the satellites launched by private actors were for internet and telecommunication purposes (see Fig. 2), forming large satellite constellations especially in low Earth orbit. The majority of these satellites are owned by billionaire companies, such as SpaceX (Starlink) and Amazon (Project Kuiper) (Witze, 2020). Despite the Covid-19 pandemic, the growth of these private space activities has not been hampered to a noticeable extent, as seen in Fig. 2. Internet satellite advancements may create new windows of opportunity for many sectors across the globe, especially in developing countries (World Bank, 2016; World Economic Forum, 2019).

Advanced satellite navigation systems are expected to enable disruptive changes in mass market applications, such as vehicle navigation, smart agriculture, disaster management, and precise power grid management. A prominent example is the Chinese-government owned BeiDou Navigation Satellite System—completed in the middle of 2020—which has been widely deployed in different regions of China for agricultural purposes (China Satellite Navigation Office, 2018). In Zhejiang province, for instance, the use of unmanned rice planters equipped with BeiDou navigation-assisted driving systems allowed for high speed, automatic seed planting (Global Times, 2020a). During the Covid-19 pandemic in 2020, companies in China also experimented with the precise positioning of the BeiDou system in unmanned delivery vehicles to help minimize human contact. It is expected that autonomous delivery vehicles and drones will become more common in the coming decade (European Environment Agency, 2020; Global Times, 2020b). The satellite systems on which these services rely may eventually be seen as generic infrastructure, driving socio-technical transitions across a wide range of sectors in more or less sustainable directions.

Satellite-based infrastructure may enable rapid economic and social development in the Global South. Africa has started to invest

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[1] We follow the International Astronautical Federation's definition that outer space begins at the Kármán line. Beyond the Kármán line, the Earth's orbits consist of low Earth orbit, medium Earth orbit, and high Earth and geosynchronous orbit.

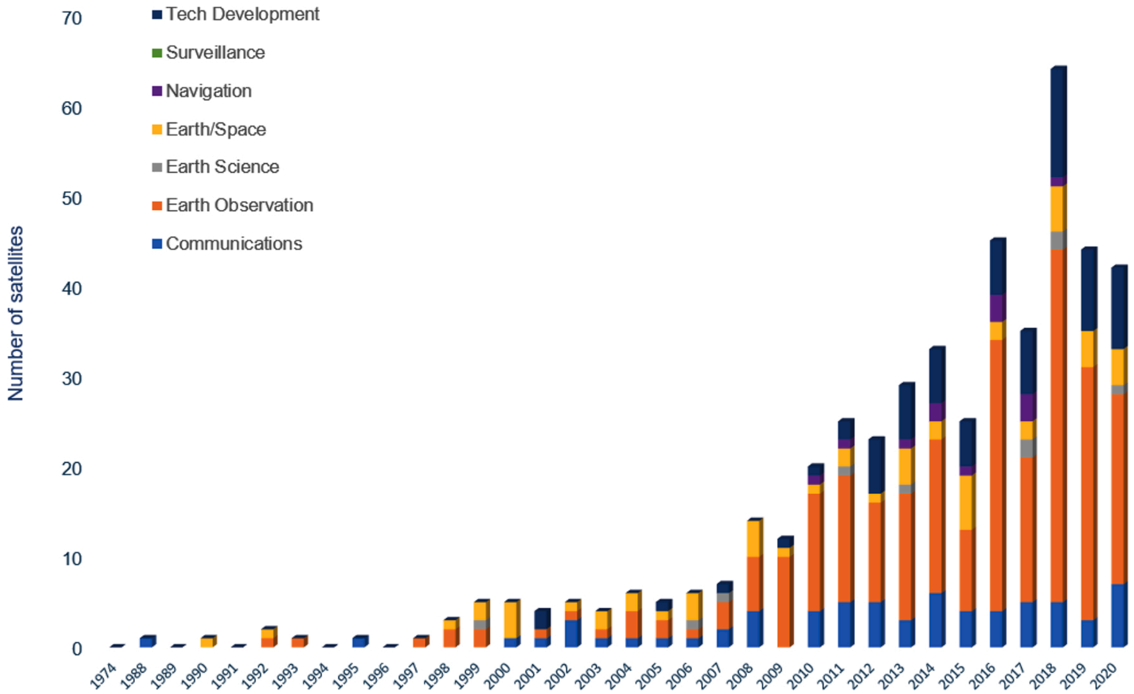

Fig. 1. Number of government-launched satellites by purpose, 1974–2020

Note: This figure highlights the increasing number of Earth observation activities. Tech Development = technology development, including research, demonstrations, and educational activities; Earth/Space = a mixture of space science or astronomy activities with other Earth observation activities; Earth Science = a mixture of Earth geoscience with other Earth observation activities. The share of total Earth observation activities is higher than is shown by the orange bar.

Source: Authors' compilation and illustration based on data from the Union of Concerned Scientists (2020), including all satellites from the United Nations Register of Objects Launched into Outer Space.

heavily in building satellite infrastructure in recent years (African Union Commission, 2019; Space in Africa, 2021), which may provide them with opportunities for technological development and learning (Aganaba-Jeanty, 2013; Wood and Weigel, 2011). This bears the question of whether the Global South can catch up and "leapfrog" in economic development without following the footsteps of the old industrialized countries (Yap et al., in press). More specifically, the promise of ubiquitous high-speed internet access could allow developing countries to benefit from internet-based application services (ITU and UNESCO, 2019; World Economic Forum 2019). The case of Kenya's M-PESA, a service that allows cellphone-based transfers of money globally, is an example of how developing countries can leapfrog the delivery of services years before OECD (Organization for Economic Co-operation and Development) countries (Mbiti and Weil, 2015; Mbogo, 2010). Similarly, the proliferation of space-based infrastructure may reveal opportunities for local businesses in countries in the Global South to offer application services, as demonstrated by India's software and IT engineering sectors, as well as by similar startups in Kenya (Baumüller, 2016; Bharadwaj et al., 2019; Guild, 2017). Recent research finds that even among the poorest twenty percent of households in developing countries, seven out of ten people own a mobile phone, making those devices more accessible than toilets and clean water (World Bank, 2016). This indicates the potential to improve access to, for instance, healthcare-related application services for those who have access to the internet but no nearby medical facilities. Space-based infrastructure could, therefore, facilitate progress in a number of sustainable development goals for emerging economies.

The emergence of universal satellite-based infrastructure has the potential to drive socio-technical transitions in many sectors. In this sense, satellite infrastructure is not just another empirical example to add to standard transition case studies, such as photovoltaics, wind energy, or electric vehicles. Rather, satellite systems are likely to develop into meta-infrastructure, shaping sectoral interdependencies and driving "multi-system transitions," a new research area that was recently identified as urgent for transition theorizing (Andersen and Markard, 2020; Rosenbloom, 2019, 2020). Satellite-based infrastructure might also shape new meta-rules across a range of sectors, as well as facilitate "deep transitions" (Kanger and Schot, 2019; Schot and Kanger, 2018). However, whether these transitions will ultimately lead to a more sustainable future still requires closer analysis.

2.2. The rising challenges of sustainable space activities

Despite many advantages, the rapid development of space-based infrastructure is also causing new sustainability challenges, both on Earth and in space. An increasing number of scientific reports are highlighting the environmental risks posed by space activities such as rocket launches and the re-entry of launched objects. A key element of this discussion is the increasing amount of soot

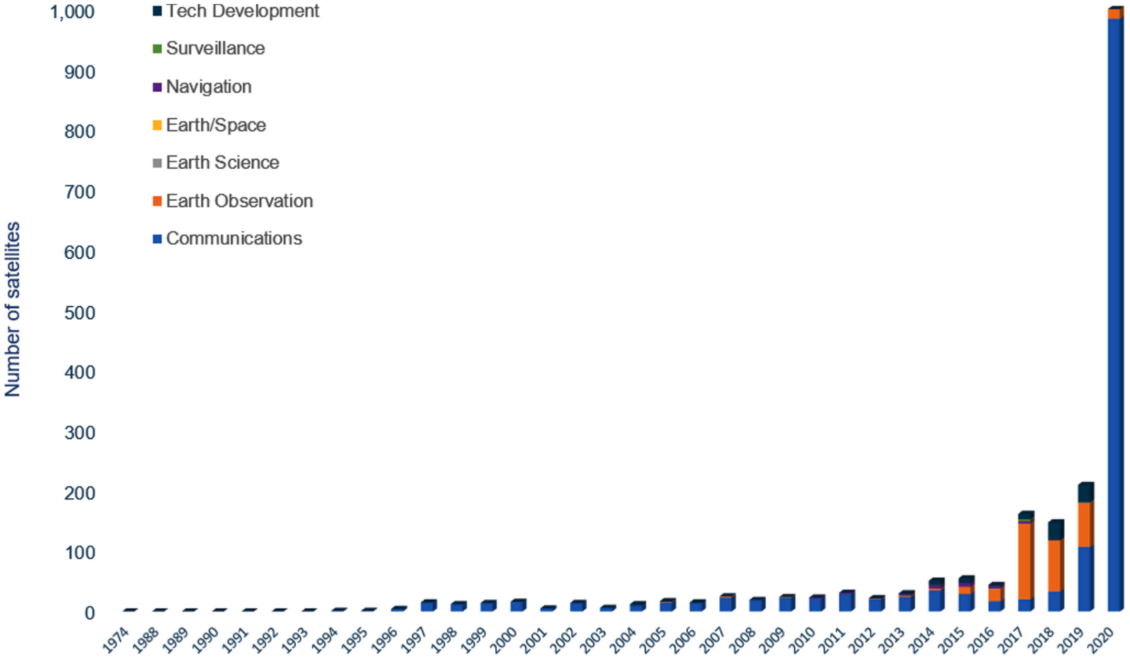

Fig. 2. Number of commercially launched satellites by segment, 1974–2020
Note: Tech Development = technology development; Earth/Space = a mixture of space science or astronomy activities with other Earth observation activities.
Source: Authors' compilation and illustration based on data from the Union of Concerned Scientists (2020), including all satellites from the United Nations Register of Objects Launched into Outer Space.

(comprising mainly black carbon) in the stratosphere, which is caused by frequent public and private rocket launches, and which could significantly exacerbate climate change or ozone depletion (Shiga, 2010). Other environmental problems, such as radiative forcing and marine pollution, have also been identified (Byers and Byers, 2017; Lonsdale and Phillips, 2021; Lucia and Lavicoli, 2019; Ross and Sheaffer, 2014). In addition, satellite constellations in low Earth orbit are obstructing astronomical observations (Kocifaj et al., 2021) and confusing migratory birds with light pollution (Lintott and Lintott, 2020).

The sustainability challenges of space activities span beyond the Earth's stratosphere and into its orbits. There are currently 8,410 satellites in the Earth's orbits, of which about 5,600 are operational (ESA, 2022). Around 31,150 debris objects are regularly tracked, but there are also 130 million space debris objects of a size of 1 centimeter or smaller travelling at the speed of a bullet (ESA, 2022). Scientists warned of the Kessler Syndrome in the 1970s, a scenario in which collisions between space objects lead to a cascade as resulting space debris increases the likelihood of future collisions (Kessler and Cour-Palais, 1978). The number of space objects will sharply increase over the next decade due to commercialization, making space congestion an increasing threat for future space safety especially in low Earth orbit (Bonnal and McKnight, 2017; Krag, 2021; Nature, 2021). This might severely disrupt activities and services on Earth if communication, observation, or navigation satellites stop functioning properly. Given that outer space has been generally perceived as a common heritage of mankind (Khatwani, 2019; Wolfrum, 2009), these unsustainable developments have raised concerns among industry practitioners, scientists, and policymakers about whether a new "tragedy of the commons" (Hardin, 1968) is unfolding in space (Kitfield, 2010). Earth's orbits are, therefore, novel territory that requires appropriate governance to ensure a sustainable future. The scope of sustainability concerns should expand to spaces that are even further away, as in-space manufacturing and space mining become popular (Butkevičienė and Rabitz, 2022; Jakhu et al., 2017; Lewin, 2018; NASA, 2019), or as more probes are launched to the Moon and Mars for exploration and exploitation activities (Nelson, 2020; Tutton, 2018, 2021).

The existing global space governance regime is ill-prepared to address the challenges of the rapidly evolving space sector, as it is still largely based on the Outer Space Treaty of 1967, which was negotiated during the Cold War Space Race (Jakhu and Pelton, 2017; Outer Space Treaty, 1967). Extant space law and governance structures are unable to contend with the new role of private actors or the multidimensional use of space, and the size of these problems is likely to grow rapidly. Owing to the increasing commercialization of the space sector, smaller companies around the world face lower barriers to launching satellites (Akyildiz and Kak, 2019; Howell, 2018; OECD, 2020), and there are no signs of any slowdown. About 16,000 new satellites are approved for launch in the next decade, with applications for tens of thousands more for internet and telecommunication purposes under review by the International Telecommunication Union in Geneva (Greenbaum, 2020; Witze, 2020). Telecommunication satellites require both physical space for maneuvering and access to a limited number of radio frequencies to operate.

The sustainability aspect of space activities calls for intergovernmental and regulatory bodies, policymakers, and scientists to introduce new institutions and regulations. International agencies such as the European Space Agency and the United Nations (UN) Office for Outer Space Affairs and its Committee on the Peaceful Uses of Outer Space have been active in driving the space sustainability discourse. Initiatives such as the Space Sustainability Rating–currently led by the Swiss Federal Institute of Technology Lausanne (EPFL) Space Center–have been introduced to incentivize private actors to carry out sustainable operations in space (World Economic Forum, 2021). There have also been discussions about including space as the eighteenth UN sustainable development goal (Galli and Losch, 2019; Losch, 2020), deriving a better understanding of the "commons" feature of space resources (Tepper, 2019), imposing orbital-use fees (Rao et al., 2020), and preventing space from becoming a new battleground where new space innovations can be used for hostile purposes due to geopolitical interests (Al-Rodhan, 2012). Intergovernmental bodies, national policymakers, academia, and companies must urgently cooperate to establish guidelines and frameworks for the sustainable, just, and peaceful use of outer space.

3. Transition studies addressing earth-space sustainability

The emerging opportunities and challenges presented by space development require new conceptual and analytical approaches, to which sustainability transition research can make major contributions. Transition research is an established field that focuses on the long-term, disruptive (re)configurations of socio-technical systems towards more sustainable patterns of production and consumption (Markard et al., 2012). However, the transition perspective needs to be extended in order to take on this new challenge. The potential for satellite-based infrastructure to shape manifold technologies and services requires responsiveness in order to transition and govern challenges across multiple socio-technical systems. In the following, we shall identify a number of salient research avenues from this expanded conceptual framing.

3.1. Earth-Space interdependencies: from single- to multi-system transition

Transition research offers conceptual frameworks for explaining successful innovation and transformation processes in Earth-bound, socio-technical systems, such as the provision of water, energy, food, and mobility. In general, the transition of a system requires a shift from one "socio-technical regime" to another, defined as highly institutionalized formal and informal rules that co-evolve with certain technologies (Fuenfschilling and Truffer, 2014; Geels, 2010; Markard et al., 2012). This points to the role that transition research can play in the future development challenges of space-based infrastructure that shape Earth-bound provision systems. Considering that space-based infrastructure is an external driver, established transition frameworks may be applied to the study of sectoral transformations that are induced by this new infrastructure. The technological innovation systems framework, for instance, can inform policymakers about likely development opportunities in different socio-technical systems and can identify stronger or weaker development conditions (Bergek et al., 2008; Hekkert et al., 2007). Meanwhile, extant socio-technical regimes can explain why radical, but potentially more sustainable, innovations are not adopted. For instance, although tackling water-related challenges is a top priority for the EU's Copernicus Earth observation program, regime actors are still reluctant to switch from in situ field inspections to space-based monitoring for dam breaks or flood management (Haarler, 2020). Transition research could analyze why regime actors promote or reject Earth observation services. As the commercialization of space continues to grow, the application services offered through space-based infrastructure are increasingly globalized. Recently proposed concepts, such as global innovation systems (Binz and Truffer, 2017), global socio-technical regimes (Fuenfschilling and Binz, 2018), or global niche dynamics (Sengers and Raven, 2015), may provide useful inroads by which to analyze these dynamics.

However, a consideration of the range of sectoral (re)configurations that could result from space-based infrastructures demonstrates that a better understanding of multi-system transition dynamics (Kanger et al., 2021; Rosenbloom, 2020) is required. This could, for instance, refer to multi-system interactions (e.g., the interactions between satellite infrastructure and Earth-bound, socio-technical systems) or multi-system transitions (e.g., simultaneous transitions among multiple socio-technical systems). These inter-related dynamics could lead to shared rules across socio-technical systems—also known as meta-rules—which might drive deep transitions (Kanger and Schot, 2019; Schot and Kanger, 2018). The space sector could serve as an important application area for the testing and further development of these frameworks. Furthermore, the development of space-based infrastructure does not seem to be converging toward one integrated infrastructure design. Owing to geopolitical ambitions, the United States of America, Europe, China, and Russia, as well as private companies, are competing for space-based infrastructure leadership by trying to establish their own standards for this emerging meta-infrastructure. It is likely that the next decade could bring major shifts toward a green, techno-economic paradigm, in which multi-regime transitions will take place. The space sector could also inspire research on other drivers of multi-regime transitions, such as artificial intelligence, digital platforms (see Frenken and Schor, 2017; Frenken et al., 2020), generic technologies (Andersen and Markard, 2020), and socio-technical "megaprojects" such as the HyNet decarbonization project in North West England (Sovacool and Geels, 2021). To ascertain if these inter-related innovation processes will actually contribute to sustainability, the directionality of these developments must be addressed explicitly (Mazzucato, 2016; Schot and Kanger, 2018; Weber and Rohracher, 2012; Yap and Truffer, 2019).

3.2. Global multi-system governance for earth-space sustainability

To ensure earth-space sustainability, the space sector must undergo a sustainability transition to mitigate the environmental impacts of increasing space activities. This requires a formidable governance approach to address a variety of dynamics across sectors and policy domains, a challenge made even more daunting as space activities are currently operating under a weak global governance regime. Emerging mitigation policies and practices are already calling for technological innovations in pre-launch satellite and spacecraft designs, to ensure the appropriate end-of-life disposal or de-orbiting of those devices. Other examples of innovations that have been promoted are space debris removal technologies and reusable rockets. However, these innovations could lead to rebound effects or unsustainable developments (Antal et al., 2020; Markard et al., 2021) if they reinforce or facilitate the rapid growth of nascent, but controversial, industries such as space tourism (Markard et al., 2020; Spector et al., 2020) or solar geoengineering (Baum et al., 2022; Gupta et al., 2020), both of which have highly uncertain planetary consequences. Sustainability challenges in the space sector are further complicated by ongoing geopolitical tensions, especially when considering dual-use technologies for national security purposes. Geopolitical tensions often lead to state competition for dominance or leadership in specific space realms without a consideration of the broader sustainability outcomes (Al-Rodhan, 2012); government anti-satellite tests that result in increasing amounts of space debris are one such example.

To ensure that space activities do not promote unsustainable practices, studies on transition policy, which have so far focused mostly on place-based or nationally bounded environmental and industrial policies, must embrace the global dimension. This includes understanding how socio-technical (re)configurations take place at the global level, contextualizing explicitly international relations (Kern and Rogge, 2016), geopolitical considerations (Kivimaa, 2022), and global governance challenges. Next, we turn to the need for integrating multi-system transition dynamics with global governance studies, in order to adequately address future earth-space sustainability.

Outer space is akin to the deep sea, Antarctica, or cyberspace, insofar as it encompasses similar governance challenges of "areas beyond national jurisdiction" (Young, 2011, 2020). The governance of space requires a better understanding of socio-technical transition or transformation processes, owing to its characteristics as an emerging meta-infrastructure. Governing beyond national jurisdiction, in this context, requires acknowledging different, or even partially opposing, approaches to framing problems. For instance, some argue that space debris management is a matter of dealing with market externalities, while others see orbital sustainability as an issue of "commons governance" (Ostrom, 1990) at the global level (Ostrom, 2010), which could be approached through international, polycentric governance (Morin and Richard, 2021; Shackelford, 2014). The different framings of these problems are applicable to other pressing global challenges, such as climate change. For instance, the Paris Agreement can be viewed as a polycentric, international multi-stakeholder approach to managing a common-pool resource (Kern and Rogge, 2016), while national emissions trading schemes frame the problem of ozone depletion as a market externality (Young, 2021). Conceptualizing the challenge of earth-space sustainability from different analytical perspectives will enable the identification of more or less desirable future states, as well as identify associated core governance challenges.

To assess earth-space sustainability, it is essential that transition research embraces the intersection points between socio-technical systems and their ecological or biophysical conditions (Ahlborg et al., 2019)—in this case, the uses of space and the implications of Earth-bound or space sustainability—from the local to global levels (Anderies et al., 2004; Janssen et al., 2007; Young et al., 2006). The literature on earth system governance provides insights to such problems as it explicitly considers governance challenges stemming from the intertwined nature of social and ecological (or biophysical) environments. In addition, this literature expounds on the need to address justice problems on a planetary scale, which goes beyond the usual focus on justice-related obligations that people owe to other people at global scale (Biermann and Kalfagianni, 2020). The unsustainable use of the orbits will affect not only societies across the globe (e.g., if space-based satellite systems for disaster and environmental management are disrupted), but also future generations and non-human entities. The earth system governance literature furthermore argues for anticipatory governance, questioning how emerging technologies should be governed, for instance by enabling or restricting particular technological developments (Gupta et al., 2020; Muiderman et al., 2020). Emerging earth-space multi-system (re)configurations will therefore require new institutional architectures that will be built from a complex mix of governance approaches (Biermann and Kim, 2020; Biermann et al., 2009; Young, 2002, 2008). To ensure earth-space sustainability, it is essential that the two fields—sustainability transition and global governance—engage more explicitly.

4. Conclusion

As space-based infrastructure becomes increasingly indispensable to activities on Earth, the research avenues proposed here are critical for addressing the opportunities and challenges of the expanding space sector, not only to accelerate Earth-bound transitions but also to maintain orbital sustainability. In particular, the increasing interdependencies between space-based infrastructure and Earth-bound sustainability, as well as between associated large-scale multi-system (re)configurations, offer a unique lens for understanding emerging sustainability-oriented paradigm shifts. In addition, the growing role of states and private companies in the management, or even "ownership," of next generation space-based meta-infrastructure might be reinforcing—if not exacerbating—distributional tensions in the current global power structure on Earth. This challenges sustainability transition research to critically assess alternative pathways toward earth-space sustainability. The analytical scope of sustainability concerns has to extend beyond the Earth's orbits, as human activities rapidly expand to other celestial bodies such as the Moon, Mars, and asteroids. The need for future earth-space sustainability urges transition and global governance research to engage more closely in the coming years.

Declaration of Competing Interest

None.

Data availability

Data will be made available on request.

Acknowledgement

Xiao-Shan Yap greatly acknowledges Prof. Oran Young at the University of California, Santa Barbara, for his valuable mentoring on research related to governing areas beyond national jurisdiction via various bilateral discussions. The authors furthermore thank the handling editor and three anonymous reviewers for their constructive comments. This article also benefited from constructive feedback generated during the presentations at the International Sustainability Transitions Conference (IST) 2020 and 2021.

References

African Union Commission, 2019. *African Space Strategy: For Social, Political and Economic Integration*. https://au.int/sites/default/files/documents/37434-doc-au_space_strategy_isbn-electronic.pdf.

Aganaba-Jeanty, T., 2013. Precursor to an African space agency: commentary on Dr Peter Martinez "Is there a need for an African space agency? Space Policy 29 (3), 168–174.

Ahlborg, H., Ruiz-Mercado, I., Molander, S., Masera, O., 2019. Bringing technology into social-ecological systems research—motivations for a socio-technical-ecological systems approach. Sustainability 11 (7), 2009. https://doi.org/10.3390/su11072009.

Akyildiz, I.F., Kak, A., 2019. The internet of space things/cubesats: a ubiquitous cyber-physical system for the connected world. Comput. Networks 150, 134–149. https://doi.org/10.1016/j.comnet.2018.12.017.

Al-Ekabi, C., Ferretti, S., 2018. Yearbook On Space Policy 2016: Space for Sustainable Development (European Space Policy Institute). Springer International Publishing.

Al-Rodhan, N.R.F., 2012. Meta-geopolitics of Outer space: An Analysis of Space Power, Security and Governance. Palgrave Macmillan, London.

Anderies, J.M., Janssen, M.A., Ostrom, E., 2004. A framework to analyze the robustness of social-ecological systems from an institutional perspective. Ecol. Soc. 9 (1), 18.

Andersen, A.D., Markard, J., 2020. Multi-technology interaction in socio-technical transitions: how recent dynamics in HVDC technology can inform transition theories. Technol. Forecast. Social Change 151, 119802. https://doi.org/10.1016/j.techfore.2019.119802.

Antal, M., Mattioli, G., Rattle, I., 2020. Let's focus more on negative trends: a comment on the transitions research agenda. Environ. Innov. Societal Trans. 34, 359–362. https://doi.org/10.1016/j.eist.2020.02.001.

Baum, C.M., Low, S., Sovacool, B.K., 2022. Between the sun and us: expert perceptions on the innovation, policy, and deep uncertainties of space-based solar geoengineering. Renewable Sustainable Energy Rev. 158 (April 2022), 112179 https://doi.org/10.1016/j.rser.2022.112179.

Baumüller, H., 2016. Agricultural service delivery through mobile phones: local innovation and technological opportunities in Kenya. In: Gatzweiler, Franz W., von Braun, Joachim (Eds.), Technological and Institutional Innovations For Marginalized Smallholders in Agricultural Development. Springer, London, pp. 143–162.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Research Policy 37, 407–429. https://doi.org/10.1016/j.respol.2007.12.003.

Bharadwaj, P., Jack, W., Suri, T., 2019. Fintech and household resilience to shocks: Evidence from digital loans in Kenya (No. w25604). National Bureau of Economic Research.

Biermann, F., Kalfagianni, A., 2020. Planetary justice: a research framework. Earth Syst. Govern. 6, 100049 https://doi.org/10.1016/j.esg.2020.100049.

Biermann, F., Kim, R., 2020. Architectures of Earth System Governance: Institutional Complexity and Structural Transformation. Cambridge University Press. https://doi.org/10.1017/9781108784641.

Biermann, F., Pattberg, P., Van Asselt, H., Zelli, F., 2009. The fragmentation of global governance architectures: a framework for analysis. Glob. Environ. Politics 9 (4), 14–40. https://doi.org/10.1162/glep.2009.9.4.14.

Binz, C., Truffer, B., 2017. Global innovation systems—A conceptual framework for innovation dynamics in transnational contexts. Res. Policy 46 (7), 1284–1298. https://doi.org/10.1016/j.respol.2017.05.012.

Bonnal, C., and McKnight, D.S. 2017. International Academy of Astronautics (IAA) Situation Report on Space Debris - 2016, Available at: https://iaaspace.org/wp-content/uploads/iaa/Scientific%20Activity/sg514finalreport.pdf.

Butkevičienė, E., Rabitz, F., 2022. Sharing the Benefits of Asteroid Mining. Glob. Policy 2022, 1–12. https://doi.org/10.1111/1758-5899.13035.

Byers, M., Byers, C., 2017. Toxic splash: russian rocket stages dropped in Arctic waters raise health, environmental and legal concerns. Polar Rec. 53 (6), 580–591. https://doi.org/10.1017/s0032247417000547.

China Satellite Navigation Office, 2018. Applications of the BeiDou Navigation Satellite System. China Satellite Navigation Office. http://www.beidou.gov.cn/xt/gfxz/201906/P020190605488535070471.pdf.

Choudhury, S.R., 2019. Super-fast internet from satellites is the next big thing in the space race. CNBC News, 22 July 2019. https://www.cnbc.com/2019/07/22/fast-internet-via-satellites-is-the-next-big-thing-in-the-space-race.html.

Clormann, M., 2021. Switching between worlds apart: negotiating European space sector cultures through innovation. Sci. Public Policy 48 (4), 521–530. https://doi.org/10.1093/scipol/scab038.

ESA, 2022. Space debris by the numbers. *European Space Agency (ESA) Space Debris Office*. https://www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers.

European Environment Agency, 2020. Drivers of change: Delivery drones and the Environment. European Environment Agency. https://www.eea.europa.eu/publications/delivery-drones-and-the-environment.

Foray, D., Mowery, D.C., Nelson, R.R., 2012. Public R&D and social challenges: what lessons from mission R&D programs? Res. Policy 41, 1697–1702.

Frenken, K., Schor, J., 2017. Putting the sharing economy into perspective. Environ. Innov. Societal Trans. 23, 3–10. https://doi.org/10.1016/j.eist.2017.01.003.

Frenken, K., Vaskelainen, T., Fünfschilling, L., Piscicelli, L., 2020. An institutional logics perspective on the gig economy. In: Maurer, I., Mair, J., Oberg, A. (Eds.), *Theorizing the Sharing Economy: Variety and Trajectories of New Forms of Organizing* (Vol. 66, pp. 83-105). Emerald Publishing Limited. https://doi.org/10.1108/S0733-558x20200000066005.

Fuenfschilling, L., Binz, C., 2018. Global socio-technical regimes. Res. Policy 47, 735–749. https://doi.org/10.1016/j.respol.2018.02.003.

Fuenfschilling, L., Truffer, B., 2014. The structuration of socio-technical regimes—Conceptual foundations from institutional theory. Research Policy 43 (4), 772–791. https://doi.org/10.1016/j.respol.2013.10.010.

Galli, A., Losch, A., 2019. Beyond planetary protection: what is planetary sustainability and what are its implications for space research? Life Sci. Space Res. 23, 3–9. https://doi.org/10.1016/j.lssr.2019.02.005.

Geels, F.W., 2010. Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. Res. Policy 39 (4), 495–510. https://doi.org/10.1016/j.respol.2010.01.022.

GEO, ClimateTRACE, & WGIC. 2021. GHG Monitoring from Space: a mapping of capabilities across public, private, and hybrid satellite missions. *Joint report of Group on Earth Observations (GEO), ClimateTRACE, and World Geospatial Industry Council (WGIC)*. https://earthobservations.org/documents/articles_ext/GHG%20Monitoring%20from%20Space_report%20final_Nov2021.pdf.

Global Times, 2020a. China's BeiDou navigation system adopted in unmanned farming in Zhejiang. Global Times. https://www.globaltimes.cn/content/1197507.shtml.

Global Times, 2020b. Unmanned vehicle and drone delivery will be common in 3-5 years: meituan. Global Times. https://www.globaltimes.cn/content/1194232.shtml.

Greenbaum, D., 2020. Space debris puts exploration at risk. Science 370 (6519), 922. https://doi.org/10.1126/science.abf2682.

Guild, J., 2017. Fintech and the future of finance. Asian J. Public Affairs 17–20.

Gupta, A., Möller, I., Biermann, F., Jinnah, S., Kashwan, P., Mathur, V., Morrow, D.R., Nicholson, S., 2020. Anticipatory governance of solar geoengineering: conflicting visions of the future and their links to governance proposals. Curr. Opin. Environ. Sustain. 45, 10–19. https://doi.org/10.1016/j.cosust.2020.06.004.

Haarler, S., 2020. From the man on the moon to space for the mankind: A technological innovation system analysis of how the Copernicus earth observation infrastructure leveraged new applications in the Dutch water management sector [Master thesis, Utrecht University]. The Netherlands.

Hardin, G., 1968. The tragedy of the commons. American Assoc. Adv. Sci. 162 (3859), 1243–1248.

Hekkert, M., Suurs, R., Negro, S., Kuhlmann, S., Smits, R., 2007. Functions of innovation systems: a new approach for analysing technological change. Technol. Forecast. Social Change 74 (4), 413–432. http://www.scopus.com/scopus/inward/record.url?eid=2-s2.0-34147185181andpartnerID=40.

Howell, E., 2018. CubeSats: tiny payloads, huge benefits for space research. Space.com. *19 June 2018*. https://www.space.com/34324-cubesats.html.

ITU and UNESCO, 2019. Connecting Africa through broadband: a strategy for doubling connectivity by 2021 and reaching universal access by 2030. *International Telecommunication Union (ITU) and United Nations Educational, Scientific and Cultural Organization (UNESCO)* https://www.broadbandcommission.org/Documents/working-groups/DigitalMoonshotforAfrica_Report.pdf.

Jakhu, R., Pelton, J., Nyampong, Y.O.M, 2017. Space Mining and Its Regulation. Springer International Publishing. https://www.springer.com/us/book/9783319392455?utm_medium=displayandutm_source=criteoandutm_campaign=3_fjp8312_product_usandutm_content=us_banner_29012020#otherversion=9783319392462.

Jakhu, R., Pelton, J., 2017. Global Space Governance: An International Study. Springer International Publishing.

Janssen, M.A., Anderies, J.M., Ostrom, E., 2007. Robustness of social-ecological systems to spatial and temporal variability. Soc. Nat. Resources 20 (4), 307–322. https://doi.org/10.1080/08941920601161320.

Kanger, L., Schot, J., 2019. Deep transitions: theorizing the long-term patterns of socio-technical change. Environ. Innov. Societal Trans. 32, 7–21. https://doi.org/10.1016/j.eist.2018.07.006.

Kanger, L., Schot, J., Sovacool, B., van der Vleuten, E., Ghosh, B., Keller, M., Kivimaa, P., Pahker, A.-.K., Steinmueller, E., 2021. Research frontiers for multi-system dynamics and deep transitions. Environ. Innov. Societal Trans. 41, 52–56. https://doi.org/10.1016/j.eist.2021.10.025.

Kern, F., Rogge, K.S., 2016. The pace of governed energy transitions: agency, international dynamics and the global Paris agreement accelerating decarbonisation processes? Energy Res. Social Sci. 22, 13–17. https://doi.org/10.1016/j.erss.2016.08.016.

Kessler, D.J., Cour-Palais, B.G., 1978. Collision frequency of artificial satellites: the creation of a debris belt. J. Geophys. Res. 83 (A6), 2637. https://doi.org/10.1029/ja083ia06p02637.

Khatwani, N., 2019. Common Heritage of Mankind for Outer Space. Astropolitics 17 (2), 89–103. https://doi.org/10.1080/14777622.2019.1638679.

Kitfield, J. 2010. *Crowded, Congested Space*. Retrieved 10 January 2021 from https://www.airforcemag.com/article/0810space/.

Kivimaa, P., 2022. Transforming innovation policy in the context of global security. Environmental Innovation and Societal Transitions 43, 55–61.

Kocifaj, M., Kundracik, F., Barentine, J.C., Bará, S., 2021. The proliferation of space objects is a rapidly increasing source of artificial night sky brightness. Monthly Notices of the Royal Astronomical Society: Letters 504 (1), L40–L44. https://doi.org/10.1093/mnrasl/slab030.

Krag, H., 2021. A sustainable use of space. Science 373 (6552), 259. https://doi.org/10.1126/science.abk3135.

Lewin, S., 2018. Making stuff in space: off-earth manufacturing is just getting started. Space.com. *11 May 2018*. https://www.space.com/40552-space-based-manufacturing-just-getting-started.html.

Lintott, C., Lintott, P., 2020. Satellite megaclusters could fox night-time migrations. Nature 586 (7831), 674. https://doi.org/10.1038/d41586-020-03007-8.

Lonsdale, J.-.A., Phillips, C., 2021. Space launches and the UK marine environment. Mar. Policy 129, 104479. https://doi.org/10.1016/j.marpol.2021.104479.

Losch, A., 2020. Developing our planetary plan with an 18th United Nations sustainable development goal: space environment. HTS Teologiese Studies /Theological Studies 76 (1), a5951. https://doi.org/10.4102/hts.v76i1.5951.

Lucia, V.D., Lavicoli, V., 2019. From outer space to ocean depths: the ‘spacecraft cemetery’ and the protection of the marine environment in areas beyond national jurisdiction. California Western Int. Law J. 49 (2), 345–389. https://scholarlycommons.law.cwsl.edu/do/search/?q=author_lname%3A%22De%20Lucia%22%20author_fname%3A%22Vito%22andstart=0andcontext=4181714andfacet=.

Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: an emerging field of research and its prospects. Res. Policy 41 (6), 955–967. https://doi.org/10.1016/j.respol.2012.02.013.

Markard, J., Van Lente, H., Wells, P., Yap, X.-S., 2021. Neglected developments undermining sustainability transitions. Environ. Innov. Societal Trans. 41, 39–41. https://doi.org/10.1016/j.eist.2021.10.012.

Markard, J., Wells, P., Yap, X.-S., Van Lente, H., 2020. Unsustainable Transitions – A blind spot for transitions research. International Sustainability Transitions (IST) 2020 conference.

Mathews, J., 2013. The renewable energies technology surge: a new techno-economic paradigm in the making? Futures 46, 10–22.

Mazzucato, M., 2016. From market fixing to market-creating: a new framework for innovation policy. Indus. Innov. 23 (2), 140–156.

Mazzucato, M., 2021. Mission Economy: A Moonshot Guide to Changing Capitalism. Allen Lane.

Mazzucato, M., Robinson, D., 2018. Co-creating and directing Innovation Ecosystems? NASA’s changing approach to public-private partnerships in low-earth orbit. Technol. Forecast. Social Change 136, 166–177. https://doi.org/10.1016/j.techfore.2017.03.034.

Mbiti, I., Weil, D.N., 2015. African Successes, Volume III: Modernization and Development. University of Chicago Press.

Mbogo, M., 2010. The impact of mobile payments on the success and growth of micro-business: the case of M-Pesa in Kenya. J. Language, Technol. Entrepreneur. Africa 2 (1), 182–203.

Morin, J.F., Richard, B., 2021. Astro-environmentalism: towards a polycentric governance of space debris. Global Policy. https://doi.org/10.1111/1758-5899.12950.

Muiderman, K., Gupta, A., Vervoort, J., Biermann, F., 2020. Four approaches to anticipatory climate governance: different conceptions of the future and implications for the present. WIREs Clim. Change 11 (6). https://doi.org/10.1002/wcc.673.

NASA. 2019. *In-Space Manufacturing*. https://www.nasa.gov/oem/inspacemanufacturing.

Nature, 2019. Cancer, climate, plastics: why ‘earthshots’ are harder than moonshots. Nature 571 (7764), 145. https://doi.org/10.1038/d41586-019-02093-7.

Nature, 2021. The world must cooperate to avoid a catastrophic space collision. Nature 596 (2021), 163. https://doi.org/10.1038/d41586-021-02167-5.

Nelson, J., 2020. The artemis accords and the future of international space law. American Soc. Int. Law 24 (31). https://www.asil.org/insights/volume/24/issue/31/artemis-accords-and-future-international-space-law.

Nelson, R., 1977. The Moon and the Ghetto. W. W. Norton and Company.

Nelson, R., 2011. The moon and the ghetto revisited. Sci. Public Policy 38 (9), 681–690.

OECD, 2020. Space sustainability: the economics of space debris in perspective. Organ. Econ. Co-oper. Develop. (OECD). https://www.oecd-ilibrary.org/docserver/a339de43-en.pdf?expires=1607636808andid=idandaccname=guestandchecksum=A56C7678D6B68481FA4DD1EB4C79C467.

Ostrom, E., 1990. Governing the Commons: The Evolution of Institutions For Collective Action. Cambridge University Press.

Ostrom, E., 2010. Polycentric systems for coping with collective action and global environmental change. Glob. Environ. Chang. 20 (4), 550–557. https://doi.org/10.1016/j.gloenvcha.2010.07.004.

Outer Space Treaty, 1967. Treaty on principles governing the activities of States in the exploration and use of outer space, including the moon and other celestial bodies. https://treaties.un.org/doc/Publication/UNTS/Volume%20610/volume-610-I-8843-English.pdf.

Perez, C., 2013. Unleashing a golden age after the financial collapse: drawing lessons from history. Environ. Innov. Societal Trans. 6, 9–23. https://doi.org/10.1016/j.eist.2012.12.004.

Rao, A., Burgess, M.G., Kaffine, D., 2020. Orbital-use fees could more than quadruple the value of the space industry. Proc. Natl. Acad. Sci. (PNAS) 117 (23), 12756–12762.

Robinson, D., Mazzucato, M., 2019. The evolution of mission-oriented policies: exploring changing market creating policies in the US and European space sector. Res. Policy 48 (4), 936–948. https://doi.org/10.1016/j.respol.2018.10.005.

Rosenbloom, D., 2019. A clash of socio-technical systems: exploring actor interactions around electrification and electricity trade in unfolding low-carbon pathways for Ontario. Energy Res. Social Sci. 49, 219–232. https://doi.org/10.1016/j.erss.2018.10.015.

Rosenbloom, D., 2020. Engaging with multi-system interactions in sustainability transitions: a comment on the transitions research agenda. Environ. Innov. Societal Trans. 34, 336–340. https://doi.org/10.1016/j.eist.2019.10.003.

Ross, M.N., Sheaffer, P.M., 2014. Radiative forcing caused by rocket engine emissions. Earth's Future 2 (4), 177–196. https://doi.org/10.1002/2013ef000160.

Schot, J., Kanger, L., 2018. Deep transitions: emergence, acceleration, stabilization and directionality. Res. Policy 47 (6), 1045–1059. https://doi.org/10.1016/j.respol.2018.03.009.

Sengers, F., Raven, R., 2015. Toward a spatial perspective on niche development: the case of Bus Rapid Transit. Environ. Innov. Societal Trans. 17, 166–182. https://doi.org/10.1016/j.eist.2014.12.003.

Shackelford, S.J., 2014. Governing the final frontier: a polycentric approach to managing space weaponization and debris. American Bus. Law J. 51 (2), 429–513.

Sheffield, J., Wood, E.F., Pan, M., Beck, H., Coccia, G., Serrat-Capdevila, A., Verbist, K., 2018. Satellite remote sensing for water resources management: potential for supporting sustainable development in data-poor regions. Water Resour. Res. 54 (12), 9724–9758. https://doi.org/10.1029/2017wr022437.

Shiga, D., 2010. Space tourism could have big impact on climate. Newscientist. https://www.newscientist.com/article/dn19626-space-tourism-could-have-big-impact-on-climate/.

Sovacool, B.K., Geels, F., 2021. Megaprojects: examining their governance and sociotechnical transitions dynamics. Environ. Innov. Societal Trans. 41, 89–92.

Space in Africa, 2021. *African Space Industry Revenue to Surpass USD 10.24 billion by 2024 Despite COVID-19 Setback*. Retrieved 4 November 2021 from https://africanews.space/african-space-industry-revenue-to-surpass-usd-10-24-billion-by-2024-despite-covid-19-setback/.

Spector, S., Higham, J.E.S., Gössling, S., 2020. Extraterrestrial transitions: desirable transport futures on earth and in outer space. Energy Res. Social Sci. 68, 101541 https://doi.org/10.1016/j.erss.2020.101541.

Tepper, E., 2019. Structuring the discourse on the exploitation of space resources: between economic and legal commons. Space Policy 49, 101290. https://doi.org/10.1016/j.spacepol.2018.06.004.

Tutton, R., 2018. Multiplanetary Imaginaries and Utopia. Sci. Technol. Human Values 43 (3), 518–539. https://doi.org/10.1177/0162243917737366.

Tutton, R., 2021. Sociotechnical imaginaries and techno-optimism: examining outer space utopias of silicon valley. Sci. Culture 30 (3), 416–439. https://doi.org/10.1080/09505431.2020.1841151.

Union of Concerned Scientists, 2020. Union of Concerned Scientists (UCS) Satellite Database (for the year 2020). https://www.ucsusa.org/resources/satellite-database.

UNESCO, 2010. Application of satellite remote sensing to support water resources management in Africa. United Nations Educ. Sci. Cultural Organ. (UNESCO). https://unesdoc.unesco.org/ark:/48223/pf0000188045.

UNOOSA, 2018. Annual Report 2018. *United Nations Office for Outer Space Affairs (UNOOSA)*https://reliefweb.int/sites/reliefweb.int/files/resources/UNOOSA_Annual_Report_2018.pdf.

UNOOSA, 2019. Annual Report 2019. *United Nations Office for Outer Space Affairs (UNOOSA)* https://www.unoosa.org/documents/pdf/annualreport/UNOOSA_Annual_Report_2019.pdf.

Weber, K.M., Rohracher, H., 2012. Legitimizing research, technology and innovation policies for transformative change: combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework. Res. Policy 41 (6), 1037–1047. https://doi.org/10.1016/j.respol.2011.10.015.

WEF, 2021. New Space Sustainability Rating addresses Space Debris With Mission Certification System. World Economic Forum (WEF). https://www.weforum.org/press/2021/06/new-space-sustainability-rating-addresses-space-debris-with-mission-certification-system.

WIPO, 2020. Innovative Technology in the Water, Sanitation and Hygiene (WASH) Sector. World Intellectual Property Organization (WIPO), Switzerland. https://www.wipo.int/publications/en/details.jsp?id=4497andplang=EN.

Witze, A., 2020. How satellite 'megaconstellations' will photobomb astronomy images. Nature (news). https://www.nature.com/articles/d41586-020-02480-5.

Wolfrum, R., 2009. Common Heritage of Mankind. *Oxford Public International Law, Max Planck Encyclopedia of Public International Law (MPEPIL)*. https://opil.ouplaw.com/view/10.1093/law:epil/9780199231690/law-9780199231690-e1149.

Wood, D., Weigel, A., 2011. Building technological capability within satellite programs in developing countries. Acta Astronaut. 69 (11–12), 1110–1122.

World Bank, 2016. *World Development Report: Digital Dividends*. http://documents.worldbank.org/curated/en/896971468194972881/pdf/102725-PUB-Replacement-PUBLIC.pdf.

World Economic Forum, 2018. Fourth Industrial Revolution for the Earth Series: harnessing the Fourth Industrial Revolution for Water. http://www3.weforum.org/docs/WEF_WR129_Harnessing_4IR_Water_Online.pdf.

World Economic Forum, 2019. How satellites can solve Africa's eco-challenges, from deforestation to illegal mining. https://www.weforum.org/agenda/2019/09/digital-earth-africa-illegal-mining-deforestation/.

Yap, X.-S., Truffer, B., 2019. Shaping selection environments for industrial catch-up and sustainability transitions: a systemic perspective on endogenizing windows of opportunity. Res. Policy 48 (4), 1030–1047. https://doi.org/10.1016/j.respol.2018.10.002.

Yap, X.-S., Truffer, B., Li, D., Heimeriks, G., n.d. Towards transformative leapfrogging. Environmental Innovation and Societal Transitions. In press.

Young, O., 2002. The Institutional Dimensions of Environmental Change: Fit, Interplay, and Scale. The MIT Press.

Young, O., 2008. The architecture of global environmental governance: bringing science to bear on policy. Glob. Environ. Politics 8 (1), 14–32. https://doi.org/10.1162/glep.2008.8.1.14.

Young, O., 2011. Governing International Spaces: Antarctica and Beyond. Smithsonian Institution Scholarly Press.

Young, O., 2020. Institutional architectures for areas beyond national jurisdiction. In: Biermann, F., Kim, R. (Eds.), Architectures of Earth System Governance: Institutional Complexity and Structural Transformation. Cambridge University Press, pp. 97–115. https://doi.org/10.1017/9781108784641.

Young, O., 2021. Grand Challenges of Planetary Governance: Global Order in Turbulent Times. Edward Elgar Publishing.

Young, O., Berkhout, F., Gallopin, G.C., Janssen, M.A., Ostrom, E., Van Der Leeuw, S, 2006. The globalization of socio-ecological systems: an agenda for scientific research. Glob. Environ. Chang. 16 (3), 304–316. https://doi.org/10.1016/j.gloenvcha.2006.03.004.