Space Policy 53 (2020) 101385

Contents lists available at ScienceDirect

Space Policy

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

A Framework for Extraterrestrial Environmental Assessment

William R. Kramer [1]

Outer Space Consulting, Frederick, MD, 21701, USA

ARTICLE INFO

Article history:
Received 24 April 2020
Received in revised form
3 July 2020
Accepted 2 August 2020
Available online xxx

Keywords:
Extraterrestrial
Environmental assessment
Space mining
Environmental ethics
Outer space development
Sustainability
National Environmental Policy Act
Outer Space Treaty
Moon Agreement

ABSTRACT

Many of the proposed and foreseeable activities on the Moon, Mars, and elsewhere in our solar system will require construction and similar actions. Most will, by intent, alter those natural environments in a variety of ways. Some impacts may foreclose future options for use of the area, hinder sustained access to resources, impede long-term human occupation, interfere with scientific or other purposes, harm cultural assets, create unsafe conditions, or cause other detriments. A long-proven method for reducing adverse effects here on Earth has been to assess the proposed actions in a structured manner during the planning process, to identify adverse impacts, and to seek opportunities to avoid, minimize, and mitigate harm. However, such a process is currently not required for space actions and has been largely ignored by space industries, academic and scientific organizations, and governments. In addition to advocating the need for an appropriate assessment and review process, this article proposes a simple framework as a starting point for discussion. While it draws upon environmental assessment procedures developed in the US under the National Environmental Policy Act (NEPA), it does not recommend that NEPA be applied to extraterrestrial actions. In fact, NEPA may be counterproductive. Rather, it suggests that space industries and other space actors themselves should consider developing and using an appropriately structured assessment process.

1. A rapidly evolving problem in space development

Nearly all reasonably foreseeable physical activities on the Moon, Mars, and elsewhere, such as construction, mining, energy production, and human habitation, may adversely affect those extraterrestrial environments [1]. Just as proven here on Earth, adverse environmental impacts have the potential to increase long-range costs, reduce efficiencies and resource sustainability, foreclose options for future use, impede scientific research opportunities, negatively affect commercial activities, decrease human health and safety, and lead to other undesirable outcomes. When an action's environmental impacts are not identified in the planning process, it is less likely adverse impacts will be avoided, reduced, or mitigated, thus compounding the aforementioned detriments [2,3]. There should be no expectation that such outcomes will be different as our actions move to locations beyond Earth [4,5]. We build roads here, and we will build roads there. We construct launch facilities here, and we will construct them there. Examples of such parallel construction actions are nearly endless. But alterations to alien landscapes could have longer-lasting implications than anthropogenic changes on Earth. In fact, they might tend to be permanent compared with those on Earth, where tectonic movements and the effects of water, ice flow, vegetation, and other life generally act to make landscapes resilient [6].

Concern for the space environment has generally been confined to objects in low Earth orbit (LEO) but that has recently begun to change in response to increased awareness of the potential fragility of extraterrestrial environments. A small number of articles have called attention to potential adverse environmental impacts to the Moon and Mars and some have cited the need for remedies [7,8]. As stated by Newman and Williamson [7] in 2018, "The lack of progress over embedding a sustainable and legally binding framework for the exploitation of bodies within the solar system could prove extremely damaging for future generations". Yet few, if any, among the space industries recognize the range of environmental impacts that their actions beyond LEO will generate [9,10]. As stated in 2013, "currently there are no widely accepted agreements about commercial exploitation or use of resources on the Moon, Mars, asteroids, or other celestial bodies, and no environmental management framework" [11]. Other than regarding orbital debris and forward and backward contamination, there has been little substantive progress toward those ends since that publication. The body of

E-mail address: williamkramer1@gmail.com.
[1] www.OuterSpaceConsulting.com.

https://doi.org/10.1016/j.spacepol.2020.101385
0265-9646/

literature discussing the foreseeable problem remains small, and the issue is largely unacknowledged.[2] But government, commercial, and private space actors are obviously aware of the dozens of journals, hundreds of books, and likely tens of thousands of articles regarding the need for, the management and practice of, and the efficacy of environmental assessment applied to actions globally over the past half century. This would be especially true given that many space ventures proposing to develop the Moon and Mars grew from enterprises mining and constructing on Earth, where environmental assessment is often required. Their general failure to acknowledge the reality of their potential impacts on extraterrestrial environments is puzzling. Then again, perhaps, they are fully aware of these adverse potentials and are hoping the issue remains unrecognized by regulators and the public. Regardless, "It is an appropriate time to ... think proactively about stewardship of the environments and resources beyond Earth orbit" [11]. While space actors' plans to actively exploit lunar and Martian resources have increased in number and scope, the issue of extraterrestrial impacts remains mostly unrecognized or unaddressed.

2. The neglected need for extraterrestrial environmental assessment

Regardless of space industries, government agencies, and other space actors, such as scientific missions, not recognizing (or choosing not to acknowledge) the critical need for extraterrestrial environmental assessments (EEAs), once proposed actions on celestial bodies are underway, it is predictable that interest groups and perhaps governments will demand them. Consider the scenario of a commercial surface mine on the Moon or Mars. Competitors (e.g., another commercial mining interest that seeks to exploit the same area) may claim that resources are being squandered by the rival corporation. Just as with resource extraction on Earth, there will be an economic incentive of those "first in time" ventures to target resources that are the least expensive to mine and process (the "lowest hanging fruit"), although the locations or techniques may not be the most efficient for sustaining that resource. For example, ensuring sustained access to water is critically important, and actions that might waste the resource or not put it to its highest and best use will need some form of oversight or review [12].

Other unrelated uses of the landscape may also be adversely affected by the mining. Rocks ejected by blasting could damage nearby infrastructure, and vibrations could invalidate data collected by distant seismic studies, and the dust created could coat solar panels or interfere with telescopes or other scientific equipment, erode gaskets and similar materials, or decrease filters' effectiveness [13]. All would reduce efficiencies and increase costs. Lubricants and other compounds could leak from vehicles, machinery, and other equipment and seep into subsurface areas of water ice or other resources, decreasing their usefulness and value.

Undocumented prospecting or similar activities that disturb the natural topography may confound future researchers. Could one determine if a particular cut through a rock was made by humans, or is it part of a geologic feature or evidence of some other unknown action? Disturbing the lunar or Martian landscape could potentially alter or destroy geologic features of scientific value and cultural artifacts [14]. Citing the history of usefulness of geoconservation here on Earth, such as the protection and preservation of geological features of special scientific, functional, historic, cultural, esthetic, and ecological value, the need for application to extraterrestrial geologies has been termed "exogeoconservation." Suggested in 2018, exogeoconservation was deemed "acutely necessary for the scientific exploration and responsible stewardship of celestial bodies" [15].

The 1967 Outer Space Treaty[3] stipulates that the "exploration and use of outer space should be carried on for the benefit of all peoples irrespective of the degree of their economic or scientific development" and that the "exploration and use of outer space ... shall be the province of all mankind" (Article 1). A claim that resources are the "common heritage of all mankind" is expressed in Article 11 of the 1979 Moon Agreement.[4] "Province of all mankind" in the Outer Space Treaty refers to activities such as exploration and use, while the Moon Agreement's "common heritage" provision refers to material objects, such as ores and other physical resources [16]. An important political and social consideration is that those who do not directly benefit from a commercial venture to, say, mine on Mars, may protest the miners' disregard for the extraterrestrial environment in response to the common heritage and province of all mankind language of those pronouncements. This may be more likely when profits begin to be generated and large sectors of the global population are excluded from its economic or technological benefits. This has been demonstrated repeatedly in the US by adverse public reaction to major environment-affecting projects that benefit only a small percentage of the population or where profits do not directly benefit the affected region (e.g., XL oil pipeline) [17]. Moreover, protestors are not limited to those living in the area where an environment may be impacted, as evidenced by broad North American and European opposition to unsustainable or environmentally damaging forestry, grazing, and farming practices in the Amazonian rainforest, logging in the US and Canadian west, and oil exploration in remote areas of the Arctic. At present, there is no formal regulatory mechanism for public comment regarding the fate of extraterrestrial environments.

Anticipating such conflicts, it would be in the self-interest of space development industries and other space actors to (1) accept that their actions will affect extraterrestrial environments, (2) acknowledge that some of those effects may be adverse and possibly irreversible, (3) realize that adverse impacts will decrease long-term profits and opportunities and reduce resource sustainability, and (4) anticipate that extraterrestrial degradation will erode investors' and global populations' confidence [1,18].

3. National Environmental Policy Act and potential sources of reticence to EEAs

If involved industries and other space actors understand the benefits of environmental awareness for space actions, their past inaction to confront the issue provides evidence they are reluctant to publicly express it. Perhaps there is a perception that acknowledgment would expose anticipated extraterrestrial actions to the same rigorous regulations that currently exist for terrestrial actions, potentially stifling their ambitions and hobbling attempts to profit from their ventures. Or they may fear that since the environmental impacts of our previous actions beyond LEO have never been

[2] Belgium's Law on the Activities of Launching, Flight Operation, or Guidance of Space Objects is an exception that anticipates the need for consideration of extraterrestrial impacts (Kingdom of Belgium, Law of 17 September 2005 on the activities of launching, flight operations, or guidance of space objects). It requires that an environmental impact assessment be submitted before a launch sanctioned by Belgium, assessing the effects of the action on both the Earth and any affected celestial body. http://www.belspo.be/belspo/space/doc/beLaw/Loi_en.pdf. Accessed April 2014.

[3] Treaty on Principles Governing the Activities of Stages in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies.

[4] Treaty on Principles Governing Activities on the Moon and Other Celestial Bodies.

formally assessed, protocols for how to start such a process would be overwhelming or politically awkward.[5] While such anxieties may exist, they may be based on false notions of the reach of regulation and an overestimate of the power of legal injunction in an international and extraterrestrial context. If they assume that existing environmental regulations, such as the US National Environmental Policy Act (NEPA) of 1969, will seamlessly apply to extraterrestrial actions, they might have cause for concern.[6] NEPA, however, does not currently apply to extraterrestrial actions.

NEPA is limited to those actions that have a US federal nexus (e.g., actions of the federal government, actions by private actors which require a federal permit [such as a launch permit], private use of federal facilities such as launch sites, and reliance on satellite communications managed by federal agencies). It states as its purpose (Sec. 2 [42 USC § 4321]), "To declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; [and] to enrich the understanding of the ecological systems and natural resources important to the Nation." References to biosphere and ecosystems would arguably apply as soon as there is permanent human presence on the Moon or Mars, even if humans and other life they bring are living in contained environments and assuming there is no endemic lunar or Martian life. Regardless of that premise, NEPA expresses sentiments favoring EEAs even though it is doubtful extraterrestrial actions were considered when it was drafted. However, defaulting to NEPA and requiring the evaluation of extraterrestrial actions through the Act's formal Environmental Assessment and Environmental Impact Statement process is not recommended – at least not at this time or in NEPA's present form. Applying NEPA directly would be both impractical and counterproductive [18]. While it continues to be successful in reducing adverse environmental impacts in the US and has provided a model for other nations' environmental regulations, it has become a cumbersome tool that frequently results in costly, lengthy, and highly litigated processes [21].[7] Environmental impact statements as required by NEPA can take years to complete and can be extremely expensive [22]. Furthermore, NEPA lacks international authority, and similar regulations in other nations lack uniformity, making its application to extraterrestrial actions problematic. It is simply the wrong tool for the extraterrestrial job.

While NEPA does not prohibit its application to extraterrestrial actions, neither is it required [23]. It is the current (2020) US administration's policy that it is not required for actions potentially affecting extraterrestrial bodies. A critical consideration is that NEPA is administered by the President's Council on Environmental Quality within the Executive Office of the President. Accordingly, the economic and environmental agendas of the sitting President influence how NEPA is applied to "gray areas" such as extraterritorial and extraterrestrial actions. The current (Trump) administration has made easing restrictions encumbering commercial recovery of space resources (e.g., minerals and water on the Moon and Mars) a priority. It is now a federal policy that the US does not consider celestial bodies to be global resources. It opposes relevant sections of both the Outer Space Treaty and Moon Agreement [24]. Simultaneously, the administration has initiated policies making NEPA's requirements less stringent and more favorable to resource development industry actions in the US, such as mining and timber. Aspirations to broaden the scope of NEPA to include extraterrestrial actions will likely not be achieved [25].

The European Space Agency (ESA) uses life cycle assessments for analyzing environmental impacts of space actions within their administrative jurisdiction. But, as with NEPA, the ESA's life cycle assessment studies have been limited to impacts to the Earth and objects in LEO, such as orbital debris. Actions beyond LEO are not addressed, and guidelines for assessing those more distant impacts have not been suggested by either NEPA or the life cycle assessment process. Although there has been some public interest for the ESA to consider impacts beyond LEO, no assessments for actions on the Moon or Mars are required except for launches sanctioned by Luxembourg [26–29].

4. Framework for EEA

An environmental assessment assists in identifying the direct, indirect, and cumulative impacts of an action affecting the environment. When completed, it demonstrates a concern for sustaining common resources. For extraterrestrial actions, an EEA would need to include measures supporting the wise use of the global commons of outer space. It would support the Outer Space Treaty and similar international sentiments and aid in developing confidence among investors. As envisioned in this article, an EEA could be a powerful planning tool that need not be encumbered by the political factors that accompany a highly regulated or enforced process such as NEPA. It can borrow what is needed from NEPA and the life cycle assessment approach to determine an action's impacts while avoiding aspects of those directives that do not transition effectively to outer space, such as social and economic impacts to local communities. The focus of an EEA would remain on documenting the action and assessing its effect on the extraterrestrial environment.

The following outline proposes a starting point that will hopefully generate discussions leading to continual refinement. The goal is a draft practical, efficient, and effective framework that will facilitate a prelaunch review process for both accurately assessing impacts and aiding space industries and other actors (e.g., science missions) in achieving their short- and longer-range objectives.[8] Clearly, input from the broad space community, including public, government, and commercial interests, will be needed.[9]

Hypothetical action: The fictitious transnational company AstroMine is proposing to prospect for water on Mars. If water ice is discovered in sufficient quantities at locations where mining and processing technologies can produce a profit for AstroMine and its investors, it will likely lead to expansion and an increase in operational capacities over time. Its goal is to establish long-term

[5] NASA's 2005 Final Programmatic Environmental Impact Statement for the Mars Exploration Program contains detailed discussions and analyses of the program's impacts on Earth, but there is no mention of potential impacts to Mars. Similarly, the 2006 Final Environmental Impact Statement for the Mars Science Laboratory Mission considers potential impacts to the Earth's upper atmosphere but does not address the impact of the Mars rover Curiosity on Mars itself. The 317-page environmental impact statement for the Mars 2020 mission describes the affected environment as "the areas on or near the vicinity of the launch site and portions of the global environment." In addition, no agency or personal comments offered in response to the Draft EIS mentioned impacts to the Mars environment [19] NASA. Final Environmental Impact Statement for the Mars Science Laboratory Mission. Washington, D.C. 2006 [20], NASA. Final Environmental Impact Statement for the Mars 2020 Mission. In: NASA, editor.2014.

[6] From the author's personal experience, mentioning NEPA in the context of space exploitation is highly discouraged by both space industries and NASA, if not *verboten*.

[7] US Council on Environmental Quality determined that the average length of an Environmental Impact Study between the years 2013 and 2019 was 669 pages and that 25% averaged 729 pages or longer.

[8] Should extraterrestrial life be discovered, many other factors would need to be included in this framework.

[9] The author can be reached at williamkramer1@gmail.com or via the website: OuterSpaceConsulting.com. Comments on this paper would be sincerely appreciated and would be used to refine the framework presented.

mining and processing there for multiple purposes. Assuming there is no endemic life on Mars, a simple framework for an EEA might include the following categories:

1.0 Introduction
2.0 Purpose and Need.
Why is the action being undertaken? What are its goals? Why is it needed?
3.0 Proposed Action.
What is the scope of the action? Provide a detailed narrative description of the action. What is to be built, how will it be built, what equipment will be employed, etc.? What are the foreseeable outcomes of the action? If the project is abandoned for any reason, how would the area be affected? What would be removed and what would be left behind?
3.1 Timing.
What are the anticipated launch dates, transit duration, landing dates, starting and completion dates of construction, proposed Earth return dates, etc.?
3.2 Location.
Details of the location of landing site, coordinates of action site, and other activities on Mars. Provide a map of all action areas, indicating specific areas of terrain alteration, road construction, storage areas, etc. Description of local topography, including any seasonal changes in topography or similar considerations.
4.0 Affected Environment (including direct, indirect, and cumulative effects).
4.1 Physical Resources.
4.1.1 Geology, Regolith, and Seismicity.
Describe these factors and how the proposed action may alter or affect them. Characterize the source and nature of any significant vibration, such as those created by equipment operation, blasting, etc., and how the structural stability of geologic formations, layers, caverns or other hollows, and other factors may be affected. Consider, where appropriate, factors such as permeability, erodibility, water table depths, and depths to impervious layers.
4.1.2 Atmospheric Composition.
What is the atmospheric composition in the affected area and how does it naturally change over the duration of the action? Will the action alter the atmospheric composition or generate dust? If so, how might that affect other actions (e.g., interfere with atmospheric studies, reduce the efficiency of solar collectors or optical telescopes)? What is the magnitude, frequency, and expected persistence of those alterations?
4.1.3 Climate.
What is the climate in the affected area and how might it be altered over the duration of the action? Will the action change the local climate? What is the expected magnitude, frequency, and duration of those alterations?
4.1.4 Solar Radiation.
What is the intensity and timing of exposure to sunlight in the affected area?
4.1.5 Water Resources.
4.1.5.1 Characterization of Water Location and Physical State.
Are there water deposits (ice or liquid, surface or subsurface) in the affected area? Where are they located?
4.1.5.2 Water Chemistry.
If water is present, what is its chemical or other composition? Will the proposed action affect water state, chemistry, or other water characteristics?
4.1.5.3 Indications of Surface and Subsurface Water Movement.
Will the proposed action affect such movement?
4.1.5.4 Water Use.
How might the project alter water resources? If water is to be extracted, for what purpose? What volume of water is to be extracted? Will water be spread on the surface or injected/reinjected below the surface? How might that affect topography, surface and sub-surface chemistry, and other factors? Is the water chemistry or composition changed prior to spreading or injecting?
4.2 Cultural Resources.
Are there any indicators of human actions which have historical or cultural significance in the affected area? If so, how might they be affected by the action? Will the action affect the aesthetics of an area?
4.3 Hazardous Material and Pollutants.
What hazardous materials will be taken to Mars or generated on Mars? What is their use and disposition? Will any hazardous materials enter the Martian environment or be left at the site after completion of the action? What is the planned fate of any wastes produced? Will any chemicals or other compounds degrade or change composition as a result of aging, exposure to the Martian environment, or other factors? If so, how might those compounds affect the environment?
5.0 Human Health and Safety.
How many humans will be involved at the site and at other extraterrestrial locations that are part of the action? Characterize their mission. How might the action affect their health and welfare? (For example, exposure to radiation, temperature and pressure extremes, and industrial and other accidents.)
6.0 Cumulative Impacts[10]
Cumulative impacts would include later-in-time mining and other actions that may be encouraged by the action under review.
7.0 Summary.
Considering the foregoing, what will be the overall effect of the action on the current environment of Mars, including indirect and cumulative effects? How might the action affect future actions on the planet?
7.1 Table of foreseeable direct, indirect, and cumulative impacts.
7.2 List of actions proposed to reduce or eliminate adverse impacts.
7.3 Potential actions to mitigate adverse effects which cannot be avoided or minimized.

This provides a highly simplified outline for the structure of an EEA. It does not include sections that would routinely be considered if the action were on Earth, such as impacts on the more general human environment, especially if it were addressing the regulatory requirements of NEPA. For example, there is little value in describing socioeconomic factors related to the action on Mars (e.g., effects on the local economy and employment). In that thoroughly completing a detailed assessment such as the hypothetical one outlined earlier may be difficult because knowledge of extraterrestrial effects is limited, there will be information gaps that would not be found for most actions on Earth. While data gaps are undesirable, they will serve several constructive purposes. First, they will highlight the difficulty of predicting environmental impacts where knowledge of those environments is limited, how technology will or will not adapt to novel circumstances, human

[10] As defined in 40 CFR Chapter 5 § 1508.7, a cumulative impact is the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of who or what undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

abilities, and similar unknowns resulting from a lack of experience. Information gaps in the EEA may foster precaution. Second, with the completion of each new EEA, our knowledge of extraterrestrial environments and how they respond to human actions will increase. Each succeeding EEA for similar actions in similar environments should contain fewer gaps and be a bit more detailed, a bit more insightful, and a bit more accurate in assessing an action's environmental impact. Each will build on the information provided by previous assessments.

Serious issues of oversight and accuracy in the production of an EEA for an action remain, however. If governments are reluctant to draft and enforce standards and monitor a review process (such as required by NEPA), how can an EEA be free from a project proponent's biases? Who will ensure that an EEA accurately describes a proposed action and that what is described is actually implemented? Resolution of the issue is well beyond the scope of this article, but, at a minimum, the EEA process will require transparency. Except where proprietary information might be withheld, EEAs should be widely available for public review and comment. Given the importance of the document, if governments will not enforce a standard, perhaps a consortium of nongovernmental space actors could monitor the process. The group could develop standards, ensure the public has an opportunity to review and comment on the EEA, and maintain an open library of EEAs and related documents.

5. Final thoughts

In addition to its direct environmental benefits, even the simplest EEA will document that a specific action was undertaken at a specific location over a specific period. Once completed, assessments could be digitally filed in a library managed by space industries or others and made available for public reference. They would become a permanent record for documenting pre-action baseline conditions that may be invaluable in decades and centuries to come. With the addition of each new EEA, the database will grow, providing not only an increasingly useful historical record of actions taken but also a compendium of accumulated planetary data. Without such a repository of incremental findings, critical and irreproducible information will be lost.

Actions on the Moon, Mars, or elsewhere in our solar system will require not only sound engineering but also innovation to solve unanticipated problems that arise once the action has begun. While an EEA cannot address what is yet unknowable, it can be amended as the action progresses to incorporate information on how novel situations were addressed when encountered: "solution X was proven (or proven to not be) an effective way to address unanticipated issue Y." Over time, a growing, indexed catalog of such determinations would assist in anticipating and avoiding similar problems that may arise with subsequent actions.

It is critical that commercial interests, as well as governments and nongovernmental groups, including scientific, academic, and others, be brought into the conversation regarding extraterrestrial impacts. As stated in the 2013 report, Committee on Space Research Workshop on Developing a Responsible Environmental Regime for Celestial Bodies, there is a need to bring "ambitious private entities into the mainstream discussion on (planetary) protection regimes, one of the major challenges in going forward with responsible planetary exploration/exploitation" [30].

6. Next actions

As stated previously, this proposal for a framework for EEAs is a starting point, not a conclusion. It is hoped that space ventures and governments will consider the benefits of such an approach in addressing the foreseeable reality of adverse impacts and begin to build a workable and efficient framework. If commercial and other actors do not seriously address this issue and create such a mechanism, governments may in response to public concern, either individually or through international regulatory agreements [18]. Industries and other private space actors should take advantage of this opportunity and begin to develop industry standards or similar mechanisms to frame a process for an EEA that achieves environmental goals while remaining practical in meeting their commercial, scientific, and other objectives.

In the US, regulatory oversight did not come until the public recognized the dramatic adverse impacts to our shared environment that followed a long history of degradation caused by assorted human activities, including the damages of hydraulic mining (where thousands of tons of soil and rock were washed from hillsides as a byproduct of gold mining), leachates from mine tailings that polluted rivers and wetlands, oil spills that smothered fisheries, the disaster of the Dust Bowl, and a catalog of species extinctions and human health issues caused by many pesticides. In fact, it took a century of environmental damage in the US before the regulations imposed by NEPA and similar legislations were finally adopted. We have an opportunity to learn from that experience so that we do not replay it on the Moon, Mars, and other bodies.

As succinctly put by Newman [31] in reference to advancements in outer space, "attention can now turn from the technically focused 'how do we do that?' to the more ecologically focused 'how should we do that?'". While extraterrestrial environments are vastly different in many ways from those on Earth, the reasons for the need to minimize adverse human impacts are the same. If space development industries and others who are proposing actions in space do not address this issue by nurturing a culture of environmental awareness in space, creating effective assessment protocols, and acting to avoid, reduce, or mitigate impacts, regulation by national or international governments may follow. Space actors should take the initiative to develop effective assessment protocols before regulation is required.

Author statement

The author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in *Space Policy*.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Acknowledgments

The author would like to sincerely acknowledge Joan E. Canfield for her continued encouragement, insight, and assistance.

References

[1] W.R. Kramer, Extraterrestrial environmental impact assessments – A foreseeable prerequisite for wise decisions regarding outer space exploration, research and development, Space Pol. 30 (2014) 215–222.

[2] B. Sadler, International Study of the effectiveness of environmental assessment-final report: environmental assessment in a changing world - evaluating practice to improve performance, in: C.E.A. Agency (Ed.), Minister of Supply and Services Canada, 1996.

[3] J. Glasson, R. Therivel, A. Chadwick, Introduction to Environmental Impact Assessment, Routledge, New York, NY, 2013.

[4] L. Viikari, The Environmental Element in Space Law: Assessing the Present and Charting the Future, Martinus Nijhoff, Leiden, The Netherlands, 2008.

[5] L. Viikari, Time is of the essence: making space law more effective, Space Pol. 21 (2005) 1–5.

[6] M. Williamson, Space ethics and protection of the space environment, Space Pol. 19 (2003) 47–52.

[7] C.J. Newman, M. Williamson, Space sustainability: reframing the debate, Space Pol. 46 (2018) 30–37.

[8] J.S. Schwartz, Where no planetary protection policy has gone before, Int. J. Astrobiol. (2018) 1–9.

[9] M. Hofmann, P. Rettberg, W. Williamson, Protecting the Environment of Celestial Bodies (PECB Cosmic Study), IAA 2010, COSPAR, 2010.

[10] F. Lyall, Planetary protection from a legal perspective - general issues, in: M. Hofmann, P. Rettberg, M. Williamson (Eds.), Protecting the Environment of Celestial Bodies, International Academy of Astronautics, 2010.

[11] P. Ehrenfreund, M. Race, D. Labdon, Responsible space exploration and use: balancing stakeholder interests, New Space 1 (2013) 60–72.

[12] J.S. Schwartz, Near-Earth water sources: ethics and fairness, Adv. Space Res. 58 (2016) 402–407.

[13] J.S. Levine, D. Winterhalter, R. Kerschmann, D. Beaty, B. Carrier, J. Ashley, Mars atmospheric dust and human exploitation, The Space Review (2018). February 5, 2018.

[14] For All Moonkind, Mission Statement, 2019. https://www.forallmoonkind.org/moonkind-mission/mission-statement/.

[15] J.J. Matthews, S. McMahon, Exogeoconservation: protecting geological heritage on celestial bodies, Acta Astronaut. 149 (2018) 55–60.

[16] J. Gabrynowicz, The Province and Heritage of Mankind Reconsidered: A New Beginning. The Second Conference on Lunar Bases and Space Activities of the 21st Century, NASA Johnson Space Center: NASA Technical Reports Server, 1992, pp. 691–695.

[17] T. Buford, Thousands Rally in Washington to Protest Keystone Pipeline, Politico, 2013.

[18] W.R. Kramer, In dreams begin responsibilities—environmental impact assessment and outer space development, Environ. Pract. 19 (2017) 128–138.

[19] NASA, Final Environmental Impact Statement for the Mars Science Laboratory Mission, 2006. Washington, D.C.

[20] NASA, Final Environmental impact statement for the Mars 2020 mission, in: NASA, 2014.

[21] D. Katz, Time to Repeal the Obsolete National Environmental Policy Act (NEPA), The Heritage Foundation, 2018.

[22] US Council on Environmental Quality, Length of Environmental Impact Statements (2013-2019), Executive Office of the President, Washington, DC, 2019.

[23] T. Boling, Associate Director for NEPA US Council for Environmental Quality, 2019.

[24] D.J. Trump, Executive Order 13914 Encouraging International Support for the Recovery and Use of Space Resources, in: White House, 2020. Washington, DC.

[25] D. Fear, For a Rare Public Hearing under Trump, a Woman Traveled 800 Miles to Speak for Just Three Minutes, The Washington Post, Online edition ed., The Washington Post, Washington, DC, 2020.

[26] N. Ko, T. Betten, I. Schestak, J. Gantner, LCA in space – current status and future development, Matériaux Tech. 105 (2017) 507.

[27] S.E. Mustow, Environmental impact assessment (EIA) screening and scoping of extraterrestrial exploration and development projects, Impact Assess. Proj. Apprais. 36 (2018) 467–478.

[28] V. Mukunth, Fiat Luxembourg: how a tiny European nation is leading the evolution of space law, Wire (2017). https://science.thewire.in/space/luxembourg-space-asteroid-mining-dsi/. (Accessed 5 January 2020).

[29] P. De Man, Luxembourg's Law on Space Resources Rests on a Contentious Relationship with International Framework, The Space Review: SpaceNews, 2017.

[30] P. Ehrenfreund, H. Hertzfeld, K. Howells, COSPAR Workshop Report on Developing a Responsible Environmental Regime for Celestial Bodies, Elliott School of International Affairs: Space Policy Institute, 2013.

[31] C. Newman, Establishing an ecological ethical paradigm for space activity, ROOM The Space Journal 2 (2015).