Cislunar Sustainability Framework

Characterizing Long-Term Sustainability of Cislunar Development Activities

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1. Introduction

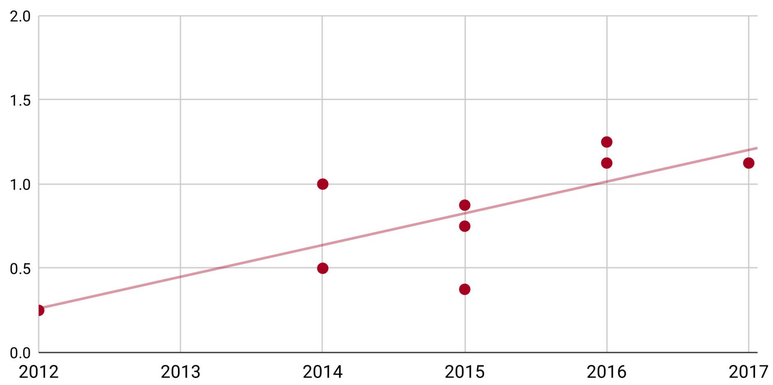
Sustainability features prominently in national policies and programmatic documents [1,2] of cislunar development efforts, yet the concept remains underspecified in a lunar context. Planned utilization of concentrated, limited resources – including water-ice, solar radiation, and viable base locations at the lunar south pole – and potential for degradation of the lunar environment and an increasing risk of competitive dynamics threaten the long-term sustainability of lunar activity [3,4]. Understandings of lunar sustainability vary widely across and within academia, industry, and government [5] and current sustainability guidelines [6] and rating tools [7] do not address cislunar activity directly. The Cislunar Sustainability Framework (CSF) introduces a flexible framework for mission- and program-level characterization of sustainability in a lunar development context. The CSF decomposes cislunar sustainability into eight individual components that emerge from the sustainable development and space sustainability literatures, adapting sustainability metrics to the unique characteristics of the cislunar domain. By introducing a publicly available tool, the CSF provides operators with means to improve sustainability of missions, incentivizes greater sustainability by enabling comparison between missions and across sectors through time, and provides policymakers and academics with a standardized tool for analysis of previous missions.

2. Components of Cislunar Sustainability

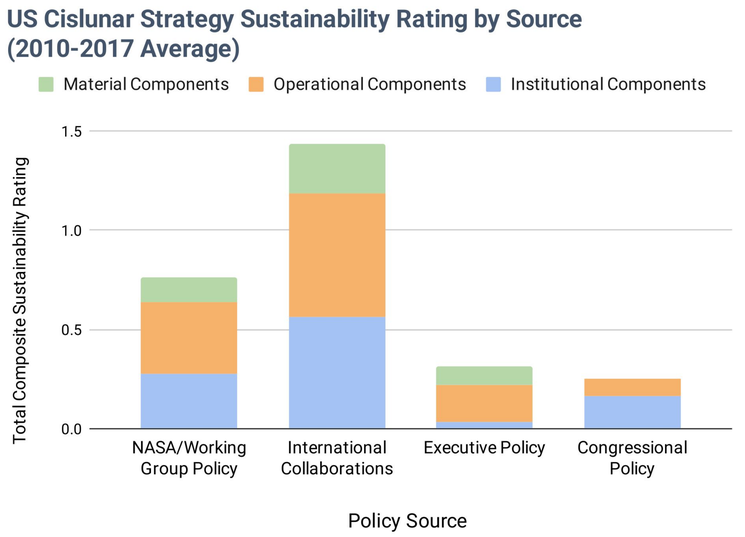
Material Components	**Resource Burden**	Does an operator, mission, or agency take steps to minimize the burden on concentrated, accessible resources while meeting current needs?
	Operational Environment Degradation	Does an operator, mission, or agency minimize environmental impact that hinders ability to operate on or around the Moon?
Operational Components	**Data Sharing**	Does an operator, mission, or agency proactively share and have mechanisms to share operational, resource, and environmental data to the maximum extent possible with other actors?
	Operational Coordination	Does an operator, mission, or agency proactively coordinate and/or have clear channels of communication through which it can coordinate its cislunar activity with other actors in order to prevent harmful interference and reduce overall resource burden and environmental degradation?
	International Cooperation	Does an operator, mission, or agency coordinate with international partners in mission planning, technology development, and/or mission operation?
Institutional Components	**Domestic Regulation**	Does an operator, mission, or agency have, follow, and participate in development of a domestic regulatory framework that includes sustainability provisions?
	International Standards	Does an operator, mission, or agency abide by and contribute to development of international standards of operation in cislunar space that include sustainability provisions?
	Stakeholder Engagement	Does an operator, mission, or agency engage with and have clear mechanisms for engagement with diverse stakeholder groups?

3. Preliminary Case Studies

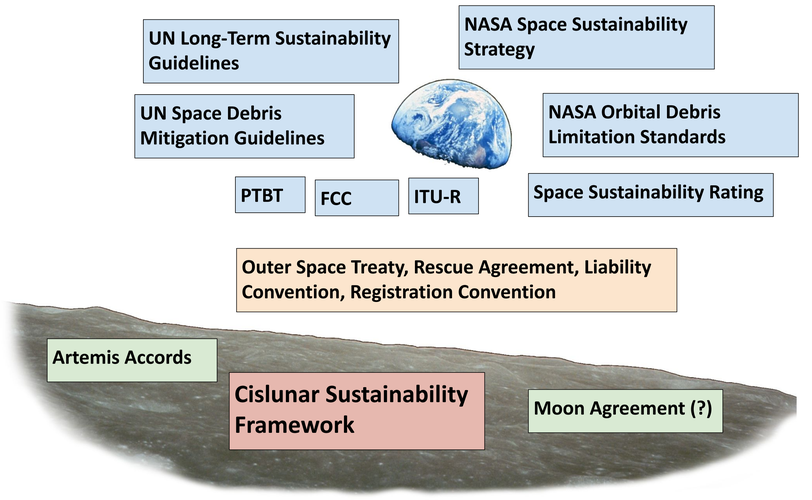
The Cislunar Sustainability Framework is employed to analyze US cislunar strategies from 2010 to 2017. To do so, the CSF is applied to NASA strategy documents, roadmaps, and reports, executive orders, national space strategies, and speeches, legislation and NASA authorizations, as well as international strategy collaborations of which the US took part. Evolution in sustainability prioritization and specification is evident in analysis of NASA documents, as is significant variation between NASA, the executive branch, Congress, and international collaborations. Individual documents are given a low (0), medium (1), or high (2) rating for each component. The composite sustainability rating is the unweighted mean across all eight components, ranging from 0 (lowest) to 2 (highest).



NASA strategy documents, roadmaps, and reports demonstrate increasingly sustainable approaches to lunar development and engagement with a broadening range of sustainability components. International cooperation consistently received highest priority within NASA lunar strategies, with stakeholder engagement and interest in international standards increasing over time. Research on resource burden remained moderate, while degradation of the operational environment received little to no attention within NASA strategies.



Comparing US lunar policy across sources reveals meaningful variation, with NASA and NASA-affiliated working groups demonstrating much higher engagement with sustainability than the Executive branch or Congress. Strategies and roadmaps produced through international collaborations in which NASA takes part demonstrate highest levels of sustainability engagement. Disaggregating component-level contribution, institutional and operational components of sustainability receive highest support, with material – resource burden and environmental degradation – only prioritized significantly in international collaborations.



A number of international treaties, UN guidelines, third-party tools, and NASA policies facilitate increased sustainability of near-Earth space activity and provide guidance for operators and agencies. Far fewer sources provide guidance or means for characterization for operators and agencies active on the Moon. Original Image: NASA/William Anders

4. Discussion and Call for Input

The Cislunar Sustainability Framework is presented here as a functional and evolving baseline intended to mature through engagement and collaboration with operators, researchers, agencies, and other lunar stakeholders. As cislunar activity expands and the technical and operational realities of mining, operating, and living on the Moon become better understood, the eight components can and should gain specificity. Establishing a shared analytical vocabulary for cislunar sustainability creates a foundation for more coherent policy development, clearer comparison across missions and actors, and stronger incentives for sustainable practice. Refining the framework's thresholds, indicators, and quantitative metrics – including calculations of resource burden, dust mitigation, best practices for data sharing and operational coordination, and modes of engagement with domestic and international standards – requires expertise from across the cislunar community.

A number of open questions where stakeholder input is valuable include:

- What additional components should be included in the CSF?
- Should all sustainability components be weighted equally? If not, what components should be prioritized?
- How should sustainable levels of resource use be calculated?
- How should mitigation measures – such as reducing landing plume ejecta – be weighed against infrastructure hardening?
- How can operators best share data while retaining proprietary information needed to support a cislunar economy?

Want to get involved and help improve the CSF? We'd love your input. Scan here to keep in touch.

References: [1] National Aeronautics and Space Administration, "Artemis Program Plan." Sep. 2020. [2] National Aeronautics and Space Administration, "NASA's Space Sustainability Strategy." Apr. 2024 [3] M. Elvis, A. Krolikowski, and T. Milligan, "Concentrated lunar resources: imminent implications for governance and justice," Jan. 2021 [4] X. Wu, "China and U.S. Lunar Cooperative Platforms: Competition or Cooperation?," Apr. 2024 [5] M. A. Janssen, K. F. Law, P. Prem, S. Syropoulos, and A. Siddiqi, "Examining the meaning of sustainability on the Moon," Mar. 2026 [6] United Nations Office for Outer Space Affairs, *Guidelines for the Long-term Sustainability of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space*. 2022 [7] M. Rathnasabapathy *et al.*, "Space Sustainability Rating: Towards An Assessment Tool To Assuring The Long-Term Sustainability Of The Space Environment," Oct. 2019