

THE CISLUNAR SUSTAINABILITY FRAMEWORK: A Tool for Analysing Sustainability in Cislunar Development Efforts

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Introduction: Current efforts to establish bases on the lunar surface constitute a significant break from previous lunar programs. The Artemis Program, the International Lunar Research Station, and published goals from a number of national space agencies indicate that coming lunar activity will comprise continuous habitation of the lunar surface, reliance on in-situ resources for the construction and operation of bases, and long-term ambitions for large-scale extraction, utilization, and commercialization of lunar resources. These characteristics distinguish ongoing programs as *development* efforts rather than exploration, with distinct implications for how sustainability should be defined, measured, and governed.

Gap in Space Sustainability Literature

Sustainability features prominently in national policies and programmatic documents associated with cislunar development programs, yet the concept remains underspecified in this context. Prior works have characterised lunar resource systems that are likely to be subject to contestation or degradation, [1], explored the policy and governance implications of concentrated lunar resources [2],[3], and surveyed stakeholder understandings of sustainability in the lunar context, [4]. To date no effort has proposed a framework for characterizing sustainability of cislunar activities, policies, or programs as a whole..

Given the rapid growth in lunar activity, expected exploitation and competition for limited resources – including water-ice, solar radiation, minerals, and viable base locations at the lunar south pole – potential for degradation of the dust environment, and stated prioritization of sustainability in cislunar development programs by space agencies, there is an emerging need for a holistic framework to enable characterization of sustainability in lunar development. Such a framework could enable clearer comparison of lunar activities, incentivize more sustainable practices, and provide guidance for policymakers and mission planners.

Cislunar Sustainability Framework

In response to this need, this paper introduces the Cislunar Sustainability Framework (CSF). The CSF informed by sustainable development literature [5] and existing works on space sustainability, notably the UN COPUOS' *Guidelines for the Long-Term Sustainability of Outer Space Activities* (GLSOA), [6] and Rathnasabapathy et al.'s *Space Sustainability Rating* (SSR). [7] These frameworks provide

important reference points but neither is well suited to cislunar contexts – the GLSOA is too broad to operationalize into a characterization framework and the SSR was developed to address debris risks in low-earth orbit. Neither addresses the distinct resource, environmental, institutional, or legal conditions of cislunar development. The CSF fills this gap.

Specifying sustainability to the cislunar context: The CSF constructs sustainability as a product of seven distinct components derived from the physical constraints of the lunar environment, expected patterns of activity, and the institutional and policy context of current programs.

Table 1. Seven components and framing questions of the Cislunar Sustainability Framework.

<i>Component of Sustainability</i>	<i>Framing Question</i>
Resource Use	Does an activity or policy minimize the burden on limited resources?
Environmental Degradation	Does an activity or policy minimize environmental impact that hinders ability to operate on lunar surface?
Data Sharing	How open and transparent is an actor or mission regarding data on cislunar resources and/or the operational environment?
Coordination and Deconfliction	Does an actor take steps to coordinate cislunar operations with other actors and prevent harmful interference?
Operational Cooperation	How extensive are international partnerships and collaborative structures within cislunar missions or operations?
National Oversight	Does an actor have a domestic regulatory framework and does it include sustainability provisions?
Engagement with International Standards	Does an actor abide by and/or contribute to development of international standards of operation in cislunar space? Does an actor prioritize sustainability in international standards?

Together, these seven components provide a structured basis for characterizing sustainability across material, cooperative, and institutional dimensions. The CSF is designed to be applied broadly and early – it can characterize sustainability engagement in policies, funding authorizations, research priorities, and programmatic discourse before missions are fully specified or launched. This distinguishes it from mission-level rating tools like the SSR, which require a defined mission architecture to score. By operating at the level of programs, policies, and institutional behavior, the CSF can reveal sustainability orientations in the current early stages of lunar development programs, providing policymakers, scholars, and industry with a diagnostic tool that is not contingent on the existence of an active mission.

Application and Findings: The CSF has been applied to characterize sustainability engagement in cislunar development activity from 2010–2017, drawing on NASA institutional documents, Congressional authorization acts, executive communications, and internationally produced roadmaps including the ISECG Global Exploration Roadmap [8]. Results demonstrate a clear stratification in sustainability engagement across institutional contexts: Congressional authorization acts and executive branch actions show the lowest engagement, NASA-produced policy and programmatic documents show moderate and increasing engagement over the period, and internationally collaborative documents show the highest sustainability emphasis.

At the component level, cooperational dimensions demonstrated the highest and most consistent presence across the period, while resource use engagement increased alongside growing scientific knowledge of lunar resources. Environmental degradation and national and international governance received comparatively little attention — with the notable exception of the Global Exploration Roadmap, which remains the primary venue where governance and sustainability receive systematic treatment. That the most substantive engagement with cislunar sustainability occurs in a non-binding international document with no enforcement mechanism underscores both the utility of the CSF in identifying governance gaps and the urgency of more robust policy development in this domain.

Future Opportunities: The CSF is intended as a living baseline, designed to be refined through engagement with stakeholders across academia, industry, and policy. Modeled on the iterative development of tools like the SSR, the framework can grow in specificity as cislunar activity expands and resource knowledge matures — including, in future

iterations, quantitative metrics comparing mission resource use against known accessible quantities. By establishing a common analytical vocabulary for cislunar sustainability, the CSF offers a foundation for more coherent policy development, clearer comparison across actors and missions, and stronger incentive structures for sustainable cislunar development.

References: [1] Open Lunar Foundation (2022) *Res Luna*. [2] Elvis M.E., Krolikowski A., and Milligan T. (2021) *Philos. Trans. R. Soc.*, 379, 20190563. [3] Krolikowski A. and Elvis M. (2024) *Oxf. Handb. Space Secur.*, Oxford University Press, 816–840. [4] Janssen M.A., Law K.F., Prem P., Syropoulos S., and Siddiqi A. (2026) *Space Policy*, in press, 101761. [5] World Commission on Environment and Development (1987) *Our Common Future*. [6] United Nations Office for Outer Space Affairs (2022) *Guidelines Long-Term Sustainability Outer Space Activities*, A/AC.105/2018/CRP.20, United Nations. [7] Rathnasabapathy M. et al. (2019) 70th Int. Astronaut. Congr. [8] International Space Exploration Coordination Group (2013) *Global Exploration Roadmap*.