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All for one and one for all: Recommendations for Sustainable International Lunar Base Utilisation and Exploration Approaches

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Abstract

The return to the Moon is widely regarded as the next step of space exploration. Fifty years after the first Apollo mission, a renewed interest is fostering large global efforts in pursuing the scientific and economic opportunities offered by cislunar space. The ultimate goal is to establish a sustainable human and robotic presence on the lunar surface as specified in Phase 2 of NASA's Artemis Program. These perspectives are deeply intertwined with the rapid growth of the private space sector and the arising geopolitical complexities, related to utilisation of outer space among space-faring nations. This study summarises the results and recommendations of the NASA-sponsored Space Exploration Working Group within the Space Generation Congress 2019, organised by the Space Generation Advisory Council in Washington, D.C. The Working Group consisted of 26 delegates from 15 different countries and representatives from NASA Headquarters. The group examined the evolution of lunar exploration in terms of international cooperation, socio-economic and technological challenges, and the inclusion of private industry. This report discusses the political, economic, and technological trade-offs between a multi-agency/multinational monolithic lunar base to multiple lunar bases operated by individual nations. Using the International Space Station as a model for international cooperation, the working group concluded that an initial infrastructure of a single station requiring a collaborative effort between nations and commercial stakeholders is the recommended approach. From this foothold, the presence is expanded to multiple bases with a standardization of planning, building, and operating lunar bases. Strategic recommendations were identified to be addressed to the United Nations and other public/private stakeholders with the vision of a cooperative legal and technical framework as the optimal foundation for a sustainable lunar economy. Recommendations include developing international guidelines for cooperation, establishing international standards for stakeholders, implementing conflict resolution avenues, configuring a single international base, and expanding global partnerships.

Keywords: Lunar infrastructure, Moon base, Outer Space Treaty, Artemis program, In-situ resource utilisation

Acronyms/Abbreviations

ARRA	Rescue and Return Agreement
CCP	Commercial Crew Program
CHACE	CHandra's Altitudinal Composition Explorer
CSA	Canadian Space Agency
ESA	European Space Agency
GES	Global Exploration Strategy
ISRO	Indian Space Research Organization
ISRU	In-Situ Resource Utilisation
ISS	International Space Station
JAXA	Japan Aerospace Exploration Agency
LEAP	Lunar Exploration Accelerator Program
LEO	Low Earth Orbit
LIAB	Liability Convention
MA	Moon Agreement

Mini-SAR	Mini-synthetic Aperture Radar
MIP	Moon Impact Probe
NASA	National Aeronautics and Space Administration
OST	Outer Space Treaty
PROSPECT	Prospecting for Exploration, Commercial exploration and Transportation
PSRs	Permanently Shadowed Regions
REG	Registration Convention
SGAC	Space Generation Advisory Council
SGC	Space Generation Congress
SLIM	Smart Lander for Investigating Moon
SLS	Space Launch System
UAE	United Arab Emirates
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
USSR	Union of Soviet Socialist Republics (Former Soviet Union)
WTO	World Trade Organization

1. **Introduction**

The advancements that transpire with the pursuit of space exploration contribute to scientific achievement, economic expansion, global partnerships, and public engagement. With the Moon once again regarded as the next target of crewed space exploration, it is anticipated that the upcoming lunar campaigns will seek to establish permanent human presence on its surface. A key characteristic surrounding the success of a lunar base is to establish sustainable lunar operations and to integrate between multiple national and international stakeholders. Some examples of lunar operations include human and robotic exploration, lunar science, and communication technology. The operation and coordination of these factors contribute to the overall vision of sustainability with an intended design for longevity. Naturally, there are varying economic, scientific, technological, legal, and political objectives that motivate and initiate space engagement, and therefore, a collaborative approach between nations should be addressed prior to lunar habitation. This paper analyses the various trade-offs between a multi-agency/multinational monolithic lunar base to an architecture that assumes multiple lunar bases are operated by individual nations. It also navigates through the current and proposed state of lunar development, the present legal structures in place, and the potential commercial use of lunar surface infrastructure, while simultaneously examining the geopolitical complexities involved when determining a path forward for lunar exploration and utilisation between space-faring nations.

2. Current State of Lunar Development

A range of international actors have shown an emerging focus on lunar exploration and the development of permanent lunar settlements. To determine the most effective architecture, the current state of international collaboration must be defined. The Global Exploration Strategy (GES) [1] includes fourteen space agencies that have voluntarily agreed upon a vision for space exploration through a non-binding forum: the International Coordination Mechanism held accountable through the United Nations Department of Economic and Social affairs [2]. Within the GES, there is a central focus on the importance of international engagement for successful human migration beyond Low Earth Orbit (LEO). National participants will not remain stagnant overtime, and the GES has built in adaptability for continued engagement. Although commercial interest in space is not new, there has been continual increased participation. There are existing public-private arrangements that have navigated complex milestones, which can be useful examples as this era of human space exploration transitions into a more globalised commercial arena.

The ongoing climate regarding lunar governance and established international legal domains must be considered when recommending a sustainable lunar exploration strategy. Current proposals for lunar development from the United States, Europe, Russia, China, Japan, India, and others are discussed in order to introduce varied propositions and highlight the need for international implementation.

2.1 Bilateral accords

The rules governing the exploration and use of space are defined in international space law, a multi-level regulatory system centered around a core group of five multilateral agreements collectively known as *Corpus Iuris Spatialis*. For an historical overview on the creation of international space law, see Cheng [3] and also Kopal [4]. Further elaborations on more recent developments, can be found in Hofmann & Tanja Masson-zwaan [5] and also in Dunk & Tronchetti [6]. The first of these treaties, known as the Outer Space Treaty (OST) [7], provides the main principles governing space activities, while the other four elaborate on specific issues. Specifically, the Rescue and Return Agreement (ARRA) [8] is dedicated to the rescue of astronauts and the return of space objects, while the Liability Convention (LIAB) [9] provides an ad hoc regime for accidents. The Registration Convention (REG) [10] establishes rules for registration. Finally, the Moon Agreement (MA) [11] outlines a governance regime for the utilisation of lunar resources, which are declared by the treaty to be the "common heritage of mankind [12]." However, of all those treaties, only the OST will be actually considered for the purpose of this paper. This is because 1) the ARRA, LIAB, and REG are not directly relevant for lunar activities and 2) the MA only presents 17 ratifications [13], none of which are from the group of countries interested in lunar exploration.

As mentioned, the only piece of law currently applying to lunar activities is the OST. However, the OST is a treaty of principles [14], laying down the foundational rules for the exploration and use of space [15], and thus needs to be further complemented by additional legislation addressing the specific issues raised by lunar surface activities. For an example of additional legislation complementing the OST principles see Salmeri [16]. For example, according to Article OST, "outer space, including the Moon and other celestial bodies, shall be free for exploration and use by all States [17]." At the same time, Article II OST provides that "outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means [18]." The combination of these articles indicate that States are free to explore and use outer space, as long as those activities do not raise to the point of national appropriation. However, the OST does not provide any indication as to the threshold whereby the lawful use of territory becomes unlawful appropriation of it. Likewise, according to Article I OST "there shall be free access to all areas of celestial bodies [17]," but then Article XII OST regulates access to stations and installations built over the very same areas "on a basis of reciprocity [19]." So one may wonder whether building a hotel on the Moon and forbidding access to its facilities would be a lawful exercise of the right enshrined in Article XII OST, or a violation of the obligation commended by Article I OST. The opinion is that monopolist behaviors would most likely be in violation of Article I OST [20]. These are just a few examples of the many uncertainties and questions left open by the general regime of the OST.

There are many ways to fill the gaps of the OST. At the origins of space law, as discussed before, this was done through the development of ad hoc multilateral regimes under the auspices of the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS). However, after the failure of the MA in 1975 and the end of the space race between the US and the USSR, many States lost interest both in the development of new space treaties and in multilateral discussions within UNCOPUOS [21]. This marked the beginning of a new era, which is still ongoing, whereby the rules of space law are developed by a combination of international soft law and national legislation [22]. At the moment, the regulation of lunar surface activities seems to have no exception to this trend, although some States are voicing their concerns in UNCOPUOS against any form of unilateral lunar governance [23]. From a legal viewpoint, the latest development is embodied by the Artemis Accords, a proposed set of bilateral agreements unveiled by the United States in the spring of 2020 [24]. These agreements are meant to govern the plan and execution of the Artemis Program, a scientific program led by the US in cooperation with international partners to return humans to the surface of the Moon by the year 2024 [25]. So far, NASA has revealed only a set of general principles which will apply to all the individual agreements that will be concluded with the Artemis partners. [24] Most of these principles, like the use of the Moon exclusively for peaceful purposes, are well-grounded in the OST, while others, like the use of space resources or the development of safety zones, have been presented as the result of a thorough interpretation activity of its uncertain elements. Notably, initial reactions to the Artemis Accords have been less enthusiastic than perhaps expected by the US Government [26]. At present, the idea is that the Accords will serve as a starting point for a broader international discussion, which will be open to all interested actors, with the significant inclusion of China. Unfortunately, the first impression was that the US wanted to unilaterally control the development of new rules for lunar governance [27]. This in turn raised strong reactions from countries like Russia or China, which appear now to be forming a parallel block with its own program and governance [28]. Another reason for this series of misunderstandings can, of course, be attributed to the tensions brought by the COVID-19 pandemic, as well as to the cancellation of the meetings of both the legal and the plenary committees of UNCOPUOS. Be that as it may, it seems that the international community stands in between two different roads. Taking the first road, there will be no common understanding among the various players interested in lunar surface exploration, with each "block" going for its own activities and governance models. Taking the second road, the international community will at the very least agree on the development of ad hoc coordination mechanisms among the different activities planned for the lunar surface, thus ensuring a minimum level of internationally accepted lunar governance.

2.2 Current proposals for lunar development

In accordance with the expanding democratization of space, a growing number of space-faring nations are cultivating lunar ambitions and are developing short-term plans to reach the Moon. The success of these early endeavours will profoundly shape the future of lunar activities and of international cooperation in space, as well as the commercial opportunities for the private industry.

2.2.1 United States

The Artemis Program represents the United States' plan for lunar occupation and infrastructure development. [29]. This human and robotic lunar exploration program involves several building blocks designed to establish and support sustained lunar activities by the end of the present decade. Key elements of Artemis will be the Space Launch System (SLS), the Orion crew vehicle and the Human Landing System, tasked to safely transport astronauts to the lunar surface and back to Earth. The Gateway, an orbiting platform flying above the Moon to support human missions, surface operations, and logistics, provides sustainable long-term staging for lunar and deep space exploration. The Gateway is being realised with the support of international partners such as the European Space Agency (ESA), the Japan Aerospace Exploration Agency (JAXA), the Canadian Space Agency (CSA), and the Indian Space Research Organization (ISRO).

2.2.2 Europe

Although Europe includes states with strong national space agencies and programs, the communal efforts towards Moon exploration are coordinated by ESA. ESA formulated Space Resources and Science at the Moon Strategies [30, 31], the first of which targets 2030 and has as a main objective to validate the potential uses of lunar resources for the benefit of space exploration. This goal shall be attained by prospecting volatiles in polar regions and other pyroclastic deposits. Similar to the US approach, this shall ultimately drive the inclusion of new private partners and the growth of European industry. The scientific campaigns share and support similar objectives, but also include geophysics and radio-astronomy research. The agency is open to collaborate with international and commercial partners. The Heracles mission planned for the late-2020s will be conducted with the help of JAXA and CSA and will take advantage of the lunar Gateway to send back lunar material to Earth onboard the Orion capsule [32]. ESA will also conduct the Package for Resource Observation and in-Situ Prospecting for Exploration, Commercial exploration and Transportation (PROSPECT) mission to study lunar soil in partnership with Russia. [33].

2.2.3 Russia

Russian past lunar programs are another key milestone in the brief history of Moon exploration. Roscosmos, Russia’s State Corporation for Space Activities, plans to launch the Luna-25 lander in 2021 [34], headed to the south pole of the Moon with the goal of collecting data on the local regolith, which suggests strong interest from the country for potential in-situ resource utilisation (ISRU) and human exploration activities. This is part of a larger lunar program that plans to send two more probes, Luna-26 and Luna-27, to the Moon by 2025, with additional missions planned for the following years [35]. It is worth noting again how the upcoming Luna missions will be conducted in partnership with ESA.

2.2.4 China

China’s Lunar Exploration Program, Chang’e, is focused on the lunar south pole. Chang’e-5 aims to return samples from Oceanus Procellarum, and other missions will follow until Chang’e-8 will test key technologies for the implementation of a human base. Other than the US, this is the only lunar space program clearly aiming at establishing permanent human presence on the lunar surface [36].

2.2.5 Japan

Japan is ramping up its efforts for lunar exploration. The country recently signed a Joint Exploration Declaration of Intent with NASA to collaborate on NASA's Artemis Program, returning humans to the Moon [37, 38]. Japan also hosts iSpace, a private lunar exploration company that can represent a great opportunity for the country to strengthen the domestic space sector while developing pioneering lunar missions. JAXA is also planning to launch its Smart Lander for Investigating Moon (SLIM) in 2022 [39].

2.2.6 India

India views the Moon as the stepping stone for furthering Mars and deep space missions. Through scientific exploration of the Moon, ISRO aims to focus on developing technologies for scientific and subsequent commercial exploration whilst promoting global alliance and inspiring generations of space explorers. Since the past decade, NASA and ISRO have been collaboratively working on joint payloads for scientific exploration and mineralogical strategies for the Moon [40]. The Moon Mineralogy Mapper on ISRO's Chandrayaan-1 mission in 2008, India's first mission to the Moon, was aimed at developing the first mineralogical map of the lunar surface. The CHandra's Altitudinal Composition Explorer (CHACE) payload, onboard the Moon Impact Probe (MIP), which was also a part of this mission, directly discovered water in its vapour phase [41]. The Mini-synthetic Aperture Radar (Mini-SAR), another instrument on Chandrayaan-1, was the first instrument to discover potential water ice deposits in the lunar north pole [42].

2.2.7 Canada

Canada's lunar programs are tightly bound to its technical leadership in robotics and autonomous systems. The country will contribute to the Lunar Gateway with Canadarm3, a robotic arm that will play a key role in the operations and logistics of the orbiting outpost. Canada has also recently devoted $150 millions in funding to the national lunar research and industry ecosystem through the Lunar Exploration Accelerator Program (LEAP) [43].

2.2.8 Others

Other nations such as Israel and the United Arab Emirates (UAE) have demonstrated capabilities to carry out missions beyond LEO, through the UAE's Hope Probe [44] and the Israeli Beresheet lander [45]. While these will probably be limited to scientific probes, their plans will contribute in shaping the international relationships patterns and equilibria.

2.2.9 Open points

The current set of planned space missions for the Moon represents a concrete scenario for the evolution of lunar activities. A juxtaposition emerges between US-led countries and China for the establishment of permanent activities on the Moon, although currently, no precedents exist to solve open lunar governance questions, nor have lunar programs reached an advancement that can request their prompt resolution. Also, it remains to assess the impact and role of other space-faring nations in lunar exploration, as their expanding capabilities, although far from mature, might soon turn them into valuable partners whose geopolitical interests can leverage space as a further driver.

3. Merits/Demerits of Single Collective Base versus Multiple Individual bases

As Borowitz and Battat alleged [46], the selection of the first Moon settlement should be consistent regarding the goal of Mars and space exploration, whilst also developing and employing the capabilities of the participating nations. They offer five criteria to analyse the merits and demerits of different scenarios for the first Mars settlement that is considered relevant and applicable to the two scenarios raised in the present analysis: potential for international cooperation, technical/economic feasibility, contribution to the eventual goal, global readiness for the mission, and political/legal feasibility.

3.1 Legal considerations for a collective international base

From a legal viewpoint, the development of a collective international base would ensure the highest level of compliance with the current system of international space law [47]. This is because the Corpus Iuris Spatialis has been drafted with international cooperation and multilateralism as essential components of space activities [15]. According to the very first sentence of the Magna Charta of space law, the OST, "the exploration and use of outer space shall be carried out for the benefit of and in the interest of all countries, regardless of their degree of economic or scientific development, and shall be the province of all mankind" [17]. Before permitting space exploration and use by all States, the OST permanently marked activities in space as global and cooperative efforts. In this respect, some authors have questioned the actual legal value of the first clause paragraph of Article I OST, arguing that its obligations, if any, are more of a moral nature [15]. However, while it is difficult to enforce this provision, also due to its very broad formulation, this does not deprive the legal value which comes from being a valid provision within an effective treaty [15]. Accordingly, and in compliance with Article 31 of the Vienna Convention on the Law of Treaties [48], the legal significance of Article I (1) OST has to be derived in light of the object and purpose of the treaty itself. The normative content of this provision will also have to be adjusted depending on the space activity in question, given the fact that using an orbital position is not comparable to using a portion of the Moon. In general, it can be safely stated that the legal significance of

Article I (1) OST is to declare space as an inclusive environment, free from predatory behaviours that would monopolise the use of space for the benefit of a few actors [15, 49]. This inclusiveness is further reinforced by paragraph 2 of Article I OST, which declares space "free for exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law [17]." From the drafting history of the OST, it is known that the clause "without discrimination of any kind" has been added to reinforce the importance of cooperation in space activities [15]. According to the negotiations between the USSR, who proposed the clause, and the US, who initially opposed it, the legal meaning of this clause can be found in the "most favored nation" rule [15]. Such a rule is a legal obligation that is part of the regime of the World Trade Organization (WTO), according to which every WTO member has to extend the same privileges and immunities granted to one country to all WTO members [15]. Therefore, Article I (2) OST forbids excluding behaviors that would jeopardise the possibility of a given country to participate, alone or in a group, in space activities. Given the enormous technical and financial challenges to be faced for the establishment of a lunar base, developing countries would inevitably be excluded from this endeavour if spacefaring nations would not allow them to join their lunar programs. Legally speaking, an absolute and unjustified refusal to cooperate could be regarded as in violation of Article I (1) and (2) OST [15]. This would most likely be the case especially if the outcome would either be that a certain country would exclusively benefit from lunar activities or that another one is left out from the possibility of participating in lunar exploration.

This conclusion is further supported by the territorial nature of upcoming lunar exploration activities. As is well known, one of the main goals of the OST was to avoid a "colonialist" approach towards the utilisation of space. Legally speaking, this is ensured by the principle of free access under Article I (2) OST in combination with the non-appropriation principle under Article II OST. Accordingly, "there shall be free access to all areas of celestial bodies [17]," which are also "not subject to national appropriation [18]" by any means. These principles need of course to be interpreted in a reasonable way, so that they would not impede the very activity that they are entrusted to protect, i.e. the free use of celestial bodies [50]. At the same time, as seen above with Article I (1) OST, they also cannot be interpreted so to actually deprive them of any practical value. As a result, territorial use of celestial bodies is allowed insofar as it is neither exclusive nor perpetual, which in fact are two main features of property, as suggested for instance in Building Block [51]. Therefore, any permanent base built over the surface of the Moon would be better off, from a legal perspective, if left open to the contributions of interested international partners "without discrimination of any kind, on a basis of equality and in accordance with international law [17]".

3.2 Legal considerations for multiple bases

From a legal standpoint, multiple national or regional bases on the lunar surface could be found to be in violation of the OST, although this conclusion depends very much on the features of the bases themselves [47]. As discussed above, international space law looks with suspicion at unilateral uses of celestial bodies [52]. This is because a scenario whereby every State is entitled to have its own exclusive and permanent base would rapidly escalate to a quasi-colonialist race, especially in a limited environment as the Moon. For example, currently the points of high interest on the lunar surface are the permanently shadowed regions (PSRs) and the peaks of eternal lights, both located on the Lunar south pole as discussed in section 4 of this paper. These areas are of great interest given the unique advantages they provide in terms of resources available, specifically the ice in the craters and the solar energy in the peaks of eternal light [53]. If any actor landing on the surface of the Moon would be entitled to simply reach these areas and de facto occupy them for its exclusive uses, what legal meaning would be left for Article I and II OST? How could the principles of sharing benefits of free access and of non-appropriation be applied, if in practice any entity could unilaterally take all the advantages offered by a unique portion of lunar territory? Accordingly, there need to be correctives. For national or regional bases to be lawful under international space law, compromises will have to be made to accommodate the main obligations stemming from the principles mentioned above. For practical suggestions on how to develop such compromises, see Salmeri & Jimenez [54]; for a set of proposed international best practices for sustainable lunar operations, see Moon Village Principles [55]. For instance, when all craters would be occupied, existing mining operations should be opened to partners (against payments of the sustained costs), or, at the very least, the extracted resources should be made available on a basis of equality, without discrimination of any kind and at a fair price [54, 55]. Likewise, when all peaks of eternal lights would be filled with solar power generators, such facilities should either be shared (against payments of the sustained costs) or access to the energy should be made available on a basis of equality, without discrimination of any kind and at a fair price [54, 55]. To name some of the most important requirements, such bases would need to be transparent, exclusively for peaceful purposes, designed for interoperable devices, and last but not least, reasonably limited as to the temporal and physical extension of the operations. Without these sorts of adjustments, national or regional bases would most likely rise to de facto appropriation of the lunar territory, in violation of Article II OST [47].

3.3 International Cooperation Considerations

The evaluation of international cooperation is given by two major contributing factors: technology readiness for a nation and the expected political interest in or commitment to developing that capability [56]. The current countries that possess the operational readiness for human spaceflight are the United States, Russia, Europe, Japan, Canada, and China. The rest of nations involved in space exploration are developing new capabilities and may play a role in future efforts. However, their space programs do not count as operationally ready, which generates indetermination and ambiguity on the capabilities that they will develop.

For example, the current major requirements for new technology development are environmental control and life support systems and advanced radiation protection techniques. Establishing these technologies will be significant for space exploration and future Moon and Mars settlements. Due to the early stage of readiness, a subsystem-level coordination could be pursued. Furthermore, the single international habitat provides a certain level of adaptability in operations, providing opportunities for relevant activities from international contributors.

The single international base lays its case on the technology and organizational elements of the International Space Station (ISS). Therefore, it was considered crucial to analyse the lessons learned on international cooperation and organization of the ISS [57].

It is crucial to develop a long-term shared vision for space exploration that transcends domestic policies, but still generates a shared goal among the partners. The main goal for Moon exploration and international collaboration will be to facilitate domestic objectives and priorities of the partners while simultaneously ensuring the development of all critical technology.

The overall plan and development should be able to abide by unforeseen events without threatening the overall mission. A withdrawal or delay due to a partner's circumstances could prove critical. However, through a governmental-level international commitment that acknowledges the domestic policies, the economic processes, and the technical responsibilities with the partners' programmatic and political needs, a single international base will result effectively.

3.3.1 International Space Station as a model for international crewed operations

When considering international cooperation on the Moon and beyond, a precedent can be drawn from existing international space projects. The largest and most relevant for future crewed projects is the ISS, as it features both human crew and major involvement of several international actors.

The ISS consists of a US and Russian segment, each operating autonomously by centres in their respective country. In addition, Europe and Japan operate their own modules [58]. While from the ground the boundaries might appear clear-cut, the crew members can move freely and can utilise any part of the station when necessary [59]. The operators on the ground also work in close cooperation and coordination, adhering to "joint flight rules," to ensure smooth common operations. Flight control crews have their counterparts in the other control centres, with whom they are in contact to remain coordinated [60]. Coordinated planning between international partners is necessary to efficiently use astronaut time and ensure proper hardware usage (e.g. in regard to power available) [61].

The degree of involvement of international partners in the ISS project is varied, and the level of contribution determines the allocation of hardware and crew time [62]. The contributions range from construction and/or delivery of modules, resupply missions, hardware and system contributions, transportation, and launch services [63]. In the past years, commercial entities have started directly participating in the project, having provided cargo and crew transportation and payload racks to be used commercially. Future commercial endeavours include the expansion of commercial transportation services for crew, commercially-funded modules, and modules for direct commercial use [64].

The field of crew transportation offers a perspective on how a monolithic project that involves numerous international partners, and whose development is regulated and coordinated by agreements between agencies and governments, can foster innovation via competition. After the retirement of the space shuttle, crew launches were solely performed by the Roscosmos Soyuz spacecraft. To regain the ability to launch astronauts from US soil, NASA awarded contracts to private companies to develop suitable spacecraft through the Commercial Crew Program (CCP) [65]. The first of these to successfully reach ISS was the Crew Dragon by SpaceX [66], launching with a human crew on 30 May 2020 and reaching the station the next day.

The ISS thus provides a relevant model for cooperation in development, operations, and utilisation in space. While it is uncertain that the same model will be applied to agency efforts in placing permanent human presence on the Moon, the ISS project sets an existing example for how to conduct such a large-scale multinational undertaking, while also offering room for innovation via commercial competition.

4. Hypothetical case study on the national and commercial use of lunar infrastructure

The OST has endured as the underlying legal framework governing space activities since 1967. While the landscape of the space industry has changed considerably in the last fifty years, the underlying principles of the OST are still important to consider, both in letter and in intent, as the private space sector develops. Given the stated objective of many governmental and intergovernmental bodies to establish a sustainable presence on the lunar surface (e.g. Artemis Accords), a discussion of the construction of, equitable access to, and eventual profit from lunar infrastructure is a pertinent one and must reasonably consider the interest of private stakeholders. In this section, one plausible scenario for the commercial use of lunar surface infrastructure and its ethical, scientific, and legal implications are used as a hypothetical case study.

The extraction and use of water ice from lunar PSRs [67] have been a common discussion point in recent years, so this will be the basis of the first case study. Rubanenko et al. [68] provided a possible upper estimate of water ice abundance at 100 billion metric tons. Within the North American Great Lakes alone, there are 22.4 trillion metric tons of fresh water [69]. Therefore, lunar water ice is unlikely to be utilised for alleviating water needs on Earth, as the costs and technological challenges of transporting such a comparably small amount of water to the Earth's surface far outweigh the benefits of doing so. As such, the lunar polar volatiles are a good placeholder in this discussion, as similarly to other often mentioned resources (e.g. lunar regolith and Moon-based solar energy [70]), they will be best utilised for the development and maintenance of in-situ resources, at least while no reliable system for the transport of material through cis-lunar space exists.

In recent years, contract-based public-private partnerships constitute the majority of publicly-funded private enterprise (as opposed to grants or purchase orders) [71]. Specifically bound contracts should continue to be used as the only access to lunar volatiles for private entities, and these contracts should be awarded and supervised by a collective of space agencies. Competition for contracts must begin with an international and open call to encourage technological innovation globally. Contracts should be awarded on an as-needed basis to construct and maintain lunar infrastructure necessary for exploration and scientific activities, and to provide critical life support should a lunar habitat be in place. The use of polar volatiles for the specific interests of one nation (e.g. to create fuel for space tourism activities) should only be permitted in the case where the aforementioned uses are fulfilled and reserves of extracted water ice are replete. Explicit extraction of finite lunar resources for solely commercial or single-nation interests should be prohibited. As alluded to in previous sections, legislation to that effect should be put in place before any one nation revisits the lunar surface. While the OST indicates that no one entity can lay claim to territory in space, it fails to specify what constitutes a claim to territory. This legislation must be clarified to preclude the development of tradable 'priority usage' or 'mineral extraction rights' by which de facto claim to the resource can be purchased.

Further, as lunar infrastructure essentially functions as a modification to public domain, any permanent or long-term structure or equipment emplaced on the lunar surface should be done so under complete transparency. The OST allows for agents of other states free access to all infrastructure in space and on celestial bodies, provided reasonable notice. The authors suggest that this be taken one step further, such that all lunar activities and construction should be internationally approved and understood to be freely accessible at all times, and 'reasonable notice' should be interpreted as ensuring that capacity of lunar habitats and life support is not exceeded and that launch and landing can be made safely and without interference. In order to obtain this level of transparency, there is an acknowledged lack of intellectual property protection that accompanies the release of engineering drawings and testing reports.

This may reduce the profit margin and thus the attractiveness of the described contract structure to private companies. However, the authors posit that the need to:

a) ensure compliance to safety standards
b) have an up-to-date, verifiable understanding of all potential risk factors or complications on the lunar surface and
c) prevent any possible loss or damage to the shared lunar resource pool

are indisputable priorities. In the particular case of lunar water ice, biological or chemical contamination of a large reservoir due to noncompliance could irreparably damage the utility of this resource, thus endangering the lives of any lunar residents and slowing future human space exploration.

6. Conclusions

The working group arrived at several recommendations, addressed to different audiences, based on the analysis outlined in the paper. The assumptions taken into account were that:

a) plans for human exploration of the Moon are already in motion internationally,
b) sustainability is a key driver for lunar activities, and
c) aspects of lunar activities could be provided commercially

Based on the analysis of the ISS as a model for international cooperation, the working group concluded that an initial infrastructure of a single station requiring a collaborative effort between nations and commercial stakeholders is the recommended approach. From this foothold, the presence is expanded to multiple bases with a standardization of planning, building and operating lunar bases.

Strategic recommendations addressed to the United Nations included:

1. Immediate development of guiding principles for international conduct of lunar activities that safeguard human rights, lunar environment, and prioritises scientific endeavors, while fostering cooperative economic development. The suggested timeline of this recommendation is to establish principles before construction begins on permanent lunar structures.

2. Encouragement of global space stakeholders to re-evaluate international partnership boundaries, specifically pertaining to collaboration bans, in order to expedite lunar exploration and enhance innovation.

3. Establishment of a neutral mediator for rapid resolution of conflicts before operations begin on the lunar surface. This neutral mediator is a third party that is capable of handling conflict resolution in order to ensure continuation of surface operations and crew safety.

Recommendations intended for the United Nations and other public/private stakeholders with the vision of a cooperative legal and technical framework as the optimal foundation for a sustainable lunar economy, included:

1. Encouragement of nations and industry partners to immediately begin devising a set of international standards (technical, operational, safety, and conduct) that allow stakeholders to collaborate to build lunar bases, with the goal of fostering international and commercial partnerships whilst ensuring safe operations.

2. Permanent human presence on the Moon should begin with a single, international base to establish a modular lunar infrastructure. To achieve this, it was recommended that interested parties extend an open invitation to governments and private companies/industry in the form of a summit.

Finally, the analysis of the status quo of lunar development resulted in the following open questions, which are open to investigation as further work. First, it is necessary to clarify the legal regime, namely what the legal status of lunar resources is. In addition, the profitability of lunar activities must be assessed to understand whether commercialization of resources is needed. Lastly, the information barriers and sharing must be understood to ensure the correct approach to protection of intellectual property while encouraging open, innovative frameworks.

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