# Explore to Exploit: A Data-Centred Approach to Space Mining Regulation

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**Abstract**

*In light of recent technological advancements in the launch industry and the accelerating development of a private space economy, the regulation of space mining is becoming an increasingly pressing matter. A regulatory regime for space mining must not only provide legal clarity on how to acquire mining rights for certain celestial bodies, but must also do this in a way that does not hinder investment in companies in this sector. To encourage a progressive development and prevent the formation of market monopolies, the regime's mechanism for acquiring mining rights must be designed to promote continued investment in new space mining companies, even after first movers have proven the concept. With a strong emphasis on the proliferation of space mining and the establishment of a spacefaring civilization, this paper proposes a regulatory regime and mechanism to acquire rights for the mining of celestial bodies while preserving the information and knowledge contained within these bodies as heritage for future generations of mankind and for science to capitalize on an emerging economy's momentum.*

**Keywords**

Space resources, Space mining, Asteroid mining, Space mining regulation, Space development, Private activities in space

## 1. Introduction

The prospect of space mining has been a part of the scientific, legal and cultural domain for a long period of time. The general accessibility of asteroids and comets alike has been demonstrated by science missions to orbits around 67P/Churyumov-Gerasimenko by ESA's Rosetta mission [1], Itokawa by JAXA's Hayabusa [2], Ryugu by JAXA's Hayabusa 2 [3] and Bennu by OSIRIS-REx [4], with samples having been returned to earth by Hayabusa and Hayabusa 2 and, as of writing of this paper, currently being returned by OSIRIS-REx.

Complementing the proven ability to access asteroids from earth, Sanchez and McInnes [5] have shown that there is “ample material that could potentially be exploited at a relatively low energy”. Genta [6] considers asteroid mining to be a necessary foundation for establishing humanity as a spacefaring civilization. Companies with the goal to realise space mining, e.g., Planetary Resources and Deep Space Industries (now acquired by Consensus Space [7] and Bradford Space [8]), have been in existence for many years. Other companies, like Momentus Space [9] or Honeybee Robotics [10], have a technological profile or dedicated roadmap set on the goal of space mining. Together with technical, legal and environmental views on the matter, some authors are also critical of space development and how it will evolve. For example, counterarguments against space expansionism in general were recently published by Deudney in his book “Dark Skies” [11]. He describes the large-scale development of space as a source of conflict with potentially existential consequences for humanity and advocates for a policy of space development that serves Earth by focussing on space-based astronomy, Earth system science, a strengthening of the Outer Space Treaty and research techniques for asteroid deflection through an international consortium. With respect to the latter, Deudney warns of the dual-use character of asteroid mining technology. Asteroid orbits could be changed to intercept the Earth’s orbit and could thus be used for orbital bombardment in a terrestrial conflict scenario or, as he states, in a war between Earth and off-world colonies. The “destructive capability vastly exceeding nuclear weapons” of techniques that alter asteroid orbits should not lie with single companies or nations [11].

However, no company has been able to achieve a dedicated exploration or mining demonstration mission yet. The reason for this is not only the complexity of design and building of the associated spacecraft, but also due to funding. This is a result of the uncertain legal status of space mining and the persisting debate on whether private property of space resources based on the Outer Space Treaty [12], the governing international law on outer space, are at all possible. At the core of this lies the Outer Space Treaty’s principle of the non-appropriation of celestial bodies by any nation. This includes the question of whether mining resources implies a form of ownership of a celestial body, which would be in opposition to the Outer Space Treaty. Additionally, the treaty does not address private mining efforts. This absence of an international regulatory system for space resource utilization is a consistent impediment to significant private investment in space mining, as “legal uncertainty is not good for business” [13].

Numerous authors thus advocate the necessity to clarify the situation and encourage private space development [6], [13], [14], [15], [16], [17], [18]. Cooper [15] and Pop [17] specifically emphasize the need for private property rights in space. Pop [17] also makes the case for the need for a means to secure those property rights, while other authors specifically address space mining with the proposal of regulatory mechanisms [14], [15], [16], [18].

In addition to the discussion on possible ways to encourage space mining development by ways of legislation, the possible positive effects of space mining on the terrestrial environment are being discussed together with questions of the sustainable use of space itself. Space resource utilization could “relieve the stress humanity puts on the environment” [15]. However, sustainability as a concept with respect to space is still ill defined, and the focus between those authors covering this topic varies [19]. Several proposals have recently been made on how to include sustainability in space activities based on bottom-up [20] and soft law approaches [21], [22] to fill the gap left in international law by voluntary measures. Palmroth et al. [21] focus mainly on low Earth orbit (LEO) satellite capacity and debris mitigation. Newman and Williamson [20] note that the matter of debris mitigation is equally important for geostationary orbit (GEO), around the moon or other celestial bodies because of the lack of atmosphere and the consequent impossibility to simply de-orbit and burn up, as in the case of LEO satellites. Chrysaki [22] describes a voluntary code of conduct for private companies with respect to sustainability. Compliance with the code would be incentivizing through the strengthening of reputation and company brand. In a study from the viewpoint of space activities serving Earth's environment, Hein et al. [23] conducted a seemingly first life cycle assessment comparing $CO_2$ equivalents of asteroid-mined water and platinum group metals with terrestrial water delivered to cis-lunar orbits and metals mined on earth. Their results show the potential for substantial benefits of asteroid mining at reasonable ratios of initial launch mass vs. mass of resources delivered to Earth. Cooper [15] contends that space resource utilization is an obligation to future generations, as not doing so would keep them from a potential future as a space faring civilization. Cooper [15] also argues that the issue of finite resources is only valid as long as the solar system is seen as the system boundary. Elvis [24] and Crawford [25] describe the possible positive effects of space development on science by a decline in launch costs, the development of infrastructure available to science, the use of cheaper space probes developed for space mining prospecting or the direct use of discoveries made by companies undertaking space mining prospecting. Schwartz [26], on the contrary, argues for the prioritization of space science over space development, especially with regard to asteroid mining, where development would still be possible after scientific exploration but not vice versa. Thus, "there is something good about the fact that the current regulatory environment is viewed as discouraging space development" [26]. Elvis and Milligan [27] use a more measured approach and propose the principle of only utilizing 1/8$^{th}$ of the useful resources of the solar system. Considering an annual growth rate of 3.5% of a space economy, this would already be reached in about 400 years. Thus, with their growth rate assumption, 1/8$^{th}$ utilization would then only require three doubling cycles of the space economy to reach a state of super-exhaustion of all the system's useful resources, equivalent to an additional time period of a mere 60 years. This principle is therefore not intended to simply protect the wilderness character of vast parts of the solar system but should function as a tripwire to alarm and protect future generations in a possibly not-at-all distant future from an existential crisis. This would, of course, require a "full science-based inventory of the solar system" [27] in the first place and the current average rate of around 15 planetary research type missions per decade would, under the given timescale, fail this goal.

In agreement with Cooper's [15] contention that space resource utilization is an obligation towards coming generations, this paper seeks to propose a regulatory regime that focusses strongly on the proliferation of a progressive space mining economy.

The ongoing debate on the possibility of acquiring private property rights to a celestial body or its resources after their removal is not considered in this paper. For various reasons, the concept of space mining remains controversial in politics. Saletta and Orrman-Rossiter [16] and Su [28], for example, provide a thorough and recent overview of the legal debate. As the scope of this paper is the proposal of a system of how mining rights can be secured by private companies, the possibility of acquiring private property rights to resources removed must be considered positively resolved *a priori*. Whereas the existence of property rights is a question of the legality of space mining in general, its regulation is a matter of its orderly conduct. An agreeable concept for orderly conduct, however, may contribute to solve the dispute about legality, which is, as the discussion in this paper outlines, a result of conflicting interests.

To establish a basis for the regulatory regime to be proposed, this paper will briefly review the relevant sections of existing treaties, space mining regulation mechanisms proposed in the literature as well as already implemented national regulations. In light of technical space mining architectures, the proposals are discussed with respect to their compatibility with the requirements of society and businesses for a mutually beneficial regulatory regime. The paper approaches the regulatory discussion thus from a techno-economical perspective rather than a legal one. Factors originating in a resurgence of great power politics that obstruct the regulation of space mining are not considered in this analysis.

Based on the findings, a regulatory mechanism is derived that balances space mining business and investor interests with the interests of the scientific community and seeks to provide a way for all countries to actively participate in the development of a space mining economy by making exploration data the central pillar in securing mining rights to celestial bodies. As the exploration data of a celestial body is, in itself, a valuable resource, its publication is proposed as a prerequisite to gaining exclusive mining rights, to prevent monopoly formation, to boost scientific progress and to preserve the information contained within the celestial bodies for future generations.

## 2. Existing treaties, national laws and proposals for space mining regulation

The "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies" [12] of 1966, referred to in short as the "Outer Space Treaty" (OST), is the foremost international treaty governing space activities. The treaty is currently ratified by 111 state parties and signed by another 89 states [29]. From a historic perspective, its intention is to prevent terrestrial conflicts from spreading into space, motivated by the Cold War between the United States of America and the Soviet Union in light of their race to the moon. Thus, Article III of the OST requires the state parties to carry out activities in the exploration and use of outer space in the interest of maintaining international peace and security and to promote cooperation and understanding. To further stress this intent, Article IV explicitly bans the stationing of nuclear weapons and other weapons of mass destruction in orbit around the Earth. Article II addresses non-appropriation, i.e., no nation can claim sovereignty over any celestial body by any means. This again is a specification of Article I of the treaty, which states that space is the province of all mankind. Exploration and use shall be carried out for the benefit of all countries without consideration of their economic or scientific development. Article I also states that space shall be free for all for scientific investigation. The treaty makes no mention at all of private companies. Together with Article II, preventing "national appropriation by claim of sovereignty, by means of use or occupation, or by any other means", this is the source of the discourse about the legality of space mining and the possibility of property rights to space resources.

The "Agreement Governing the Activities of States on the Moon and Other Celestial Bodies" [30] of 1979 commonly designated as the „Moon Agreement", attempts to specify on the OST. In many cases, the document uses the term "moon" to represent other celestial bodies, as indicated in the document's title. Article 4 of the Moon Agreement states that, in the exploration of the moon, "due regard shall be paid to the interest of present and future generations and to promote higher standards of living and conditions of economic and social progress in accordance with the UN Charter". Article 6 first mentions the use of resources by specifying that samples may be removed and shall remain at the disposal of the removing state for scientific purposes. Scientific investigations may also comprise the use of minerals and other substances on the moon for the support of the respective mission, enabling *in situ* resource utilization for science missions. Article 11 explicitly addresses space resources and designates the moon and its natural resources as the common heritage of mankind. The non-appropriation principle of the OST is then extended to these resources and is applied to states, all types of national or international governmental and intergovernmental organizations, non-governmental entities and natural persons. This factual prohibition of space mining is accompanied by paragraphs focussing on a roadmap towards its regulation. The parties to the Moon Agreement shall undertake to establish an international regime to govern resource exploitation at the time of its imminent feasibility. The benefits derived from the resources shall be shared by the parties to the Moon Agreement in an equitable way with a special emphasis on the developing countries.

One could argue that under these terms the case for space resource utilization is clear and a way towards its regulation has already been sketched out. However, with only 18 parties and 11 additional signatories [31], the Moon Agreement carries far less weight than the OST. In fact, none of the major space faring nations has ratified the Moon Agreement, with developing countries comprising the majority of its signatories. None of the nations that today claim the possibility of commercial appropriation of resources removed from celestial bodies has ratified the Moon Agreement.

In a summary, Buxton [32] describes the different interpretations of the “province of mankind” and “heritage of mankind” formulation, with the first from the OST being interpreted as warranting free access to space, while the latter is interpreted by less developed countries as describing a sort of common property leading to the claim that resources be divided in an equal fashion, regardless of participation in their recovery. Despite the lack of widespread international acceptance of the Moon Agreement, Cooper [15] points out that, without the prospect of equity, a future international regulatory framework for space resource utilization will not gain support by developing countries. Following the lack of a regulatory regime in international law, several proposals have been presented in the literature, including mechanisms to acquire mining rights to certain celestial bodies and/or ensure a share in the benefits from the “heritage of all mankind” for all countries.

Looking for a simplistic yet proven example of a regulation mechanism, some authors have found an answer in the past: the United States’ “General Mining Law” of 1872. Simply put, this law allows for exploration activities on public lands and, if valuable minerals are discovered, the explorer may file for a claim, which also requires a minimum fee. If the claim is further developed and work to the equivalent of $500 is performed on site, the explorer may request a patent on minerals and surface rights to be granted. This is accompanied by a body to appeal to in the case of conflicting claims. To uphold a claim, an annual amount of labour equivalent to $100 is required. Shaw [18] proposes adapting this regulation for asteroid mining with some minimal changes. In an ideal situation, the claims would be managed by an international organization with an appeal board to resolve conflicts. To avoid monopolies, claims would have to expire if not used, with a proposal to employ mining activities or the dispatching of a mining vessel as proof of use of the claim. To avoid interfering with the OST, Shaw proposes restricting any property rights resulting from a claim on the resources and thus avoiding any indications of sovereignty. The general concept behind the original mining law of 1872 and its adaption to asteroid mining by Shaw is to keep all fees to a minimum while providing legal clarity to encourage development. The legal process is not designed to generate revenue for the state, as it is supposed to be a result of the actual development and business activities.

Saletta and Orrmann-Rossiter [16] propose the implementation of an international “outer space resource fund”. Such an entity would be established, for example, under the roof of the World Bank and be funded by leasing out space resources. The proposal, based on the Alaska Permanent Fund model, further suggests that a dividend be paid to all world citizens from the investment proceeds of such a fund. The establishment of "such a system would provide a framework encouraging commercial exploitation of outer space by ensuring legal clarity while simultaneously ensuring that the exploitation of 'the common province of mankind' accrues tangible benefit to all of humanity".

Wojciechowski et al. [14] propose the installation of an international "mediating organization". Companies interested in the exploitation of resources of a certain celestial body would have to enter a "rental agreement" with the mediating organization and pay a fee for the right of exploitation. The fee should be small and be used to fund the administrative process as well as "assist underdeveloped States' space programs". Resource exploitation is intended to be limited in time and quantity, with strict requirements related to documentation and control by a customs office-like authority. The information on resources gathered has to be published and less developed countries can petition for resources. Compliance with these petitions would, however, be voluntary.

Cooper [15] proposes honouring the spirit of the Moon Agreement by dividing space into parcels and assigning property rights to each nation via a lottery. These can subsequently be acquired by organizations or individuals according to their respective national laws. Alternatively, Cooper [15] proposes a resource survey to be conducted by the space faring nations, allowing them to divide space into parcels with lesser developed countries subsequently choosing their parcels first. Although the lesser developed countries might not be able to exploit the resources themselves, they could use the open market to benefit from their property, e.g., by selling it.

Some state actors try to capitalize on the ambiguity of the legal situation concerning space resources and implemented national legislation that explicitly legalizes these activities with the intent to attract businesses active in the field and profit from the potential of an emerging space economy.

Luxembourg passed the "Law on the Exploration and Use of Space Resources" [33], the core of which is the statement in Article 1 that "space resources are capable of being owned". Article 2 makes it clear that no one can explore or use said resources without authorization from the ministers responsible for the economy and space activities This authorization, as stated in Article 3, will be granted to a mission operator by the ministers upon written application, requiring a potentially substantial fee (Article 13) in the range of €5,000 to €500,000. Except for the exclusion of satellite communications, orbital positions and frequency bands, the term "space resources" is not defined, again allowing for much ambiguity in its all-encompassing range of claims.

In the United States of America, several pushes have been made towards a national law concerning space resource utilization, notably the "ASTEROIDS Act" [34] and the "Space Resource Exploration and Utilization Act" [35], whose respective compatibility with the established space law is discussed by Tronchetti [36], [37]. However, none of these initiatives were instated as law. Space resource utilization was finally included in the "U.S. Commercial Space Launch Competitiveness Act" [38]. This law gives a United States citizen engaged in the commercial recovery of space or asteroid resources the right to possess and own resources obtained and the associated right to transport, use and sell these resources. Asteroid resources are defined as space resources on or contained within an asteroid, and space resources are restricted to abiotic resources *in situ* in space, including water and minerals. In a disclaimer, the US Congress states the belief that this does not mean the assertion of sovereignty or ownership over any celestial body. Activities shall be conducted in accordance with international law. Although much shorter, the definition of resource in US law is clearer than that given in

Luxembourg law. It does not describe a regulatory mechanism at all, it only eliminates ambiguity about the legality of space resource utilization under US legislation in general.

The United Arab Emirates issued Federal Law No. (12) of 2019 on December 19, named "ON THE REGULATION OF THE SPACE SECTOR" [39]. The law addresses the possibility of "permits for the exploration, exploitation and use of Space Resources, including their acquisition, purchase, sale, trade, transportation, storage and any Space Activities aimed at providing logistical services in this regard" ([39], Article 18). "Conditions and controls" relating to the permits must be defined by the Council of Ministers. Permits are granted by a decision of the Board of Directors based on a decision proposal by the Director General of the Emirates' Space Agency.

## 3. Proposed regulatory regimes in light of space mining architectures

### 3.1 Space mining architectures

Most proposals for regulatory regimes and mechanisms to acquire mining rights are presented unconnected to the technical aspects of space mining systems and consequently the conditions of their economic boundaries. To allow for a profound overview and an informed assessment of proposals for regulatory regimes, this section summarizes the different types of space mining system architectures described in the literature.

There are several journal and conference papers available describing different space mining missions, either from a technical standpoint (e.g., [40]) or, to some degree, including their economic feasibility (e.g., [41], [42]). However, an economic discussion always requires, to some extent, the definition of a mining mission architecture, including technical aspects such as launch systems utilized and spacecraft capability. Ehresmann and Herdrich [40] focus on the main asteroid belt, while Calla et al. [41], Hein et al. [42], and Andrews et al. [43] focus on near-Earth objects (NEOs).

Proposed mining systems range from small spacecraft up to large multi-ton mining vessels using nuclear electric propulsion. A distinction can be made between system architectures employing *in situ* resource processing, delivering the refined material targeted by the mining mission and missions returning raw materials. Small spacecraft seem to be restricted to the return of water or other volatiles as a processed resource due to the relatively simplistic methods needed for their extraction in comparison to the extraction and refinement of metals.

The most promising resources for exploitation based on projected demand in cis-lunar space or on high market values in terrestrial markets are water [5], [41], [42] and platinum group metals (PGM) [5], [43].

The return of resources is either achieved by cycling of the mining spacecraft itself or by employing specialized cyclers to support the mining activity.

Due to their limited delta-v capability (an indicator of manoeuvrability concerning the ability to leave, translate to and enter orbits of different celestial bodies), small spacecraft are confined to use on a limited fraction of NEOs within their respective delta-v threshold. Sanchez and McInnes [5] provide object population estimates for given spacecraft delta-v capabilities. For a small-scale combined mining and cycling spacecraft, a mission to main belt objects is not possible. Because NEO orbits vary to a high degree, changing the mining location from one object to another (referred to as hopping [40]), due to resource exhaustion or if the location is found to be unsuitable, is also unlikely to be feasible for small spacecraft. For non-cycling large scale mining vessels, such a manoeuvre would only be economical in cases where the first mining location is depleted. Thus, the selection of an object suitable for mining is crucial for the viability of the business case. This necessity is, in most cases, mentioned in literature, but is not always explicitly accounted for in the modelling of the respective mining system's economics. Andrews et al. [43] include a prospecting spacecraft sent ahead of a large-scale mining vessel's mission to identify and confirm the suitability of the target.

Ehresmann and Herdrich [40] describe a large scale mining vessel for use in the asteroid belt focussing on the technical aspects. They argue that, based on more similar orbits in the main belt (in comparison to NEOs), the transfer of a mining vessel from one object to another may be possible. For this, a mass driver is proposed as a propulsion system, which, in normal operation, is used to accelerate mined resources to send them to their target location. The "hopping" capability would enable operation without prior prospecting, since if the actual location is not suitable for the intended mining operation, transfer to another object is possible. However, even if no precursory prospecting mission to identify or confirm a suitable target body is intended in this approach, *in situ* prospecting has to be conducted to identify the most promising part of the celestial body to start the mining activity at [40].

The diversity of the mining systems described in the literature makes it impossible to provide an individual value representing the investment necessary to start a successful mining endeavour. Multiple billions of dollars would be necessary for even a relatively simple small spacecraft water mining architecture. To decrease the timespan for a potential return on invest (ROI), the use of a fleet of mining craft with multiple launches per year and multiple active mines is proposed [41], [42].

While the above overview proves that an archetypical space mining mission does not exist, prospecting and exploring potential mining destinations can be found as a common denominator to make sure the far larger amount of capital later invested in the actual mining effort supports a mission with a high probability of success.

### 3.2 Discussion of the proposals in the literature

In light of the mining architectures described in the literature, it becomes clear that the proposed regulatory systems are not in lockstep with the needs of space mining companies. In a best-case scenario, a regulatory mechanism would reflect the complexity of the overall space mining economy and provide stimuli for beneficial development.

The current non-existence of international regulations does not impose additional hurdles to space mining. The fact that the question of property rights to space resources is still subject to academic discussion (which, again, is not discussed here) will also not hinder the development of the industry in the long run. The existence of the U.S. Commercial Space Launch Competitiveness Act and other national legislations makes the business *de facto* legal and thus pursuable within the domain of the respective legislating country. As developments progress, the acceptance of property rights to space resources could extend to other countries that do not wish to fall behind. These countries might issue their own national legislations. Thus, without clarification in international law, the normative power of the factual could make property rights to space resources a reality in a cascade of national legislations if the trend continues.

The unilateral national legislative approaches to legalizing space mining activities remain controversial and are criticized in the academic literature and by state actors alike. In the United Nations Office for Outer Space Affairs' 55th session of the legal subcommittee, several delegations expressed concern that unilateral legislation "may amount to either a claim of sovereignty or a national appropriation of those bodies and thus could constitute a violation of the Outer Space Treaty" [44]. Hao [45] specifically highlights objections from the delegations of Russia, Belgium, Chile and Mexico. Hobe [46] calls Luxembourg's national law "blatantly contrary to international law … and therefore essentially null and void". Su [28], Boley and Byers [47] describe leaving mining regulation to national governments as a risk for a "race to the bottom" and possibly leading to "flag[s] of convenience" as a result of nations striving for minimal regulation to attract companies.

Without any further international regulation, a "first in time, first in right" principle [28] would be the consequence. Whichever way a space mining industry evolves, the regulation of its orderly conduct is needed. Without regulation, drawbacks exist for all parties involved. The current situation promotes monopolies, potentially stirs conflict between companies and is not incentivizing to investments due to a lack of legal enforceability. For what may "first in time" in space mining mean, and what action exactly is required to become "first in right"? Is a resource prospecting mission sufficient, or a probe landing to mark the rightfulness of the claim? Or rather a sample return or the beginning of exploitation *in situ* itself? This is especially important for companies targeting the same celestial body. When these companies are located in different countries with potentially differing legal opinions on the matter, which countries' law is binding? When considering the timeline of asteroid missions, it is entirely possible that missions targeting a celestial body may be under way at the same time and arrive at the target location in a different order than their launch order, depending on their propulsion system, and potentially with different technological levels of their exploration spacecraft. Considering the stakes involved, like scarce resources to be gained for their own economy or state taxes to be levied on the company's profits, conflict between the nations involved can easily be imagined.

Conflict, however, is a factor not only relevant in an environment without dedicated regulations, but also in cases where regulation mechanisms are only in place in a single or a few countries. The ASTEROIDS Act (which was ultimately not passed into US law), for example, tries to mitigate this by offering its extension to companies outside the USA who declare themselves to be under the act's jurisdiction. This ignores the existence of different or even rivalling political systems and economic spheres. Consequently, his analysis of the rightfulness of the US ASTEROIDS Act, Tronchetti [36] states that it endangers "international peace and security" by introducing the possibility of claims based on different national laws. Would the claim of a company from another economic sphere based on their own respective regulation be accepted? Considering mining systems with fewer large-scale mining spacecraft, the uncertainty surrounding a mining claim to a target NEO between companies under different regulations has severe repercussions, as a large percentage of the capital invested in these companies is bound in the large mining vessel and their business' success depends on the success of its mining mission. In terms of the potential value attainable through space mining, the success of such large-scale businesses quickly gains the attention of the respective national governments. The threat to the investors' ROI from conflicts about claims thus quickly evolves into an affair of the strategic interests of nations. For small spacecraft mining approaches, the possible impact of such a conflict is less severe as far less capital is bound up in a single spacecraft/mission. However, the limited delta-v capability of these spacecraft limits the number of accessible objects. In these mining scenarios, the probability of conflict increases because of the typically large numbers of spacecraft involved. This is even more important in a “first in time, first in right” environment, where all parties must rush to claim the most accessible objects.

One category of proposed regulatory mechanisms requires the mining company to pay a fee, rent or licence fee to be granted the rights for mining or the use of a resource (see for examples [16], [33] and [14]). From an investor or a mining company perspective, paying for a right if the regulatory regime is not globally accepted is not attractive. In that case, it does not provide additional security for the investment because the claims are still subject to conflict. Even where payment-based solutions for being granted these rights are part of a global regulatory system, this places an additional financial burden on the mining business, which is already a costly endeavour in itself.

In addition, where these are assumed to be in place globally, payment mechanisms are inherently another type of “first in time, first in right” situation. Without any prior effort being made towards the celestial body that is to be mined, except for payment by the company, this mechanism lacks suitability to prevent the formation of monopolies. Existing companies with high capitalization could acquire rights to the most valuable and/or easiest to exploit celestial bodies of a certain type, thus preventing other parties from entering the market by limiting either their potential ROI or by driving the initial investment required for successful exploitation so high that investment in this endeavour is unlikely in the first place. As a consequence, market entry for newly-founded companies is becoming progressively more difficult, even though resource exploitation of the already claimed bodies has not yet begun. The budget required to reach, claim and successfully exploit celestial bodies thus increases over time, making investments in companies not already active in the market less attractive for investors. This greatly favours the first movers or companies with the highest available budgets, leading to a “winner-takes-most” scenario as is currently the case in the digital platform economy.

Possible countermeasures could include a restrictive grant policy with case-by-case decisions or preventively high rents/fees, with the former making the mechanism somewhat non-transparent and tending to arbitrariness where further decision rules are absent. It is clear that this situation is a long way from a free-market situation. In addition, high rents/fees pose the question of how the revenue would be put to use and how an open market could be ensured despite these high rents/fees, especially considering market newcomers and start-up companies already dealing with the investment needed for technology development and facilitation of the mission. Another question would be the legal basis for such a rent/fee. If linked to the use of a right, the question is who holds the right in the first place and on what basis. Because of its incompatibility with Article II of the OST, this cannot be connected with state sovereignty. If required payment is merely an administration fee, a higher fee with the desired controlling effect would not be justifiable.

The case of significantly high fees or rents entangles the process of allocating mining rights and the revenue interests of the governing organization, often justified with the Moon Agreement. The fees are intended to satisfy the request for “equitable sharing by all State Parties in the benefits derived from those resources, whereby the interests and needs of the developing countries, as well as the efforts of those countries which have contributed either directly or indirectly to the exploration of the moon, shall be given special consideration” ([30], Article 11/7(d)). The case of the Moon Agreement offers two insights: as previously stated, it does not have many signatories, indicating that the contents of the treaty are controversial; however, its formulation indicates that the interests of less developed countries and their share in equity [15] will have to be considered in an international mining regulation if a consensus is to be reached.

A payment-based mechanism, however, is not positively inclusive for less developed countries. The mechanisms tend to merely redistribute some of the revenue to them, which, as Buxton [32] aptly states, may be detrimental to their development of capabilities for real participation in a more active role. The system proposed by Wojciechowski et al. [14] in particular seems ambiguous with the intended "small" fees to be put to use to support space programs of less developed countries (either the fees are high and thus can meaningfully support those countries, or the fees are low and the concept fails its intention) and the additional option of petitioning for resources from asteroid mining, which however can be rejected by the mining company. The latter point could even encourage countries to remain eligible for petitioning, should (in the unlikely event) the acceptance of petitions gain the status of a norm of behaviour or legal obligation. This clearly shows that the intention to recognize the spirit of the Moon Agreement is not easily satisfied and often fails its own ambition.

More generally, the very practical question arises of whether a payment-based mechanism would be in any way acceptable to be applied to a celestial body discovered by a company now seeking the rights for the mining of its resources from an organization that was, until the application, ignorant of the existence of the body. With objects still being discovered numbering in the hundreds or even thousands (more than 1,000 annually continuously since 2013 [48]), this is not an unlikely scenario.

In the case of Luxembourg's Law on the Exploration and Use of Space Resources, which is clearly not intended to be altruistic but geared to attract businesses and to profit from their future taxes, there are other sections that might be considered inconsistent with the OST. The need for permission from "the ministers" [33] and the payment of fees for being given the permission to explore a space object is in opposition to the OST freedom of exploration statement. The definition of space resources that can be owned, excluding only satellite communications, orbital positions and frequency bands, is as comprehensive as it might get. By its design, it even includes possible extra-terrestrial life. Whereas the US Commercial Space Launch Competitiveness Act attempts to define resources as strictly and as compatibly with the OST as possible, Luxembourg's Law on the Exploration and Use of Space is at least disregardful of the OST.

Cooper [15] approaches the demands for equitable sharing in the Moon Agreement differently. The allocation of parcels of space resources to nations via a lottery or selection process as previously described solves this problem by including all nations in the sharing process upfront and leaving the question of resource exploitation to national law. However, a lottery of predefined parcels or the selection of parcels ordered by the level of a country's development status after prior exploration does not necessarily ensure a satisfying degree of equity. It is not clear whether lottery parcels are accepted to be of random value or if the selection-based process uses parcels of equal value. In the first case, the outcome could be in opposition to the intention. In the latter case, a selection order is not necessary, since equality, rather than equity, would be ensured. If the parcels have different values, the countries doing the exploration would end up being the ones with the least valuable parcels. The issue of as-of-yet unknown celestial bodies is neglected. The concepts of parcel lottery or selection both seem not to be suited for achieving international consensus, since there will be disadvantages or inequalities for someone either way. However, consensus is necessary for such a concept to be viable.

The application of the 1872 mining law to space mining by Shaw [18] is remarkably simple. Imposing the requirement of a physical effort required prior to the admissibility of any application is a first measure to prevent the formation of monopolies by a simple buyout of mining rights as is possible in payment-based systems without the implementation of further protective mechanisms. The mechanisms for resolving conflicting claims as described by Shaw [18] are not entirely suited for avoiding conflict in asteroid mining activities. If a conflict arises, it has, by definition of the proposed regulatory system [18], to be a result of conflicting exploration attempts on the same celestial body. As stated above, distances and technologies involved in spaceflight make conflict, even under good intentions, entirely possible. Avoiding such conflicts in the first place would appear to be a better solution. Implications of the Moon Agreement are not reflected in Shaw's [18] proposed mechanism as a result of not being revenue-oriented for the governing institution of the regulatory regime.

Buxton [32], on the contrary, proposes the opposite extreme: if no international regulatory regime can be established that adequately represents the "heritage of all mankind" character of the Moon Agreement and provides less developed countries with an equitable share from mining activities, "the international community could agree to abstain from exploitation for a period of time" to prevent the upholding of the "ancient first in time, first in right". As a moratorium would also require international consensus to be effective, this is as unrealistic as an unanimously accepted international regulatory framework. As a result, the "barbaric" [32] principle of "first in time, first in right" would indeed emerge as reality.

Coming back to the space mining architectures presented at the beginning of this section, the interest of space mining companies is any kind of legal framework that ensures the legality of the business as a means to encourage investment and to avoid conflict with other companies over resources. Thus, a regulatory mechanism must unambiguously clarify who is allowed to mine where. Additional financial hurdles as part of the regulatory mechanism are to be avoided. From the perspective of a society that desires space mining to become reality, the same holds true. Investment in the space mining economy should be stimulated and not discouraged by the regulating regime. The prevention of conflict between nations as a result of conflict between businesses is also a common goal. Thus, rivalling exploration efforts should be prevented. Society's requirements for a regulation mechanism for space mining also include the prevention of monopolies in such a way that the space mining economy stays open and competitive. To likewise enable sustainable development, the interest of future generations should be considered in a non-restrictive manner. In order for such a regulatory regime to become reality, it must be able to achieve broad international consensus. For this reason, it must acknowledge the intentions of the Moon Agreement and reflect the desire of less developed countries to be able to participate in an equitable way. To be attractive to the state parties, a regulatory regime should be inclusive and offer benefits, rather than being restrictive.

The first hurdle in the serious development of a space mining economy is the question of how to regulate the acquisition of mining rights to a celestial body in compliance with the abovementioned characteristics. The author proposes to decouple this challenge from the desire to divide and redistribute profits from space mining to when profit is literally due. This very aspect is, as underlined by the low count of signatories to the Moon Agreement, a main source of dissent. The long time period associated with the development of a space mining economy and new insights into its emerging structure gained along the way will make possible the design of a suitable system to make space mining's benefits serve the welfare of all humanity.

However, besides money, there is another valuable asset in space mining that can be used in a rights acquisition mechanism that poses no additional financial hardships on mining companies and offers the opportunity for reconciling the development of a space mining economy, planetary sciences and future generations: the exploration data of a celestial body itself.

## 4. The data-centred approach to space mining regulation

### 4.1 Core description of the regulatory regime and mining rights acquisition process

The data gathered in the exploration of a celestial body is not only of value for space mining companies for informing them whether, where and how to exploit resources from the body in question, but also for science. The irretrievability of information relating to the solar system contained in the body that will be lost during resource exploitation carries a value for humanity and future generations and can thus be assigned the characteristic of a common heritage for all mankind as invoked in the Moon Agreement. This characteristic makes exploration data an exceptional and unique candidate for use in a mechanism for acquiring mining rights, because its preservation is of public interest and its disclosure in exchange for exclusive mining rights does not place any additional burden on the mining company. The following principles would form the cornerstones of the proposed regulatory regime and rights acquisition mechanism based on exploration data:

- Without preconditions, no entity has a right to mine the resources of a celestial body.
- An international regulatory body administers the existing rights of companies for mining a specific celestial body.
- Mining rights to such bodies can be applied for from this international regulatory body, with applications made public. The application expires after a pre-set time period.
- Mining rights are granted upon the provision and disclosure of exploration data on the celestial body within the pre-set time period, proposedly gathered *in situ*, characterizing this body and its resources in a pre-defined manner.
- The explorer's mining right to the resources of the celestial body is published by the regulatory body in a *mining rights grant*.
- The data concerning the celestial body are made public as part of the rights grant within the domain of all participating members of the regulatory regime.
- The exclusive mining rights to any specific body are tradeable.
- The scope of the regulatory body with respect to the granting of mining rights is not revenue-oriented.

The international regulatory body would thus act as a curator of a rights register and an attached database of exploration data. The concept is superficially comparable to patent law, where exclusive rights are granted following the disclosure of an invention to incentivize the efforts made in the development process. In the following section, the characteristics of such a regulatory regime are further discussed with respect to the formation of monopolies, market dynamics, conflict avoidance, inclusivity towards less developed countries and the viability of implementation.

**4.2 Discussion and means of implementation**

The proposed regulatory mechanism has advantages both from a business/investor and society perspective. First, it prevents already highly capitalized companies from acquiring exploitation rights in bulk to deny competitors those objects that are easiest to exploit or most valuable, which would otherwise be possible in any kind of pay-for-right mechanism and could result in preventing market access to smaller, emerging companies. Thus, early monopoly formation can be avoided.

The use of data disclosure for the granting of mining rights ensures the scientific community has access to this invaluable source of information. In this way, space mining prospecting missions can lead to a boost in research on small celestial bodies at a speed unmatchable by pure government/agency funded science probes. This usefulness to the scientific community could lead to sustained partnerships between prospecting companies and scientific institutions and could even provide a source of funding for the companies through R&D grants and public-private partnerships. The results of the exploration efforts contribute to research on the formation of planets and the history of the solar system and provide valuable insight for space defence against asteroids. The transition of exploration from a tailored mission profile with a purpose-built spacecraft to a standard task in space flight would also lead to a cost reduction of the respective exploration spacecraft through economies of scale. This describes the very benefits Elvis [24] and Crawford [25] imagined as possible effects of a space economy. Thus, there is an immediate return for society from the exploitation rights grant. It also reconciles the adverse interests of space development and space science as laid out by Schwartz [26]. It ensures that, by exploitation, information contained in celestial bodies is not lost for future generations.

The application's time period should not be set in a manner that creates a situation that can be abused through the potential for stockpiling inventory rights. Rather, it is intended to prevent conflict in the phase before exploration data gathered by a mission as a prerequisite to the mining rights grant is available. In other words, only one exploration effort at a time can be permitted for a specific body. The time frame between the application and the granting of mining rights (meaning: availability of the required exploration data set) should be tight and should only consider necessary exploration time on site, transit time and possibly a reasonable launch preparation and data processing markup. These contributors to the application period make it clear that the timeframe could be dynamic and individualistic, depending on the exploration target (transit time, duration of exploration) and the technology of the exploration probe (transit time). After the expiration of the application period, applications for the exploration target would again be permissible. To prevent the abovementioned stockpiling of inventory rights, credible proof of an imminent exploration intention would need to be part of the application process, e.g., a fixed launch contract or the advanced build- status of the exploration probe. Such a mechanism would not contradict the statement in the OST that outer space shall be free for both exploration and scientific investigation. Applications would not apply to purely scientific exploration. An application would only be necessary as a prerequisite for mining. Even resource prospecting could take place without an application (for whatever reason), with a subsequent application comprising *in situ* data already gathered. For such cases, the application process would need to provide a short period for objections to enable the secretive explorer to make their efforts public. The publication of the application for the mining rights, which is nothing more than a statement of intention to explore, thus provides a strong measure for avoiding conflict.

The transparency of where exploration spacecraft are located and, at a later stage, where mining activities take place, provides additional benefits for the sustainable use of space, trust-building and deterrence against malign misuse of mining technology. Involuntary spacecraft collisions of competitors in deep space are prevented by the reduction of exploration efforts at the same destination through the application for mining rights by one applicant at a time. As pointed out by Newman and Williamson [20], this is relevant because space debris does not de-orbit in deep space as in the case of LEO. Deep space may be vast, but the velocities involved mean that small debris particles are no less dangerous. Considering NEO mining with fleets of small spacecraft, malfunctions and/or destructive events could create debris clouds crossing Earth's orbit around the sun on a regular basis, presenting another danger to satellites in the Earth's own orbit. Thus, by effectively preventing the collision of two spacecraft, one source of debris creation can be mitigated through this regulation mechanism. With respect to Deudney's [11] scepticism of asteroid mining and the dual-use character of technology to manipulate orbits of celestial bodies, it has to be stated that this potential is truly inherent to asteroid mining. An asteroid redirect mission for scientific purposes was pursued by NASA [49] before reorientation towards a manned lunar mission. In one way or another, each type of asteroid mining will require the delivery of the targeted resource to a destination via a comparable technology as formerly envisioned by NASA, be it as a raw material or a useable resource processed *in situ*, even if this is not necessarily through redirecting the whole asteroid and placing it in a lunar orbit. However, in order to be misused as a weapon, space mined resources would have to surpass a certain mass threshold to survive atmospheric entry at the target. This seems unfeasible for currently discussed mining concepts using small scale spacecraft as described in this paper. Redirecting larger masses or whole asteroids would require far more powerful mining vessels or small amounts of thrust over long periods of time. The continuous (for a mining activity), untypical change in the orbit of an asteroid would make a redirect attempt with hostile intent easily identifiable, effectively deterring such an activity in the first place by ensuring the identification of the aggressor long before the projectile hits its target. The proposed database would provide a catalogue of asteroids with exploration and mining activities in place that should be tracked more closely due to their interaction with spacecraft. This would, in fact, be necessary *per se* as a precaution to avoid catastrophic mishaps, such as the accidental change of a NEO's orbit to intercept Earth by changing its mass through mining.

The data-driven mechanism also addresses another potential risk of an emerging space-based resource economy: the reinforcing of the incontestable market positions of the market leaders based on an advantage in knowledge unattainable by new competitors. Explorations of celestial bodies will have a likelihood of failing from the perspective of the actual value of the explored object vs. the expected value. In this case, the costs of exploration would be a loss for the company, that could be significant and possibly ruinous considering the budgets needed for contemporary space agency-led exploration missions. Sanchez and McInnes [5] explicitly mention the uncertainties in object distribution models used in their asteroid distribution study and for the conclusions drawn concerning reachable object masses with certain delta-v capabilities of spacecraft. With an increasing number of exploration missions led by a company, the data collected may lead to better in-house models and a higher probability of exploring the "right" body for the value/resources aimed at. This may even provide information on the best spacecraft designs for matching the targeted objects' orbit distribution. This risk is known from the digital platform economy, where the companies that are now leading have an uncatchable advantage in user data compared to market newcomers, translatable to a more refined and comfortable user experience, attracting additional users and thus offering superior services to business customers. This also holds true for space mining companies. Through their lack of legacy mission data, market newcomers would have a higher risk of misallocating exploration missions, making investments in those companies riskier than in established companies. To avoid the preferred investment in a single or a few companies, the risk of the investment in emerging companies is reduced by the proposed mechanism by ensuring the equal access to data for market newcomers and established companies alike. From a prospecting risk perspective, the market entrance of a new company becomes progressively less risky for investors with increasing amounts of publicly available exploration data, promoting progressive and dynamic development.

The long lead times of asteroid mining ventures coincide with a long timeframe for an ROI. The exclusive mining rights granted after the exploration phase give investors security half-way into their space mining endeavours. The proposed tradability of the rights offers an early chance of gaining investment proceeds. It also offers the possibility of new business models: the classical asteroid mining system concept, as shown by Andrews et. al. [43] for example, covers exploration, exploitation and resource transfer. This maximizes the investment needed to develop the technologies required for the entire process chain. Giving exploration a value could lead to a division of labour. Dedicated prospecting companies could emerge, providing mining companies with the data and mining rights to a body with the specific resource profile they are seeking. In this way, the investment needed for a successful mining endeavour is divided between different specialized companies. This considerably reduces the risk for investors as well as the investment needed for a company to meet their business goals, which are now aimed at just a particular part of the overall space mining endeavour. Third party applications for mining rights should be possible to allow a mining company to subcontract to exploration companies. Such a regulatory mechanism design would also be more easily inclusive of less developed countries. They could simply contract exploration missions made affordable through economies of scale to become part of the emerging space mining economy as holders of tradeable mining rights. Through a wise selection of such missions' targets, they could gain powerful positions of influence.

The proposed mechanism also serves the need to accelerate exploration that was noted by Elvis and Milligan [27]. According to them, their proposal to limit resource use in the solar system to 1/8$^{th}$ of the overall usable resources requires as a prerequisite knowledge of what is available, where and at what cost. The "on average 15 missions per decade" [27] of planetary exploration missions would not serve this purpose. The privatization of exploration and publication of the results, which is incentivized by the granting of mining rights, would accelerate space exploration in general and allow for an overview of currently-known resources based on the exploration data, which would otherwise be restricted to internal use within the private companies. In addition to this "awareness" advantage, there is also another economic benefit: the entirety of the disclosed data on celestial bodies and their resource content would allow for an overview of the resources currently claimed and available for mining. This would enable dynamic pricing for the trade of mining rights based on the accessible supply and demand of the associated resources in relation to the necessary exploitation efforts and timeframe of availability according to mission timelines and orbital dynamics.

With respect to realizing the proposed regulatory mechanism as a functional international regulation, one might argue that recent times show more of a decline in international order than a tendency towards resolving longstanding debates. The core description of the regulatory regime in section 4.1 is an aspirational, idealized version. While an all-encompassing international consensus is desirable, the regulation mechanism can, at first, only be set up by a small number of states. In contrast to many of the other proposals, the data-centred approach to space mining regulation is not restrictive, but rather incentivizes exploration. Joining this initiative would not only be beneficial for providing legal clarity but is also attractive from a business perspective: being a member state would ensure access to the entirety of the exploration data already available and provide domestic companies with this knowledge. It is also attractive for less developed countries or countries without the technological capability to partake in exploration and mining efforts themselves, since it allows them to actively participate in the space mining economy as owners and traders of mining rights that offer "equitable sharing ... in the benefits derived from those resources" as required in the Moon Agreement [30] beyond their more abstract benefit from scientific advancements.

### 4.3 Open questions and limitations to the concept

In this first rudimentary form, the proposed regulatory mechanism refers to small-scale celestial bodies. However, asteroids have a wide variety of sizes, leading up to the large planetoids of the asteroid belt. The question of resource exploitation will also, if not at first, be relevant for the Earth's moon and will undoubtedly become relevant for other planets alike. This reflects the current lack of an undisputed definition for the term "celestial body" in the international law governing space activities and the academic literature, despite its use in the OST as discussed by Su [28]. It seems sensible to put an upper limit on the size of celestial bodies whose resources can be claimed for exclusive exploitation by one company. For larger bodies, the concept may be expanded or applied to a limited surface area, or a consortium of companies could be formed to apply for exploitation rights on larger bodies, thus sharing in the exploration effort. The decision concerning the maximum size of celestial bodies for which exclusive exploitation rights could be granted will require thorough discussion. Elvis and Milligan [27] pointed out the same need for applying their 1/8$^{th}$ principle, as did Shaw [18] for applying the 1872 mining law to asteroids.

It can be argued that exclusive mining rights should be limited in time after the right has been granted. In this case, the time frame of mining activities should be considered and the time limit be specified in decades, or even centuries. It has to be taken into account that mining rights granted but unused over a longer period of time still have a positive effect on the mining economy in general. They provide information about resource availability through the required disclosure of data that would have taken place to acquire the mining right in question. Expiry of the grant should also only be possible where no resource exploitation is taking place at the end of the grant's time frame and should otherwise be extended. The impact on market dynamics, investment stimulus and inter-company relations must be carefully considered.

While supporting the interests of future generations through preserving information contained in the explored asteroids and possibly also comets, avoiding space debris through collision prevention and contributing to an overview of the resources available in the solar system in the spirit of Elvis and Milligan [27], the proposed regulation mechanism can be seen as contributing to the sustainable development of space activities. However, Iliopulous and Esteban [19] note that the understanding of sustainability varies between authors. It either "limits the risk of human extinction, minimizes space pollution or environmental degradation in space (such as space debris) and/or increases the welfare of humanity on earth" [19]. Efforts made today to reduce orbital debris creation by advocating soft law approaches, e.g., by Palmroth et al. [21] for LEO satellites, should be applied to deep space spacecraft too, as already proposed by Iliopoulos and Esteban [19]. Other proposals are not that easily aligned with the concept of space mining. Chrysaki's [22] voluntary code of conduct for sustainable space activities is very specific in its proposed content. It requires companies to "adopt measures to prevent environmental degradation in outer space, celestial bodies and their orbits" (from "The principle of precaution", [22]), or to refrain from these activities if this is impossible. Depending on the interpretation of "degradation", this could practically exclude the possibility of space mining, since it inherently alters celestial bodies by changing their mass and thus their orbits. In light of the increasing importance and awareness of sustainability in both the public discussion and policy-making, the question of how to define a sustainable space mining activity remains to be answered, and the answer will, again, depend largely on the author's definition of sustainability.

Because the regulation mechanism presented here is intended to settle and allocate rights without revenue interest for the governing institution, dealings with profits from space mining itself are not addressed here. A first important starting point would be to implement learnings from the digital platform economy and prevent the creation of tax havens or their respective equivalents. As mentioned above, some proposals are already available in the literature (see, e.g., [16]), often as part of a regulating mechanism. The author encourages the scientific community to develop ideas that consider not only the implications of the Moon Agreement but also the interests of space mining businesses in light of current international politics. If proposals for space mining are not rooted in realpolitik, the mechanism that will rule the foreseeable future will be that of "first in time, first in right", with all its associated implications for space development and international security.

## 5. Summary

The review of technical space mining architectures highlights the fact that a mere clarification of the legal status of space mining to remove the negative impact of uncertainties for investment is just the first step. The investment requirements for a space mining endeavour are very high and the time period for an ROI long. An ideal regulatory mechanism must be designed in such a way as to not create additional burdens for the mining company but rather to support and advance their development. This includes the avoidance of conflict, between both the companies and their countries of residence alike.

With respect to the proposals in the literature, a conflict exists between the authors' intention to provide a legal framework and mechanism to support the development of space mining and the effort required to take into consideration the implications of both the content of the Moon Agreement and its lack of widespread acceptance.

To resolve this conflict, the step of securing mining rights to a celestial body was separated from the revenue-oriented interpretation of the equitable sharing of recovered resources, while still honouring the spirit of space as a "heritage of all mankind" by enabling less developed countries to actively participate in the process.

The gathering of exploration data as a natural step in the space mining process chain and their publication within a regulatory regime's domain are proposed as a mechanism to secure exclusive mining rights that does not impose additional burdens on a mining company.

This mechanism does not only benefit space mining companies, but also science and thus humanity. The wealth of data contained in the celestial bodies in the solar system is preserved for future generations and made public to support the planetary sciences, to help protect humanity from space-based threats and to prevent data-based hurdles for later market entrance to ensure a progressive and diverse mining economy. It allows for a division of labour within the mining economy, providing potential for specialized companies that can be contracted for exploration and mining rights acquisition. This point offers a chance for less developed countries to become integrated in the regulatory regime in an active role, as it provides the possibility for acquiring and trading mining rights without a domestic space industry.

Because the concept offers benefits beyond mere clarity on the legality of space mining, it is inclusive. Even if initiated by a small number of member states, the regulatory regime would become progressively more attractive to other states, both to those actively seeking to mine themselves through the prospect of access to the entirety of exploration data available and to less developed countries wishing to participate in the growing market for mining rights and their trade between countries and companies by contracting their own exploration missions.

Space mining will undoubtedly be necessary to sustain a spacefaring civilization and may be the very key to establishing one. Careful consideration must be given to the design of a regulatory regime that governs such activities, as it will define what kind of society mankind will become.

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