LEGAL PROPOSALS FOR DEBRIS RECYCLING TO IMPROVE SPACE RESOURCES MANAGEMENT AND SUSTAINABILITY

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ABSTRACT

Debris threatens the sustainability of space activities. *Ex ante* mitigation strategies (satellite design, collision avoidance) and *ex post* disposal methods (deorbiting, graveyard orbits) exist, but no clear regulations promote and/or govern space debris recycling. However, orbits are limited resources (ITU Convention, Art. 44.2); thus, given recent legal developments, like EU's Regulation 2024/1252 on Critical Raw Materials supply, space actors should better integrate recycling into End-Of-Life (EOL) strategies to enhance resources' sustainable use. This paper examines International Space Law (ISL) treaties, soft-law instruments and national regulations, to assess EOL requirements or potential rules on debris recycling. Findings show that, despite growing interest in environmental protection and sustainable resource use, no measures currently promote or regulate debris recycling**.** In response, *new practices* –inspired by ISL– could emerge, together with *policy measures* promoting (national) market-based incentives: recycling benefits, e.g., alongside a structured system including preferential treatment and a dedicated registry to ensure efficiency.

1. INTRODUCTION: ASSESSMENT OF THE SPACE DEBRIS PROBLEM

Space debris is commonly defined as a non-functional artificial object –including related fragments– in orbit, which poses a major threat to space activity. Despite the growing significance of this issue, legal theory has yet to establish a universally accepted definition. Instead, a number of practical descriptions have been proposed by key organizations, such as the widely cited definition in the *IADC guidelines*, which characterize space debris as "all manmade objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional [9: 3.1]". Importantly, beyond such a general approach, debris could be further classified into distinct subcategories (e.g., total debris, tracked debris, catalogued debris etc.), as is underlined in recent reports [30].

In this context (i.e., although no clear universal consensus exists on the definition of this concept), a concrete and pressing need to address the issue nonetheless emerged, leading to steps that are aimed at promoting and adopting *practical solutions*. The responses mainly focused on key *ex-ante* measures (Satellite Design for Debris Mitigation; Automated Collision Avoidance), rather than on *ex-post* strategies (End-of-Life Disposal plans / EOL); the latter being defined as operations involving deorbiting defunct objects for atmospheric reentry, or relocating them to a "graveyard orbit".

Still, this proved to be an insufficient response, notably given that: (i) orbital slots –including graveyard orbits– are limited natural resources, based on Article 44.2 of the ITU Convention [17] (therefore, although relocating the defunct satellites to graveyard orbits has been a widely adopted practice, these regions, too, will eventually face congestion); and (ii) there is growing worldwide interest towards sustainability, including the responsible use of natural space resources. Following on from the above, integrating the idea of recycling –especially given the strategic importance of Critical Raw Materials (CRM), as outlined in Regulation (EU) 2024/1252 [40]– into debris management is increasingly being discussed. In other words, the question arises as to *which measures would most effectively address the debris management issue, taking into account the recent legal developments (in EU law), as they may potentially mandate the integration of recycling.*

To first lay out the framework for the analysis below, it is necessary –yet only for the purposes of this paper– to introduce the concept of a *point zero*, defined as the moment a space object becomes non-functional and is

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therefore classified as debris. This point may thus mark the transition from *ex-ante* to *ex-post* measures in debris management. *Ex ante* measures are preventive, adopted before the generation of debris: they aim to mainly limit debris creation before it occurs (e.g., they may include satellite design and/or operational protocols), or plan the management of debris via End-of-Life (EOL) disposal plans (deorbiting and graveyard relocation). However, these measures do not address debris already in orbit. Once an object reaches "point zero," the focus shifts to *ex post* responses – i.e., measures that deal with existing debris: these include tracking and collision avoidance, developing Active Debris Removal (ADR) technologies, and implementing remediation policies.

International Space Law (ISL) and soft law instruments do not refer to any "point zero" marking when a space object becomes debris, although the distinction between *ex-ante* (preventive) and *ex-post* (remedial) measures is widely recognized. However, such a distinction offers a framework for understanding policies and identifying regulatory gaps, while evaluating potential solutions. Indeed, from a policy perspective, two elements are key: the *timing* of the measure (whether it is applied before or after debris is created – i.e. whether it is an *ex-ante* or *ex-post* measure), and the *nature* of the action itself (i.e., deorbiting or relocating objects to a graveyard orbit). Clarifying such aspects may help assess what a given measure contributes to –in particular, whether it aims to prevent future debris *or to manage existing debris*– thus to what extent it offers a solution to the existing issue.

Building on this framework –and following on from the introduction (see, Section 1)– the paper initially explores international and national rules of law governing space activities to assess whether the debris issue is addressed (Section 2). It then analyses the substance of existing measures, highlighting the current preference for *ex ante* approaches among space stakeholders (Section 3); this, in turn, exposes regulatory gaps that have now sparked growing interest in *ex post* rules and actions to manage existing debris, as presented in Section 4. Importantly, this evolving focus has coincided with broader efforts to advance recycling solutions as a more general approach to resource sustainability, a shift reflected in recent EU legislation that both redefines priorities and lays the groundwork for applying similar recycling principles to space debris (Section 5). The paper concludes with final observations in Section 6.

2. EXISTING FRAMEWORKS & GROWING AWARENESS OF THE DEBRIS PROBLEM

All activities in outer space –commonly considered to begin at the *Kármán line*, a widely accepted but not formally defined boundary [27]– are primarily governed by the core International Space law (ISL) treaties, which were adopted during the 1960s and 1970s. In addition to these five fundamental treaties, ISL also includes soft law instruments (i.e., UN resolutions and international guidelines) while, to complement the above or allow for their implementation, national space laws have been enacted in several States. Therefore, national space laws will be examined as well, as they may provide detailed rules, including in reference to the debris problem.

2.1 International Space Law treaties

The five foundational treaties of international space law include: the *Outer Space Treaty* (OST) [1], adopted by the UN General Assembly Resolution 2222 (XXI), and establishing basic principles to regulate the outer space activities; the *Rescue Agreement* (adopted in1968) [2], which ensures the safety of astronauts and the return of all space objects; the *Liability Convention* (1972) [3], which lays down liability rules for damage caused by space objects; the *Registration Convention* (1975) [4], mandating the registration of space objects to aid in their identification and tracking; and finally, the *Moon Agreement* (1979) [5] (the latter, which came into force in 1984, sought to regulate the exploration and use of the Moon and other celestial bodies but remains largely ineffective due to its limited ratification; only around 18 States are parties). As a result, any rules on space debris, their management or other related matter, should either be explicitly established in the said fundamental treaties or derive from them.

Interestingly, although first concerns about space debris date back to the late 1950s [6], the term itself –and the legal concept it represents– is absent from all the above core treaties. Indeed, no provision explicitly addresses or prohibits the creation of space debris [28], leading to an ongoing debate even about whether a debris should be classified as a "space object" or a "component part" (the only terms used in ISL), or whether it constitutes an entirely separate legal category [7; 8; 28] – which not only fails to solve the debris issue, but also significantly complicates efforts to address it.

Hence, to bridge this regulatory gap, scholars proposed broad interpretations of existing treaty provisions. For instance, Article IX of the OST –which obliges States to take measures in case their space activities may result in potentially harmful effects– could be used, coupled with other provisions of the OST (such as Article I) as a legal basis "… to avoid debris creation and ensure that space remains usable for all countries now and in the future" [43]. Moreover, Article VI of the OST –establishing State responsibility for all space activities– is also considered relevant, particularly in cases where debris results from negligence, or even failure to adhere to the current best practices e.g. to avoid potential damage [8]. Similarly, the Liability Convention, which complements the OST by regulating liability for damage caused by an object (in space), could be invoked to treat the creation of debris as a fault (given its potential to cause a collision) [3: Art. III]; and the Registration Convention**,** by requiring States to maintain registries of space objects, could aid in debris tracking and identifying the owners, although ownership determination is in this case challenging [7] (*n.b.* – the limited ratification of the Moon Agreement weakens its role in creating obligations to support debris mitigation efforts).

Thus –overall–, ISL treaties *lack explicit rules* on debris, even more on incentivizing EOL disposal or recycling measures (lack of rules on such urgent issues is a reason why many scholars argue that these decades-old treaties are inadequate to address modern challenges). However, international space law extends beyond binding treaties; indeed, non-binding soft law instruments also play a key role in shaping governance frameworks, and they must be examined for their complementary regulatory impact.

2.2 Soft Law instruments and measures

As the debris issue is neither mentioned nor regulated in ISL treaties, space actors advocated for the enactment of non-binding frameworks aimed at filling this normative gap. As a result, soft law guidelines were adopted to establish principles for space debris management.

To mention only major instruments in the order of their adoption, the *Inter-Agency Space Debris Coordination Committee (IADC) Guidelines* were initially developed (in October 2002 and soon revised –in 2007– [9]), by an intergovernmental body comprising key space agencies; they provided technical recommendations on spacecraft design and operation, while they also added (based on a recent revision, in 2025 [44]) measures to additionally regulate end-of-life (GEO) disposals to minimize space debris. In the same line of thinking the *UN Space Debris Mitigation Guidelines (2007)* [10] were issued –by the UN Committee on Peaceful Uses of Outer Space (UN COPUOS)– to mainly outline measures to limit debris generation, while promoting post-mission disposals, to prevent collisions. Following the above instruments, the *Long-Term Sustainability Guidelines (2019)* [11] were released by the UN COPUOS, to emphasize sustainable practices in space operations, focusing on preventing the further accumulation of space debris as well as fostering international cooperation. Finally, the *ISO Standards* [12] should also be mentioned, as they created technical standards (see ISO 24113) and provide best practices for debris mitigation, *inter alia* – in general, these guidelines are broadly followed by national space agencies and/or by private entities, promoting some level of coherence in space debris mitigation, though full uniformity remains limited.

Indeed, despite their adoption, these instruments do not impose legally binding duties, either on the States or on private operators. Compliance is voluntary; hence, their implementation depends on national policies, industry standards, and/or the willingness of individual actors to incorporate such recommendations into their operational frameworks.

At the same time, States are clearly expected to exercise *continuous oversight* over space activity, as stipulated in ISL [1: Art VI]. As a result, discussions on transforming the above guidelines into norms and/or binding rules of law gained momentum, which prompted several national legislators to take initiatives in that direction.

2.3 Rules of national (space) law on debris

Stricto sensu, States are not required to adopt national legislation on space matters. Still, they are obligated to authorize and continuously supervise all space activities, as set out in Articles VI and VII of the OST. Therefore, the practical need for regulation led them to adopt laws implementing these provisions, along with Article VIII, and also in alignment with the Liability Convention, the Registration Convention and the Rescue Agreement [see 3; 4; 2].

Importantly, while States were required –both by treaty provisions and by practical necessity– to adopt national laws regulating and implementing obligations related to the authorization and continuous supervision of space activities, there is *no direct obligation* under ISL treaties (for them or space operators) to adopt specific measures for the protection of the space environment. In fact, only one provision of the OST [1] addresses environmental concerns: Article IX, which states that "States (…) shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, adopt appropriate measures for this purpose".

Following on from that, it has been argued that ISL does not impose concrete or binding obligations on States or on space operators to protect the space environment. For example, it has been noted that "when it comes to the protection of the environment, there are no provisions under ISL that stipulate defined obligations with respect to the environment" [13], given that ISL has established no clear or binding framework to address environmental issues [14]. Such a view is mainly based on the limited scope of Article IX of the OST –that is, furthermore, the only article directly addressing environmental concerns– which sets out only a general duty for States to conduct outer space exploration in a way that avoids any harmful contamination of celestial bodies or adverse changes to Earth's environment. As such, its application is limited to specific cases, mostly aimed at prohibiting the release of harmful microbiological organisms [15].

However, this approach is gradually evolving, based on two considerations: (i) Art. I and III of the OST subject space activities *also* to general international law, which – by extension– additionally includes, now, international environmental law ("through Article III of the Outer Space Treaty, states are likewise bound to international environmental law" [13]); while (ii), Article IX, though narrowly worded, is increasingly seen as a *foundational step* toward environmental protection in outer space, in general. Indeed, despite specific wording, Article IX has been interpreted as establishing a "proscriptive positive legal obligation" for States [15] and operators to avoid harmful contamination and to engage in international consultations prior to *any* activity that could cause an environmental harm. Thus, from this perspective Article IX may be regarded as a legal basis for advancing space law towards the protection of the space environment, and it could be argued that States must safeguard outer space and establish adapted rules to that effect.

Building on this framework, and based on the increasing recognition of the obligation to implement both concrete and effective environmental protection measures, *as a general rule* [16] –together with growing interest in the sustainable use of natural (space) resources, especially in light of Article 44.2 of the ITU Convention [17]– there is now broader agreement among the international community that States should *also* ensure the protection *of the space environment*.

As a result, more States have begun adopting legislation focused on space environmental protection. By way of illustration, several national legislators introduced an obligation to submit Environmental Impact Assessments (EIA) to gain approval for conducting space activities, as is the case for numerous terrestrial activities [18] (one should note that the obligation to submit an EIA is also grounded in draft Article 4 of the Sofia Guidelines [19] –which explicitly mandates that outer space activities should not cause any environmental harm to the Earth or to outer space– coupled with draft Article 7, explicitly mentioning the above obligation to submit an EIA).

In other words, national space laws increasingly follow a broader trend of including environmental protection measures –either by requiring EIAs or by setting general measures against harmful environmental impacts [13]– thus showing a stronger commitment to sustainability in space.

Therefore, we may observe that ISL lacks specific rules to address the debris issue, while soft law instruments, though more detailed, remain non-binding and fail to ensure consistency; in parallel, national laws, although binding, also do not achieve uniformity. Still the next step should be to examine the substance of said rules –derived from the interpretation of ISL, explicitly outlined in soft law, and/or codified in the national laws– to assess their effectiveness in managing the existing debris, including their removal and/or recycling. This analysis will clarify whether a trend or practice is forming that could support future developments at the international level, aimed at regulatory coherence and promoting workable solutions, including recycling.

3. CONTENT OF THE RULES ADOPTED – THE FOCUS ON *EX ANTE* MEASURES

Having established the growing awareness of the need to protect the space environment, and to address the space debris problem –reflected in the increasing adoption of legal, or soft law instruments– it is important to examine *the content of these rules* at the international, regional, and national levels; the goal being to identify whether a general trend is emerging that could shape future legal developments.

As noted, international space law (ISL) does not directly address space debris, and broad interpretations of such provisions remain insufficient, leaving little to assess within this framework. However, as the debris problem escalates –i.e., due both to uncollected debris of space missions and the growing use of outer space– raising the risk of collisions and the potential for a cascading effect (Kessler syndrome) [20], some progress has been made through soft law instruments and national legislation. Hence, these now represent the main legal avenues for addressing debris. It is therefore useful to explore their content more closely, particularly to assess whether they address the management of debris once it has already been created.

3.1 Emerging Trends in Soft Law Instruments

Space debris has become an important challenge for *all* stakeholders. However, those directly involved in space operations –namely, space agencies and operators– have been the most directly affected. Indeed, unlike States (who in essence address space governance issues from an administrative level while having the financial capacity to absorb potential losses), operators and agencies face operational risks firsthand, namely through their *direct* involvement in missions and infrastructure deployment.

As a result, space agencies have played a leading role in shaping (normative) initiatives and efforts to address the debris issue (see Section 2.2), while practical interest in mission safety and sustainability has also driven them to support and comply with emerging standards. Crucially, many of these initiatives have been backed by States, leading to the adoption of important *soft law guidelines* that reflect a growing collective commitment to tackling this global concern.

Overall, these soft law instruments appear to principally focus on preventing debris generation and on planning its disposal once a space object becomes non-functional. They all include guidelines on mission design, collision avoidance, relocating defunct satellites to the graveyard orbits, or allowing natural deorbiting over time. Hence, in truth, they mainly emphasize *ex ante measures* –those that are planned before launch. In terms of content, such measures principally consist in relocating or deorbiting objects to remove them from active orbit, often leaving them in graveyard zones indefinitely; which approach reflects a clear strategy of managing debris primarily by (simply) moving it to designated, less disruptive areas.

Thus, by way of illustration the *Space Debris Mitigation Guidelines* developed by the *Inter-Agency Space Debris Coordination Committee (IADC)* [9] recommend that all satellite operators design and plan missions with a clear End-of-Life (EOL) disposal strategy, e.g. by "Removing spacecraft and orbital stages that have reached the end of their mission operations from the useful densely populated orbit regions" [9: Introduction, point (b)]. In this context, the guidelines established (mainly) general rules, such as the need to include a "plan for disposal of the spacecraft and/or of orbital stages at end of mission" [9: point 4.4], essentially focusing on disposal solutions ("Spacecraft that have terminated their mission should be manoeuvred far enough away from GEO so as not to cause interference with spacecraft or orbital stage still in geostationary orbit." – point 5.3.1, and point 5.3.2). In the same line of thinking, the *COPUOS Space Debris Mitigation Guidelines* [10] emphasized the necessity to deplete or render safe all the on-board sources of stored energy –such as *inter alia* propellants, batteries, and any pressurized systems– when they are no longer required, mostly to facilitate post-mission disposal and to prevent the risk of explosions or even fragmentation that could generate additional debris [10: Guideline 5]; the need to limit the long-term presence of a spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) area [10: Guideline 6], as well as their long-term interference with the geosynchronous Earth orbit (GEO) region, after the end of their mission [10: Guideline 7]. Finally, the *Long-Term Sustainability Guidelines* [11] emphasized the necessity to control the removal and safe disposal of defunct spacecraft and launch vehicle stages in order to minimize debris, by mentioning that, in low-Earth orbit (LEO), space objects should be deorbited or moved to orbits to avoid their long-term presence in LEO; while for geosynchronous Earth orbit (GEO), space objects must be relocated to orbits above GEO to prevent interferences and reduce collision risks [11: Guideline A.4.6]. At the same time, it mentioned that States and/or international organizations should also encourage manufacturers and operators of objects to substantially "limit the long-term presence of space objects in protected regions of outer space after the end of their mission", and "share their experiences and information on the operation and end-of-life disposal of objects", in order to support the long-term sustainability of all outer space activities [11: Guideline B.8.2].

Therefore, soft law instruments provide important space debris mitigation measures; be that as it may, their lack of binding force *limits their effectiveness* in supporting ISL. Moreover, they mainly focus on *ex-ante* actions –planned before a space object becomes non-functional– and they emphasize relocation to graveyard orbits as the primary EOL strategy. Thus, the challenge of managing existing debris and reducing the current burden remains *unaddressed*, making it necessary to examine national legislation and assess whether more specific and binding rules have been adopted to promote new, and potentially more effective approaches to EOL debris management.

3.2 Measures adopted at the national level

As noted, States are not legally obliged to adopt national space laws; yet many have done so to better implement ISL, protect their space activities, and safeguard assets under their jurisdiction. Hence, in this context, a number of national measures have been introduced to address the space debris issue; however, they largely mirror soft law approaches, since they prioritize *ex-ante* regulations and emphasize disposal strategies.

Specifically, many States require operators to plan End-of-Life (EOL) disposal in advance, in conjunction with preventive measures like debris or collision avoidance.

For instance –to only mention a few examples–, the US adopted laws to encourage the responsible disposal of space hardware (see e.g. *US Government Orbital Debris Mitigation Standard Practices*, 2001 – [21]), and to also promote the adoption of End-Of-Mission (EOM) plans, including measures to ensure the monitoring of critical spacecraft and launch vehicle stages for conditions that may impact end-of-life disposal manoeuvres (see *NASA Procedural Requirements (NPR) for Limiting Space Debris*, point 3.3 – [22]). In a similar way, the Russian Federation established the obligation to implement end-of-operation measures, highlighting that "spacecraft and launch vehicle orbital stages, operating in geostationary orbit (…) *shall be deorbited* above the geostationary orbit so as to avoid collision with the space objects which continue to be in geostationary orbit" (emphasis added); while the orbit of spacecraft should be designed so that they all naturally re-enter the Earth's atmosphere and burn up within 25 years, i.e., after the end of their operation [23]. In the same vein, Japan mandated that "the satellite control plan must include (…) end-of-life measures," which must be described and may consist of one of the following: namely, (i) deorbiting and re-entry to Earth, with public safety at landing ensured; (ii) deploying the satellite into a "graveyard orbit"; or (iii) deploying the satellite into the orbit of another celestial body, or allowing the satellite to fall into the celestial body [24]. Eventually, China's recently adopted *Interim Measures on The Administration of Permits for Civil Space Launch Projects* (2002) [25] clearly mention that all space operators must submit a report on how to avoid space debris to obtain authorization for a space activity, based *inter alia* on safeguards outlined in the I.A.D.C. recommendations [26].

Parallel to that, at the EU level, ESA, together with four national space agencies, formulated the *European Code of Conduct for Space Debris Mitigation* (in 2004) [45], which was later endorsed by major space agencies and introduced specific measures for end-of-life passivation (point 4.2.1 and point 5.2.1); de-orbiting/re-orbiting of objects (point 4.2.2, point 4.2.3); disposal manoeuvres (point 5.2.3), etc. More recently, the EU further adopted the *Zero Debris approach* (endorsed by Member States in 2022 [46]) and updated two fundamental documents regulating space operations in detail [47]: the new *Space Debris Mitigation Policy* as well as the *Space Debris Mitigation Requirements*. Importantly these two updates mandate shorter disposal phase durations in LEO, a high probability of successful disposal, and the adoption of collision avoidance as well as space traffic coordination standards [47]. In this context, the *Zero Debris Charter* encourages a global commitment to space sustainability, setting an ambitious goal of achieving debris neutrality by 2030 [47].

Overall, although national and regional laws are binding –unlike soft law guidelines– they still only apply within their own jurisdictions. This jurisdictional scope results in regulatory fragmentation, as each State develops its own normative framework, hindering uniformity at the international level. Hence, while national laws share the goal of protecting the space environment and managing debris, important divergencies in their implementation create inconsistencies that complicate global mitigation efforts.

More critically, though, national laws also focus on *ex-ante* measures, requiring operators to act before debris is created. They primarily mandate the disposal of defunct satellites into graveyard orbits and/or impose design and operational standards to minimize debris generation.

Hence both soft law instruments and national legislation place limited emphasis on *ex-post* measures or actions, like removing or managing *existing* space debris. This reveals an important gap: no current framework offers effective solutions for debris already in orbit. Instead, current rules focus on preventing further accumulation, mainly in the protected areas, often using quantifiable thresholds like the evolving 5-year disposal rule for the LEO [47]. Still, this preventive approach alone cannot ensure long-term sustainability, particularly since orbital slots are limited natural resources, as recognized in the ITU Constitution. Given these weaknesses, it becomes ever more urgent to develop legal or policy mechanisms for the management of existing debris.

4. ADVANCING *EX POST* APPROACHES: ADR & RECYCLING SPACE ELEMENTS

Despite growing awareness and the promotion of many mitigation strategies, current efforts remain inadequate to address the escalating space debris problem. Indeed –as presented above–, most measures focus on avoidance and disposal, although debris continues to accumulate at an alarming rate.

Thus, it is argued that "compliance with mitigation rules (...) will not be enough to reverse the negative trend (...) a combination of mitigation and remediation measures is needed" [28]. In other words, it is becoming evident that solutions must go beyond prevention and target the management of existing debris *as well*. In this context, Active Debris Removal (ADR) initiatives have emerged as a potential solution –despite facing legal, technical, and financial barriers–, while the idea of progressing from (simple) removal to the recycling of space debris is at the same time gaining wider acceptance.

4.1 ADR efforts and their shortcomings

As argued, ISL does not regulate the problem of space debris, particularly with regard to *already existing* ones (i.e., in orbit); in this context, while soft law instruments address debris mitigation or the long-term sustainability of space activity, they primarily focus on preventing the creation of new debris, thus lack specific provisions for dealing with the current issue. This persistent regulatory gap has led several countries to adopt national initiatives aimed at managing the existing debris population, which ultimately paved the way for the development, *inter alia* of post-mission solutions – like Active Debris Removal (ADR).

More precisely, a wide range of systems and techniques for transporting space debris –often referred to as *active debris removal* and widely defined as any activity that is aimed at eliminating "intact but non-functional and/or uncontrolled objects (i.e., defunct satellites and rocket bodies)" [28]– are currently under development and/or testing. They mainly include technologies such as solar or electromagnetic sails, various inflatable or deployable structures, and laser-based solutions [29; 30]. However, *from a legal perspective* ADR measures face substantial challenges. In particular, significant uncertainties exist as to whether an operator or a State –other than the State of Registry/Launching State, which retains "jurisdiction and control" over its space objects/debris, under Article VIII of the OST (subject to any agreements between the launching States)– may lawfully remove any debris that remains under the jurisdiction of its State of Registry, without its prior consent. Yet, additional complications involve liability issues, notably under Article III of the Liability Convention, which requires fault for damage in space but offers no definition of fault, leaving ambiguity in cases where damage could occur during space debris removal [28; 30]. In theory, all these legal uncertainties hinder the development of a harmonized and/or binding international framework for the effective regulation and promotion of ADR activities.

However, despite all the legal challenges in establishing uniform, binding international rules on debris removal, some States –recognizing the increasing risks posed by existing debris to space operations and infrastructure– have acknowledged the necessity to allow removal *first, in exceptional cases*. Following this line of thinking, these States have accepted debris remediation as a valid option, particularly in emergencies. For example, it was established that a State may "implement as part of (the) licensing process a provision that enables it to order remediation as a possible solution in an appropriate situation" [30:33], i.e. in light of the urgency to mitigate debris and the dangers it presents.

Building in this direction and driven by operational and *practical imperatives*, additional proactive legal/policy initiatives have recently emerged. For instance, the *US Orbital Sustainability Act* (ORBITS Act 2022) promotes ADR technologies and provides a regulatory framework for debris removal, stating that "the Administrator and the head of each relevant Federal department or agency may acquire services for the remediation of orbital debris, *whenever practicable*" (emphasis added) [31]. In a similar manner, Japan's 2021 legislation [34] includes a few provisions on on-orbit services (OOS), covering both satellite repair and active debris removal [33]. The UK likewise announced a regulatory review to "incentivise sustainable practises (…) hence allowing today's latest innovations in technologies, such as Active Debris Removal (ADR), In-Orbit Servicing and Manufacturing (IOSM) as well as sustainable development to become tomorrow's norms in space operation" [37]. As well, on the operational front, ESA's *ClearSpace-1* mission was developed so as to: "(i) remove from orbit ESA-owned object(s) with a total mass greater than 100 kg by no later than end 2025; (ii) demonstrate the technologies needed for debris removal, and (iii) open a new market for in-orbit servicing and debris removal" [32].

In this context, as key legal measures (particularly at the national level) are gradually adopted and ADR becomes more prominent in public and policy debates, increasing attention is being paid to the question of *what to do with collected space debris*. Indeed, alongside discussions on removal strategies, a significant issue is whether parts of debris *could be reused*, for instance by salvaging and/or repurposing critical components from defunct satellites [28]. In truth, although automation and space robotics still face important challenges [28], technologies aimed at capturing and retrieving space objects are advancing rapidly. Methods such as tethering, tugging, electrostatic tractors, ion-beaming, net capture, and drag sails are under development. Thus as said advancements improve the viability of debris removal, the concept of recycling space technologies is being explored more seriously.

4.2 Recycling, reusing, using recyclable parts

One could argue that the idea of recycling space objects appears to have already originated, such as through the concept of *scavenging*, defined as recovering, repairing, repurposing, or reusing defunct or non-operational space objects (i.e., debris) while still in orbit. More precisely, scavenging involves techniques like refueling, repairing damaged parts of space objects, upgrading systems, or salvaging valuable components from inactive satellites, with the aim of extending their operational life or even creating new functional assets. In doing so, it seeks to transform discarded objects into useful resources, hence promoting more sustainable operations and also helping reduce the accumulation of debris while –at the same time– lowering mission costs [35].

For instance, it is mentioned that "the first experiment in outer space to service a space object with another space object was carried out by the Japanese space agency in 1997"; and in 2007, the U.S. DARPA tested the "Orbital Express' servicing system, with a chaser satellite and a target satellite" [35]. As expected, additional initiatives emerged, based on the belief that satellite components and/or structures can remain valuable for years, and that repurposing such elements offers strong economic and operational advantages.

Following on from the above, *legal questions* that were once mainly theoretical –such as whether a State may collect debris (i.e., non-operational objects) belonging to another State under the jurisdiction and control principle in Article VIII of the OST– have now become pressing economic concerns. As collecting or repurposing space debris appears to finally offer financial and operational benefits (e.g., reducing manufacturing and launch costs while optimizing resource use), the refusal of a State to sell and/or agree to the collection of its defunct objects (debris) leads to practical obstacles; this is particularly relevant given that jurisdiction and control remain with the State of Registry (see OST, Article VIII), effectively preventing any other actors from recovering such space objects without consent. Notably, it is rightly observed that, the "Launching States may not agree to suspend their jurisdiction and/or control over decommissioned satellites with sensitive technology and expose them to close inspection by unauthorized space actors" [35]. Yet on the other hand, when space objects are relocated to graveyard orbits, it may be viewed as abandonment [7], raising additional questions about the continuing legal rights (of the State of Registry) over such derelict assets.

At the practical level, i.e. beyond the legal complexities, substantial operational issues also hinder the promotion or the implementation of space object recycling**.** Many defunct satellites and rocket bodies (especially the ones launched between 1981 and 2000) are outdated, often incompatible with today's technological and/or mission requirements. Furthermore, even when the reuse appears technically feasible, there is no guarantee that all these objects could be successfully serviced or integrated into future missions, raising doubts about the practicality of large-scale debris repurposing [36]. Thus, said practical concerns should be examined carefully, since any viable recycling framework must account for both the technical limitations of existing space objects and the challenges of integrating them into future operations.

Still, despite the legal and practical challenges outlined above, expert market projections suggest that recycling space objects is a realistic and also potentially profitable endeavor [36]; and in this context, the transition from a linear to a circular space economy is increasingly seen as viable ("Circularity" –in this case–, refers to waste-management principles that encourage designing objects for reuse or recycling at the end of their lifecycle [38]). The concept of reusing space technology is not new, yet fully reusable spacecraft remain in development; indeed, only partially reusable launch systems have been flown until now [39]. Despite this, space stakeholders' interest in reusability is now growing. Europe, for instance, has invested or developed a range of reusable technologies, built test infrastructure, and successfully launched the IXV demonstrator in 2015, as current efforts are shifting toward reusable booster stages (e.g., SpaceX's Falcon 9, and reusable orbital vehicles such as NASA-USAF's X-37) [39].

In light of this evolution, the concept of *recycling space objects is gaining momentum*. Still, normative proposals remain fragmented and experimental, lacking a coherent and harmonized framework. Considering the urgency of the space debris crisis, it is however, critical to intensify efforts and to explore all viable solutions. A structured and comprehensive approach is needed (considering the evolving dynamics and unique complexities of the space sector), that would incentivize technological innovation while establishing legal certainty; adapting lessons from other legislative frameworks (such as those in ISL, but also EU law) could well enhance the effectiveness of the proposed strategy.

5. PROMOTING RECYCLING IN SPACE & EU REGULATION 2024/1252

In legal theory, recycling has principally been promoted for its environmental benefits and its role in preserving natural resources; however, its *importance for economic actors as well seems to be gaining recognition*. By way of illustration, Regulation (EU) 2024/1252 places clear emphasis on its economic value for producers and/or operators themselves, by highlighting that recycling not only supports long-term sustainability across all sectors of the industry but it also *helps reduce* production and operational costs by allowing actors to reuse assets and reintegrate recovered materials into the supply chain.

This practical incentive is the core of Regulation (EU) 2024/1252, which seeks to ensure EU's secure supply of Critical Raw Materials (CRM) and also reduce external dependencies. Adopted on 11 April 2024, it mainly aims to promote enhanced resource efficiency and resilience across strategic sectors. Hence, given the space sector's heavy reliance on such materials, it is in truth pertinent to explore whether this legislative instrument could also support the development of recycling practices within space operations and the broader management of orbital debris.

5.1 Regulation 2024/1252 -critical raw materials

Regulation (EU) 2024/1252 begins by highlighting the fundamental importance of particular raw materials, and is describing them as "essential for the EU economy and the functioning of the internal market". It introduces two distinct categories: (i) *critical raw materials*, defined by their high economic importance and high supply risk, often due to the EU's dependency on a small number of third countries [40: Recital (1)]; and (ii) *strategic raw materials*, which are considered critical but also vital for the functioning of the internal market, for the green and digital transitions, and/or for the defence and aerospace sectors (i.e., "if not managed properly, (*their*) increased demand could lead to negative environmental and social impacts" [40: Recital (1)]).

In this context, the Regulation explicitly states that EU's "recycling capacity should therefore be able to produce at least 25% of the Union's annual consumption of strategic raw materials and ... be able to recycle significantly increasing amounts of each strategic raw material from waste" [40: Recital (11)]. To this end, two lists were included in Regulation (EU) 2024/1252: one for strategic raw materials (*Annex I*) [40: Art. 3.1] and one for critical raw materials (*Annex II*) [40: Art. 4.1]. Importantly, the Regulation provides that both lists will be subject to regular review and updated as needed, in accordance with Articles 3 and 4.

Building upon the above, the instrument introduced a set of key rules to ensure a secure and diversified supply of strategic raw materials; e.g., it called for diversification of supply sources [40: Art. 1, Art. 20] and promoted the creation of strategic partnerships with non-EU countries [40: Art. 37]. Notably, it created a specific framework to support "*Strategic Projects*", that are defined as projects which make a meaningful contribution to the security of "the Union's supply of strategic raw materials" [40: Art. 6], as such projects aim to enhance domestic extraction, processing, and recycling capacities, thereby reducing reliance on external sources. Thus in view of facilitating their implementation, Strategic Projects are granted a special legal status: they are considered "to be of public interest or serving public health and safety" and "may be considered to have an overriding public interest" [40: Art. 10.2]. As a result, where applicable under national law, they should be treated as projects of the highest national significance and prioritized in permit-granting procedures –provided such thing does not conflict with obligations under EU law [40: Art. 10.4]. Moreover, in line with existing environmental law, such projects must undergo an Environmental Impact Assessment (EIA) [40: Art. 11 et seq.], as set forth in the Environmental Impact Assessment Directive (2011/92/EU, amended by 2014/52/EU) [41; 42] – on this basis, recycling projects with significant environmental impacts (e.g. due to their nature, size, or location) should include an EIA as part of their approval process [41: Art. 2]. Eventually, it also established a governance body (the Board), tasked with monitoring implementation and advising the European Commission: thus, the Board may provide advice to the EU Commission which may then issue guidance to the States, like recommendations on expanding strategic raw material stocks (e.g., in doing so, it must "give particular weight to the need to maintain and *promote incentives for private operators*, which rely on strategic raw materials as inputs, to constitute their own strategic stocks …" (emphasis added) [40: see Art. 23.4].).

Hence, building on this specific framework, Regulation (EU) 2024/1252 introduced mandatory company-level risk preparedness obligations as the Member States must *identify large companies* using strategic raw materials in key sectors (e.g., *data transmission, robotics, satellites, rocket launchers, advanced chips*) [40: Art. 24.1]. These companies are required to assess supply chain risks and, in case substantial risks or vulnerabilities are detected, adopt mitigation measures [40: Art. 24.4].

To support these efforts, the regulation requires Member States to also enact national measures so as to promote *circularity*, including actions to improve the collection, sorting, and processing of waste containing recoverable critical raw materials, such as metal scraps (i.e. ensuring their integration into appropriate recycling systems [40: Art. 26.1(c)]), as well as report quantities extracted and recovered from such waste [40: Art. 26.5]

Overall, one may note that Regulation (EU) 2024/1252 is primarily oriented toward terrestrial industries. Indeed Articles 28 and 29 explicitly exempt space applications from several key requirements; e.g., from recyclability labelling, design-for-recycling duties, or from minimum recycled content rules [40]. As a result, the spacecraft manufacturers *are not subject* to recycling transparency requirements under this regulation. Furthermore, it must be added that activities in space that would be aimed at collecting or recycling space debris remain governed by ISL, and (as mentioned above), raise both technical and legal issues. Therefore, given said substantial challenges it would be premature (even) for the EU to establish binding recycling obligations on space actors, under the current legal and technological conditions.

Nevertheless, the regulation strongly promotes recycling *as a core strategy* for securing access to all critical raw materials, setting a target that at least 25% of the EU's annual consumption of said strategic essential resources must come from recycling [40: Art. 5]. Hence, as space technologies rely heavily on these raw materials –many of which are also explicitly listed in the regulation–, this objective is highly relevant. For example, Aluminium is used in structural components of rockets and satellites; Lithium powers high-energy-density batteries; rare earth elements (e.g. neodymium, praseodymium, dysprosium) are found in motors and/or sensors; Gallium is essential for semiconductors; and Tungsten is used in high-temperature and/or in shielding applications.

Thus in light of this characteristic dependence, the space sector is explicitly identified in the regulation as a key, strategic domain [40: Art. 2; Annex I, Section 2]; which, accordingly, requires *large space companies* to assess and manage supply chain risks [40: Art. 24]. From this perspective and although the regulation does not directly address space debris recycling (i.e. debris recycling falls outside its immediate scope), it may nevertheless still indirectly support or inspire future developments in this area.

5.2 Debris recycling - Incentivizing the Progress

Space debris recycling currently falls outside the direct scope of Regulation (EU) 2024/1252, as the regulation does not impose any explicit or binding obligations on space actors to recycle existing debris. Nevertheless, it *creates important momentum* by reframing recycling not only as an environmental necessity –a perspective that has traditionally dominated the discourse– but also as an *economic imperative*. It emphasizes the EU's increasing dependence on critical raw materials, given the strategic and economic importance of long-term sustainability in supply chains. Following on from that, one should note that although the regulation is essentially tailored to govern terrestrial industries, it does not confine material recovery to Earth-based sources, thereby leaving open the possibility that recovery efforts could also target space debris; especially given space technology content of valuable materials and the growing reliance on space-based infrastructure.

In this context (i.e., even though the instrument does not explicitly require space debris recycling), the regulation places obligations on *all large companies* dependent on strategic raw materials, to carry out supply chain risk assessments [40: Art. 24]. Therefore, space actors (who rely heavily on critical raw materials) *do fall* within the scope of these obligations. Thus, notwithstanding that it is currently unfeasible to impose binding requirements for recycling debris still in orbit, the regulation may still encourage companies to explore recycling possibilities once objects re-enter Earth's atmosphere; legally, such an approach is facilitated by long-standing international frameworks, such as the Liability Convention [3], which governs the collection of space objects after re-entry and grants specific rights to the launching authority (the two legal frameworks, namely Regulation (EU) 2024/1252 as well as the Liability Convention, may eventually help enhance in-orbit recycling efforts – once the necessary technology is available and the international community is prepared to address the relevant legal challenges).

More critically, Regulation (EU) 2024/1252 establishes a *core policy objective*, that at least 25% of EU's annual consumption of strategic raw materials must derive from recycling. Thus, while Articles 28 and 29 exempt space companies from specific obligations –such as labelling and design-for-recycling requirements– the 25% target is framed as a general goal *applicable across all sectors*. As a result, it appears that space operators may not be excluded from the broader circular economy framework. They will ultimately need to contribute by improving supply efficiency and integrating recycled materials into their production. Hence, even though it is not explicitly mentioned, space debris recycling could/should become part of this broader goal, particularly as more materials are recovered from re-entered objects; or, in the future, from in-orbit recycling initiatives.

In reality, though promising, the concept of space debris recycling is still constrained by major technological and legal difficulties (i.e., collecting and recycling debris *in orbit* remains a key challenge): although Active Debris Removal (ADR) has gained recognition as a mitigation strategy, the necessary technologies for large-scale in-orbit recycling are not yet fully developed – and ISL provides no clear framework to support such activities. Nevertheless, given the economic value of recoverable materials found in space debris, growing interest is now expected from space operators. The shift from removal to recycling appears to be *a matter of time*, as advances in robotics and orbital servicing improve their technical feasibility, and as consensus grows around the need for *sustainable practices* in space operations.

Based on the above, it is plausible that future regulatory developments will *expand recycling obligations* to also include materials recovered from space; that is, once the relevant technologies mature and the costs are reduced, binding measures could emerge too, to promote in-orbit recycling (while the EU could –eventually– incorporate debris recycling explicitly into its sustainability agenda). However, until then, *more immediate action is needed* to ensure supply security. The most practical approach would be to offer targeted incentives to space operators. These could include *inter alia* financial support for the development of recyclable space systems, subsidies for debris retrieval and recycling, or funding mechanisms to encourage the use of recycled materials in the spacecraft design (*n.b.*, in exchange for such incentives, operators could be expected to deliver benefits, such as creating high-tech jobs and attracting investment in advanced recycling and in-orbit servicing technologies).

At the same time, the manner in which such incentives would be structured remains *an open (critical) question*. Hence, as space debris poses substantial operational and economic risks to all the space assets, the stakeholders who will take the lead in developing a viable regulatory framework will not only gain normative influence but also establish moral authority in shaping the future of space governance. Defining a clear path toward debris recycling and space sustainability is therefore crucial, as it will foster responsible behaviour and, practically, help ensure the (long-term) viability of space activities.

In essence, given the current state of ISL –where the last binding treaty, the Moon Agreement, dates to 1979 [5]– and the heavy reliance on soft law instruments (like the IADC guidelines), key future regulatory efforts should better adopt a *flexible, incentive-driven approach*. New measures could be implemented within existing bodies, (e.g., ITU or UN COPUOS), and harmonized with their frameworks. Such rules should also be practical, directly applicable to space operators, and promote operational efficiency. Indeed, their success will mostly depend on providing tangible incentives aligned with the industry needs, while advancing sustainability and legal clarity in the space domain.

6. CONCLUSIONS

This paper has examined the principal issues associated with space debris recycling, highlighting the significant legal and operational gaps in existing (ISL) frameworks. However, although current space law does not directly address such debris recycling, recent legal developments –namely Regulation (EU) 2024/1252– seem to suggest a *policy shift*, i.e. strengthening environmental protection, advancing circular economy principles, and securing the sustainability of critical materials, while also promoting recycling as a rule. This shift underscores the need to advance normative clarity and practical mechanisms to make *all* debris recycling a feasible and more effective solution – thus, building on this, a number of proposals could be put forward to promote the recycling of space debris in particular.

First, from a legal standpoint, enhancing legal certainty is an essential precondition for operationalizing space debris recycling. Indeed, given the persistent obstacles – particularly the risk of liability for operators that collect debris belonging to another state– future reforms should put the focus on clarifying responsibility, authorization procedures and ownership rights. In this context, major *questions arise*, particularly with regard to *identifiable* debris, that is space objects for which the owner is well known (i.e., the State of Registry):

(A) whether a space object (when it is debris) should be considered abandoned, and (A.i) if so, who is entitled to *retrieve it* (also, if a *procedure* should be followed), and then (A.ii) who should own the *recovered* material.

* debris whose ownership cannot be determined or that

is not claimed (i.e., *unidentifiable* due to size or lack of registration data) should all be presumed abandoned to mainly ensure operational efficiency and legal certainty.

(B) if the debris is not considered abandoned property, it should be assessed: (B.i), if the entity seeking to collect the debris should be required to *obtain the consent* of its owner (State of Registry, or the launching State); and, if so, whether any *formal framework* should govern such requests (e.g., including deadlines for response); as well as: (B.ii), whether an unjustified refusal by the owner could give rise to liability for contributing to increased risks in space, regarded to be a *fault under Article III* of the Liability Convention (that is, irrespective of whether material damage has occurred – this would introduce a form of legal accountability that incentivizes launching entities to cooperate with debris recycling efforts).

(C) furthermore, safeguards should be implemented to *prevent any misuse of recycling*, namely as a pretext for unauthorized access to foreign debris and/or to sensitive scientific components onboard (non-functional) objects. Indeed, many space debris could still contain valuable data or technologies; thus, to prevent abuse of any legal framework, future regulatory instruments should include robust procedural mechanisms. They could set forth e.g. (C.i) documentation requirements e.g., when applying for a consent or recycling license, and (C.ii) the creation of a specialized authority –for instance, similar in role to the Claims Commission under the Liability Convention [3]– to assess requests and mediate disputes relating to debris recovery and recycling missions.

Fundamentally, introducing such radical changes would require a new treaty and broad international consensus. However, until such a framework is adopted, States and operators *could begin forming relevant practice*, based (for instance) on the procedural model of the Liability Convention [3: see Art. IX seq.]. In fact, although said Convention primarily concerns damage compensation, it nevertheless provides a robust structure for cooperation between states. Thus, *mutatis mutandis*, such framework could be adapted to support preventive practice (e.g., to have consent to collect debris for subsequent recycling), i.e., through formal inter-state communication, that may involve diplomatic channels and also the UN Secretary-General. This approach could furthermore promote the recognition of recycling missions as critical activities, *eligible for preferential treatment*, namely similar to the "strategic project" status in Regulation (EU) 2024/1252.

Second, on a practical –and more immediate– level, it is important to adopt *tangible, economic incentives*, since financial considerations are a primary driver for (space) operators' involvement. In light of this:

(D) at the international level, within the key competent institution, that is the International Telecommunication Union (ITU), there is so far no provision for preferential orbital allocation based on any mission type. The ITU's Radio Regulations (RR) are initially designed to ensure equitable access to the radio-frequency spectrum and to orbital resources, to avoid harmful interference between space services (i.e., on the basis of Article 44 of the ITU Constitution). In this context, although the ITU does not impose orbit and/or frequency usage fees *stricto sensu*, it still requires the payment of Satellite Network Cost Recovery fees [49: 45]; at the same time, even though the ITU released a set of recommendations highlighting the significance of space debris mitigation, the above rules remain non-binding [48]. Be that as it may, and given the critical importance of the debris problem, (D.i) the Member States *could propose updates* so as to introduce incentive mechanisms (such as Satellite Network Cost Recovery discount or fast-track coordination), for space operators investing in ADR, with a view to recycling. Such proposals, that would aim at facilitating missions with recycling objectives, would be grounded in Article 44.2 of the ITU Constitution [17], which establishes the duty to ensure the rational, efficient, and economical use of the radio-frequency spectrum and orbital resources, and in line with the above recommendations. In addition to that (D.ii), since the current "first-come, first served" principle is based on practice rather than law, any future *revisions could allow for a degree of prioritization*, i.e. to promote missions contributing to sustainability goals, such as debris collection and recycling.

(E) Finally, as the easiest and most immediate approach is to *introduce targeted measures at the national level*, adapted incentives could and/or should be enacted under national space laws, to enhance the implementation of Article IX of the OST (regarded as being the basis for the protection of the space environment) and Regulation (EU) 2024/1252 (on critical raw materials), such as to:

(E.i) *prioritize licensing requests* for missions aimed at debris recycling, accompanied by reduced authorization fees, if designated as projects of strategic value;

(E.ii) offer *certain financial support* or tax incentives to reduce R&D and operational costs for space recycling technologies;

(E.iii) include information on space debris recycling operations in their national registries of space objects and transmit it to the UN Secretary-General under Article IV of the Registration Convention [4], to help develop a *state practice* and increase transparency. Such mentions could also appear in the UN's public index of registered space objects, to indicate that this practice is gaining momentum, and to potentially encourage others to take similar action.

Overall, addressing the space debris challenge through recycling requires both legal innovation and coordinated policy action. All the efforts should be combined (i.e., international cooperation with practical, market-driven incentives), to allow the global community to pave the way for a more sustainable and secure environment in space. In this regard, the European Union, building on its recent regulatory momentum, could play a leading role to shape future standards and promote responsible space operations – both at the regional and international levels.

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