Space Sustainability: Reframing the Debate

Professor Christopher J. Newman (Northumbria Law School)
Dr. Mark Williamson (Space Technology Consultant)

1. Space activity and the sustainability vacuum.

The nature of space activity has changed dramatically over the course of the last sixty years. Where once it was characterised by voyages of exploration beyond the Earth, the past three decades have seen a steady rise in commercial and private sector activity focused around low Earth orbit (LEO). Both the exploration and subsequent exploitation of space promised much in terms of satellite applications on Earth and (more ambitiously) by using the almost limitless mineral resources within our solar system[1]. Yet such endeavours are not without cost and all periods of the Space Age have had a significant, cumulative impact upon the space environment near Earth[2]. The law and regulatory framework that could have addressed this environmental degradation has instead stagnated, with the dominant legal instrument for 21st Century space exploration – the Outer Space Treaty of 1967 - predating humans landing on the Moon.

The seriousness of the situation was summed up recently by Gerard Brachet, former chairman of the United Nations' Committee on the Peaceful Uses of Outer Space (UNCOPUOS), who wrote:

> *"…our use of outer space since 1957 has been rather careless of its long-term sustainability. The situation might be compared to that of the 19th and 20th centuries with respect to maritime shipping and exploiting the oceans' resources where there was a wilful ignorance of the negative impact of pollution and a general blindness to the long-term effects of over-fishing"*[3].

In recent times, the need for a sustainable approach to space activity has gained increasing recognition within the space community. One reason that awareness of space as a fragile environment has improved is the increase in major debris-creating incidents in LEO, most significantly the deliberate destruction by the Chinese authorities of their Feng Yun 1C weather satellite in January 2007[4] and an unintentional collision, in February 2009, between the Iridium 33 commercial communications satellite and the defunct Russian Cosmos 2251 spacecraft[5].

While it is laudable that issues such as debris mitigation and removal are at last being taken seriously for LEO, and at least considered for higher orbits such as geostationary orbit (GEO), the current debate appears to have become limited to the Earth's immediate space environment. There appears to be little consideration of the long-term sustainability of activities and operations in the wider space environment, particularly regarding forthcoming Moon and Mars exploration[6]. Within the next decade or two, if current plans come to fruition, there will be tele-operated rovers, scientific bases and perhaps even space tourists on the Moon; meanwhile, space entrepreneur Elon Musk has announced plans to establish a colony on Mars[7].

The United Nations Conference on the Human Environment, held in 1972 in Stockholm, is credited with bringing the concept of 'sustainable development' (of the terrestrial environment) to public attention, but the applicability of the concept to the space environment is still not broadly accepted in anything like the same way. Although the term 'sustainability' has become increasingly common in space policy discourse, its applicability has been focused on a limited part of the space environment - chiefly low Earth orbit (LEO)[8].

This discussion will examine sustainability in LEO, where, despite the consensus that is emerging vis-à-vis the threat posed by orbital debris, there is little evidence of legislative or governmental action to ensure its broad applicability throughout the space environment. Having looked at where sustainability efforts are being concentrated, the inquiry will then attempt to move the debate beyond LEO, by highlighting some of the technical, legal and ethical issues that arise from human activity in both exploring and settling other celestial bodies. Finally, there will be analysis of some of the policy aspects and legal solutions that need to be established if humanity is to avoid replicating the environmentally harmful behaviours that have characterised operations in LEO.

2. Sustainability defined

In the early days of the Space Age there was little thought of sustainability in any sense of the word; launching objects into space and operating the nascent 'space technology' in an alien and largely unknown environment was enough of a challenge without worrying about longevity. This soon changed, of course, as space scientists moved beyond the 'snapshot' stage of simply wanting to get into orbit and projects demanded hardware that would operate long enough to provide data on how aspects of the space environment they were studying developed over time. Arguably the first manifestation of 'space sustainability', therefore, was the sustainability of the hardware. As hardware reliability improved and missions developed into programmes – for example, for satellite communications, Earth observation and weather forecasting – the sustainability of funding, predominantly from government coffers, became a key sustainability issue. This manifestation of the sustainability concept became particularly important as the Apollo lunar programme reached its peak and the final three missions were cancelled; clearly, in the late 1960s and early 1970s, lunar exploration by humans was not politically sustainable[9].

Notions of sustainability tie in closely with the emergence of environmentalism as a construct of the latter half of the twentieth century. As William Kramer has identified[10], the works of Carson[11], Ehrlich[12] and, perhaps of most significance, the 'Tragedy of the Commons' by Garrett Hardin[13] all contributed to the recognition that sustainability in a terrestrial context was imperative[14]. The risk identified is broadly that the resources of the Earth might be exhausted but also that the wider environment could be damaged beyond nature's ability to repair itself. When considering sustainability in this context, it can be broadly characterised as '*development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*'[15] The Secure World Foundation has applied this to space exploration, suggesting that sustainability of the space environment means '*Ensuring that all humanity can continue to use outer space for peaceful purposes and socioeconomic benefit now and in the long term.*'[16] Indeed, the term 'space sustainability' has risen in prominence within the space community over the past decade to the point where it has become the subject of a United Nations Office for Outer Space Affairs (UNOOSA) "Working Group on the Long-term Sustainability of Outer Space Activities".

In general, the language or terminology used with respect to space resources (again, predominantly in LEO) has been developing over the past decade or so. Phrases such as 'space situational awareness', 'space traffic management' and 'space safety' have been applied to the sustainability of satellite systems and space stations in LEO. In other words, 'space sustainability' increasingly refers to the future sustainability of government, military and commercial spacecraft operations in LEO. There is, however, more to outer space than LEO, as discussed below.

As has been identified elsewhere[17], sustainable development in space requires that all participants in space activity must mitigate the harmful effects of their exploration and reduce their environmental footprint, so that future ventures do not require additional expenditure to mitigate the effects of previous generations. As will be seen, however, despite technological and engineering advances, the crucial legal element has been neglected, with guidelines and voluntary codes of conduct being used to buttress the OST. Any meaningful attempt to embed sustainability within space activity needs to be underpinned with a robust and enforceable legal regime. Obtaining the necessary consensus for this is, arguably, as formidable a task as any technical challenge.

3. Space exploration and space law

The successful launch of Sputnik 1 in October 1957 launched humanity into the Space Age. In the two decades that followed, the international community, under the auspices of the United Nations, negotiated a series of general, multilateral treaties that would form the basis of international space law. The foundational treaty, which provided the basis for the international governance of space activity is the Treaty on the Principles Governing the

Activities of States in the Exploration and Use of Outer Space including the Moon and Other Celestial Bodies, known colloquially as the Outer Space Treaty (OST)[18]. It was the result of deliberations within UNCOPUOS, building on previous resolutions passed within the UN General Assembly, and entered into force on 10 October 1967. Created in the shadow of the Cold War hostilities between the two dominant superpowers, the United States of America and the Soviet Union[19], the preamble to the OST betrays many of the concerns that were prevalent at the time. It speaks of the need for space to be used for peaceful purposes, and of the need for mutual understanding and cooperation.

Despite this historically-specific context, the OST has laid down the normative legal principles on which the exploration and use of outer space has been conducted for the last fifty years[20]. These key values are enshrined within the fabric of international law (and arguably the customary practice accepted as law[21]) and encompass such principles as outer space being free for exploration and use by all states, the prohibition of claims of sovereignty over outer space and the responsibility of states for all activities conducted by both state and non-governmental entities[22]. Perhaps of most significance, as identified by Lyall and Larsen, is that the OST established the fundamental principle that space is not a lawless frontier, free from any legal constraint or principle[23].

The principles found in the OST, therefore, form the legal base of current space activity. Yet the OST remains a creature of its time. The overriding concern of those drafting the treaty and creating the international framework was one of security[24]. The prevailing geopolitical climate has changed markedly in the fifty years since the coming into force of the OST, with numerous state and private actors taking part in space activity. Similarly, the focus of the activity has appeared to go through a paradigm shift from being the manifestation of military superiority by journeys of exploration to that of a commercial activity designed to harness the profit potential of space-based applications in low Earth orbit. As the geopolitical situation changed, states turned away from the Moon and focused back on the Earth, in particular the 'high ground' of LEO, a few hundred kilometres above the planet. As a result, it became the focus for a small community of space scientists and engineers concerned about the dangers posed by the growth of human-made, orbital debris, much of which was derived from launch vehicle upper stage explosions.[25]

Human-derived debris was, largely, not considered as being problematic during the pioneering era of the early Space Age[26]. Indeed, beyond the forward contamination of extra-terrestrial bodies encapsulated in the phrase 'planetary protection', and the protection of Earth from so-called 'backward contamination' by alien pathogens, environmental awareness is largely missing from the binding treaties of space governance[27]. Accordingly, there is no mention of space debris within the OST, nor is there any recognition that states have a duty to use the space environment in a manner which is sustainable.

By the time the Space Age was but two decades old, however, it was clear to some observers that the debris situation in LEO could reach catastrophic proportions, prompting two such experts to publish a paper entitled 'Collision frequency of artificial satellites: The creation of a debris belt' [28]. It warned of a possible 'collisional cascade effect' in LEO, now widely known as the Kessler Syndrome. This hypothesized that, as the amount of debris objects in a given orbit increased, so would the probability of collisions between them, and if a sizeable object hit a satellite it could produce hundreds or thousands of additional debris objects, which could in turn impact other satellites[29]. Eventually, this cascade effect would produce the 'debris belt' foretold in the paper's subtitle and render the orbit unusable; in terms of its intended use, the orbit would become unsustainable.

4. The challenge of orbital debris

The long-term nature of the orbital debris issue poses several challenges to on-going space activity, both from a technical and a legal standpoint[30]. Although the ideas that became known as the Kessler Syndrome were first postulated as long ago as 1978, it was not until the formation of the Inter-Agency Space Debris Coordination Committee (IADC) in 1993 that guidelines for debris mitigation began to take shape. These guidelines were built upon by UNCOPUOS and in 2007 the UN Debris Mitigation Guidelines were issued. However, it was only in 2002 that these guidelines were approved by space agencies and submitted to the UN; they were finally approved by the UN's Science and Technical Subcommittee (STSC) in 2007. At the time, a UNCOPUOS report acknowledged that "it has been a common understanding that the current space debris environment poses a *risk to spacecraft in Earth orbit*."[31] Despite these warnings, and a number of academic texts devoted to the subject[32], the concept of sustainable development of the space environment has not received the necessary political attention.

Despite the clear evidence that space debris represents the primary threat to humanity's continued use of the extraterrestrial environment, states continue to behave in a way that generates more debris and the desire for rigorous debris-management regulation binding on all space users is worryingly deficient. The governance difficulties of managing debris are almost as significant as the technical ones. Hobe suggests that, if the 'soft' guidelines are discounted, the OST does not explicitly render the creation of space debris unlawful[33]. Whilst it has been argued that actively creating debris, or stubbornly refusing to remove debris could be viewed as interfering with free access to space under Art I OST and possibly harmful contamination under Art IX of the OST, such concerns have not been tested by states[34]. Debris mitigation governance therefore resides in the arena of voluntary international codes of conduct and there are currently no legally enforceable provisions limiting the amount of debris at the design stage of the mission.

The major space agencies recognize that the UN Space Debris Mitigation Guidelines are an example of 'best practice' and represent a prudent first step towards limiting future orbital debris.[35] Such recognition, however, falls short of full-scale, universal adoption. Indeed, within the text of the regulations, it is made clear that these are guidelines and are not legally binding under international law[36].

By contrast, work undertaken by national space agencies and the IADC indicates that there is no shortage of recognition amongst the spacefaring community that orbital debris is a problem[37]. This has led to international collaboration on mitigation technologies and the sharing of best practice (including the passivation of spacecraft elements such as batteries and propulsion systems and deorbiting spacecraft where possible). Coupled with the wider discussion occurring within the UN, there is, therefore, some cause for optimism. A nascent normative position in respect of the dangers posed by orbital debris to the future viability of space activity is clearly emerging via these mitigation guidelines[38], based on a need to reduce current debris and limit future debris[39].

More problematic from a legal perspective, as well as being technically more challenging, is the issue of debris remediation, i.e. the active removal of debris from densely populated orbit regions[40]. Remediation is missing entirely from the UN guidelines and, indeed, any other instrument regulating space debris management. Just as the technology to effect the safe removal of redundant, non-functional satellites and other debris from LEO remains highly experimental[41], the accompanying legal framework poses some formidable obstacles to cleaning up Earth orbit. The OST legal framework is based upon responsibility for authorization, liability and on-going control of space objects being imposed upon named, launching states. Those responsibilities do not cease once an object has ceased to function. However, as mentioned previously, there is no corresponding duty on the launching state to remove a satellite or piece of debris from orbit once it has ended its useful life.

The conundrum for those seeking to engage in remedial activities is two-fold. First, any actor, be it private or public sector, will need to secure the permission of the launching state before engaging in debris remediation. States may be reluctant to grant this as, currently, remediation activity remains hazardous and may result in damage to another space object. Liability for any damage caused by a space object (including financial liability for damage caused by space debris and the cost incurred by any attempt at removal from orbit) will be on the launching state. Most of the spacefaring states, are therefore obviously less inclined to accept liability for space debris, including liability for in-orbit damages and removal costs, and feel that the responsibility for removal belongs to all states, including the associated costs[42]. Clearly, this is an area where consensus will be both vital and yet extremely difficult to obtain without nations adopting a more altruistic approach than is currently observed.

The need for international consensus and cooperation on the issue of debris management has never been greater. If the sustainability of LEO cannot be addressed, then other, broader concerns regarding the sustainability of the fragile space environment may well be moot. A debris cloud in LEO renders access to space difficult and, ultimately, perhaps almost impossible. The need for sustainability in this context is clear: ensuring that LEO remains viable for future generations, whilst satisfying the needs of the present. As has been outlined above, the current legal framework for space activity (and specifically the OST) is silent on this issue. Given the risk to space activity from debris, this continued silence is no longer an acceptable response. The ready-made consensus on debris mitigation should embolden states to tackle the technical and legal challenges of remediation collectively. Any consensus that embeds sustainability as a core concern will undoubtedly be to the benefit of future generations.

5. Sustainability challenges beyond LEO

The case has been made for the need to urgently ensure that all activity in LEO prioritises the protection of that important orbital environmental. This discussion has already illustrated the significance of inter-agency collaboration through which debris mitigation guidelines have been published[43] and are, at least to some extent, adhered to[44]. In practical terms, this reflects the inherent 'value' the space community places on LEO. It appears, however, that this is only acquired once the asset is at risk of becoming unavailable – for example, due to the onset of the Kessler Syndrome. Although satellite manufacturers and operators recognise the commercial value of geostationary orbital positions and specify measures to remove satellites to the so-called 'graveyard orbit' at the end of their lives, the smaller debris population in GEO makes the situation less urgent. Indeed, some satellites are still left to drift uncontrolled across the geostationary arc providing potential ammunition for future collisions[45].

Unfortunately, the lack of affordable technology to remove satellites entirely from the geostationary environment has made the graveyard orbit (a mere 300km or so above GEO, which itself is 36,000km above the Earth) the best option. As has been pointed out previously[46], depending on future launch rates, between 10 and 20 defunct satellites could be added to the graveyard each year, which would amount to 500-1000 in 50 years (which is double the current age of the satcoms era). The fact that these satellites are abandoned and uncontrolled implies that a collision will one day occur in the graveyard, producing debris that will intersect the geostationary ring and threaten operational satellites.

In many respects the predilection towards sustainability of Earth's orbital resources, as opposed to more distance resources, is hardly surprising. Human space exploration, unlike robotic exploration, has been 'stuck in LEO' since December 1972, when Apollo 17 returned from the Moon. This absence of crewed space missions beyond LEO since that time[47] would tend to suggest that, in terms of sustainable operations, the mainstream space community mind-set has also, until recently, been confined to LEO[48]. There are several reasons for this.

Firstly, it is easier to consider short-term issues than to extrapolate into a relatively unknown future. Secondly, it is more acceptable (especially in a constrained financial environment) to consider practical sustainability issues, rather than 'what if' scenarios. Thirdly, space professionals under the age of 45 have lived only in a world bound by the limitations of human travel to low Earth orbit, much as their forebears did before December 1968 when Apollo 8 travelled to the Moon. It is perhaps equally understandable, therefore, that international attempts at regulating the lunar environment, in the form of the Moon Treaty of 1979[49], have been equally unsuccessful[50]. Nations have both lacked the will to form a consensus and have engaged in disputes as to how any minerals harvested from the Moon should be apportioned. In respect of technical accomplishments and law and policy focus, lunar exploration has regressed rather than progressed[51].

Nevertheless, history has shown that when technical, financial and political factors align favourably, resources can be mobilised and developments can take place quickly (and often without much thought of the consequences). Those with interests in protecting the space environment and thereby ensuring its availability for future generations typically take a longer-term view of the space sustainability issue. It is always difficult to predict the future, but it seems sensible to assume that, when humans again travel beyond LEO, the Moon will be among the early destinations (not least because it is only three days away). Amidst the virtual moratorium on government lunar landing missions, the Google Lunar X-Prize (announced in September 2007) has seemed the most likely mechanism for lunar missions for many years. The concept of a commercial rover that could potentially visit the historic Apollo landing sites, and possibly despoil them, has exercised those interested in preservation since the announcement[52]. Although future development under the X-Prize banner is currently unclear, it is likely that at least one contender will conduct a mission in due course[53].

Before that, it is likely that another Chinese rover will be deployed on the lunar surface following the planned 2018 launch of the Chang'e-4 mission. This renewed interest in lunar exploration spearheaded by China is significant, not so much for the use of near-side, robotic rovers, but for plans to explore the far side[54]. As the Moon is in 'captured rotation' about the Earth, it presents the same side towards Earth at all times; so a lander, rover or lunar base on the far side will require a communications relay satellite to maintain contact with Earth. This could be provided by a single lunar satellite (for intermittent communications), a constellation of satellites, or a spacecraft at the L2 Earth-Moon Lagrange point. Whatever the technical solution, this begs the question of sustainability of the communications link and the future sustainability of the putative lunar base. And since lunar orbit is as much a part of the space environment as Earth orbit, this automatically feeds the debate on the sustainability of the space environment (at least for the practical needs of communication). Given that we have a problem with space debris in Earth orbit, it is not too much of a leap to foresee a potential problem with debris in lunar orbit.

Although a discussion of the orbital dynamics that make a stationary orbit (cf. geostationary orbit) around the Moon impossible is beyond the purview of this piece, it is worth pointing out that a future lunar communications system would most likely involve a constellation of many satellites. The same is true for a lunar version of the Global Positioning System, which would be necessary because the Moon has no magnetic field to attract a compass needle. As a result, any significant human development of the Moon will eventually require a population of satellites in low and medium altitude orbits of various inclinations from equatorial to polar. It would be complacent to believe that such a scenario offered no possibility of orbital debris, so sustainability of the systems and of the orbital resource itself would have to be considered.

This suggests the need for debris mitigation measures for lunar orbit analogous to those already available for low Earth orbit. Unfortunately, one of the key solutions for LEO – deorbiting – is not so readily acceptable for lunar orbit because it has an arguably greater environmental impact for the Moon than it does for Earth. Since the Moon has no atmosphere, spacecraft and debris will impact the surface intact rather than burning-up and disintegrating en route; and, of course, 'ocean disposal' is not an option. And whereas the Earth's environment has a natural ability to repair itself, the lunar environment does not and will bear the scars of any impact for the foreseeable future[55]. In this sense, the Moon can be considered a 'more fragile' environment than the Earth.

When considering specific examples of environmental damage from space debris, or indeed from mining, it is accepted that not all analogies to pollution on Earth are directly applicable to outer space activity. In respect of lunar orbital debris, whether the appearance of 'yet another crater' on the Moon 'matters', the possibility of impact in a 'developed area' must be considered, as must the option of a dedicated 'impact zone' for discarded spacecraft. Of course, this ignores the possibility of unintended and uncontrolled entries and argues for the active removal of defunct satellites from lunar orbit. In respect of the damage caused by mining, as stated above, the contamination to the lunar environment will be far more enduring than on Earth.

It is, of course, not just the Moon that is being posited as a possible location of future human activity in space. Already there are ambitious plans to mine Near Earth Asteroids by companies such as Planetary Resources[56] which are looking to 'prospect' for resources on bodies such as Ceres. Perhaps most ambitiously, in his keynote speech to the annual International Astronautical Congress in Guadalajara in September 2016, Elon Musk outlined ambitious plans for the colonisation of Mars within the next century[57]. Each one of the projects presents significant technical challenges, but, as befits such ambitious plans, these technical challenges are matched by legal and policy questions. Moreover, prospective missions to celestial bodies other than the Moon will pose difficulties in respect of crew management on long-distance spaceflight that have yet to be adequately addressed[58].

6. Embedding sustainability in future exploration

Not all space resource missions are necessarily purely profit driven or commercially focused. For example, the Chinese state-sponsored Chang'e missions involve an assessment of potential resource benefits[59]. Nevertheless, the scale of Chinese lunar objectives, coupled with the ambition shown by numerous commercial ventures, illustrate the need to begin embedding sustainability into the normative rules underpinning any future development of the Moon and other celestial bodies. The current regulation of lunar activities, indeed all the environmental provisions of international space law, have been extensively criticized, in all respects, as being inadequate[60]. The Moon Treaty was promulgated in 1979 and to date only 17 countries have ratified the agreement. No states with human spaceflight capability (specifically USA, Russia or China) are party to the treaty and as such it is a treaty that both lacks consensus and traction in international space law[61]. The Moon Treaty develops the limited environmental provisions of Art IX of the OST[62]. Viikari notes, however, that the Moon Treaty, like all the UN treaties has little in respect of environmental issues due to the fact that *'…at the time of their conclusion, such considerations were not among the highest-ranking items on the agendas of space faring nations.'*[63]

The lack of progress over embedding a sustainable and legally binding framework for the exploitation of bodies within the solar system could prove extremely damaging for future generations. It is argued that peaceful, scientific exploration of the Moon and other celestial bodies, supported by a fundamental commitment to limiting human-made degradation of the lunar environment is desirable as the cornerstone of a new treaty. Furthermore, these principles are far from unattainable given the consensus that already exists. A framework which provides for sustainable, environmentally sensitive scientific exploration of the Moon should chime with the current recognition of the need for guidelines for the mitigation of orbital debris. It should also be noted that, despite the criticism of the Moon Treaty, much of the substance of the 1979 Treaty is no more than a restatement of the principles outlined in the 1967 Treaty[64].

Sustainability in activities beyond LEO, on other celestial bodies, is an area where there is time for technical and legal professionals to work in harmony to provide optimal solutions whereby the needs of the present can be satisfied without compromising the viability of future exploration and development. The question is, with the promise of lucrative mineral resources, whether interested parties – state or private - will be prepared to wait for consensus to emerge. If the lure of access to mineral wealth proves too great, given the ambiguity inherent in the OST, states may seek to legislate on an individual basis leading to a fragmented approach to sustainability and fragmentary protection for the fragile space environment. Sadly, this may already be the direction of travel as, in November 2015, the US Government passed The Space Resource Exploration and Utilization Act[65] (hereinafter, Space Act 2015) that *inter alia* promotes "the right of U.S. citizens to engage in commercial exploration for and commercial recovery of space resources"[66]. Indeed, the act goes on to provide that US companies and citizens shall be entitled to any asteroid resource or space resource obtained, including to possess, own, transport, use and sell it per applicable law.

There have been diverging opinions as to the compatibility of the Space Act 2015 with international law, specifically whether it conflicts with the non-appropriation provisions of Art. II of the OST[67]. Equally concerning, however, must be the absence of any environmental regulation of celestial mining within the Space Act. Terrestrial experiences illustrate that there is no such thing as environmentally sensitive mining[68]. Yet consensus on the distribution of mineral resources predominate in discussions of regulating space activity beyond LEO. It is suggested that this is illustrative of the problems facing all advocates of sustainable development: when placed against the need to generate profit and mercantile opportunities, sustainability becomes an afterthought rather than a fundamental concept. Such a mind-set is a serious barrier to embedding sustainable practices within space activity.

7. Ethics and values in space policy

So far this inquiry into sustainability within space activity presents something of a disheartening picture. Where sustainable practices are recognised as being warranted (e.g. in LEO to combat space debris), it would appear to be a case of 'too little, too late'; where they are not yet recognised, perhaps because that part of the space environment has yet to be developed, it is a case of 'too early'. Where the activity is part of a bold vision of the future, the focus is upon enrichment and colonisation rather than environmental harmony. For historical reasons, the underlying space governance framework is mired in the geopolitics of the Cold War and not reflective of the current multi-sectored space industry. It is suggested that part of the reason sustainability has not embedded itself within mainstream space activity is because it was not embedded within the normative behaviour promoted by the space treaties. It is the purpose of this element of the discussion to relocate the underlying environmental values that could form the basis of a sustainability policy, feeding into a revivified system of space governance.

A starting point for this is the fundamental question concerning the moral relationship between humanity and the space environment. Specifically, whether there is an ethical obligation to respect or constrain activities on celestial bodies, and to what extent this should impact upon what humanity then chooses to do in space[69]. This is a logical starting point as any value system is based on accepted standards and needs to reflect what the community considered to be 'right'. The belief that space ethics, environmentalism and sustainability are part of the same nexus is possibly due to the conflation of these ideas by writers such as Eugene Hargrove[70] who examined notions of inherent value as it relates to terraforming[71]. Nonetheless, it can be argued that the majority of those involved in space activity have given primacy to achievement of mission objectives over the environmental impact of that achievement.

In the early days of space exploration, the goal was simply 'getting there'; achieving that goal was difficult enough without having to worry about the space environment. However, now that the technology is more mature, and thus more reliable, and the cost of doing so shows signs of decreasing, it is time for a correspondingly enlightened attitude towards that environment. Drawing on the example of terrestrial environmentalism, it is clear that there is broad agreement on the need to avoid or reduce pollution in that there are policies and treaties in place to protect at least parts of the terrestrial environment. Yet, as can be seen from the final iteration of the Space Act 2015, such policies and treaties continue to be vigorously challenged as they impose unwelcome regulation on companies and governments. There is no reason that the value system of terrestrial environmentalism should not be extended to the space environment such that parts of it are protected, either because they deserve protection or because it is in the best interests of the user community.

Although the sustainability of LEO appears, at last, to be part of the value system for the space environment, the sustainability of GEO and the graveyard orbit has yet to be included. Given that the protection of geostationary assets is a purely pragmatic aspiration, there is little cause for optimism that altruism will triumph over self-interest when it comes to protecting the surfaces, features and general environment of distant celestial bodies. In such cases, out of sight may truly mean out of mind. The promotion of sustainability as a core value in space activity becomes ever more urgent when considering the planning and development of such missions. This bottom-up approach - embedding sustainability within actual missions as a starting point - may succeed in creating a broad consensus, in much the way that debris mitigation within mission planning for LEO is now broadly embedded.

Additionally, there is a growing recognition amongst those outside the immediate space community that the topic of space sustainability and environmental protection has support: according to the results of the first 'Citizens' Debate on Space for Europe', organised by ESA in November 2016, feedback from the 2000 participants included the conclusion that "84% think space should be protected from polluting and potentially harmful human activities"[72]. While this is interesting anecdotal background, it is unlikely to carry much weight among those who wish to profit from the development of the space environment. Space activities remain difficult and expensive, so additional financial outlay on environmental protection measures may not be welcome.

The OST is entering its 50th year and has been criticised extensively by academics and practitioners alike for failing to reflect the modern reality of space activity[73]. Yet, we have experienced more than 50 years of peace in outer space, there has been no perceived threat from orbital nuclear weapons, and states have (broadly) adhered to the normative values laid down in the treaty. State responsibility for space activity is entrenched within both custom and practice of space activity and there is a presumption that no state can make territorial claims in outer space[74]. The US Space Act 2015 goes out of its way to illustrate that it is complying with existing international law. Similarly, private companies, such as Moon Express and its founder Bob Richards have spent both time and money in ensuring that commercial activities comply with, not only the terms of the OST, but also the underlying spirit[75]. The great shame is that the OST was drafted at a time when environmentalism, as we know it today, was in its infancy. It is tempting to speculate whether sustainability could have become part of normative space regulation had it been embedded within the OST.

Regrettably, the portents for successful negotiation of a new, overarching space treaty to replace the OST are not good. As Danilenko identifies, rather than channelling consensus, the uncertain political reality of the world at present means that a comprehensive space treaty is likely to encounter serious political opposition[76]. Despite the change in both the sophistication of the technology and the nature of the participants, there has been a lack of binding international space law over the last four decades, despite an increase in space activity. Recent political events such as the imminent British exit from the European Union (Brexit) have shown that all-encompassing international treaties have fallen out of favour as states prefer more agile individual agreements[77].

Regarding the space environment, Yasushi Horikawa, former chair of the UNCOPUOS, states: "*All the space actors must behave responsibly to ensure sustainable use of outer space. For this again, international cooperation is necessary and advanced space-faring nations should consider capacity building for the long-term sustainability of outer space.*"[78] There is a place for non-binding agreements and soft provisions; they operate in areas such as planetary protection and form the basis of the International Telecommunication Union (ITU). The use of non-binding codes of conduct and guidelines (such as the UN Debris Mitigation Guidelines) can go some way towards filling the gap and shaping normative behaviour.

However, these 'soft mechanisms' may be of little use in persuading private space actors, more focused on return on investment and potential profits than on embedding environmental sustainability. The debate on space sustainability is far from over.

8. Conclusions

Sustainability and sustainable development are terms that tend to be used without any clear indication as to what sustainability means; all too often, they are catch-all terms devoid of specific goals beyond a vague reference to an ecological ideal. This inquiry has reaffirmed that, in a space context, sustainable development is a specific requirement to satisfy the needs of current space missions while ensuring the viability of future ventures. In concert with that, sustainability should mean that minimising harm to the environment becomes part of the mission objectives alongside other technical and scientific goals; it is, however, argued that, beyond LEO applications and beyond the field of biological contamination summarised in the term ‘planetary protection’, this is too rarely the case in practice.

More positively, the exploration of space is currently driven by factors other than a race to showcase competing ideologies and there exists an opportunity for dialogue among all actors, both public and private sector, in both developed and developing nations, to ensure an orderly and equitable exploration of space. It is suggested that the lessons learned from space activity in LEO and GEO mean that this dialogue needs to be predicated on an underpinning value system that recognises and respects the fragile nature of the space environment.

Specifically, the emerging consensus on orbital debris should be channelled into more robust action and its focus extended beyond LEO. Clearly, replicating current behaviours beyond LEO will lead to similar environmental issues that are being witnessed there today. The Earth has a natural mechanism to deal with debris from space; the Moon does not, and this must be recognised in any plans for lunar development. Similarly, the prospect of riches from the sky must not blind policy makers and mission planners to the environmental harm that any form of mining can cause. Although cautionary in tone, this discussion has illustrated that by recognizing the need for sustainable practices from the outset, individual missions and ventures can incorporate environmental protection and sustainable practices as integral mission objectives[79].

The move from state actors to a multi-sectored space activity poses difficult regulatory questions that will need to be addressed. For example, relying solely on regulation to accomplish the paradigm shift from ‘simply achieving the outcome’ to ‘incorporating harmony with the environment as part of the outcome’ is unlikely to work. Those responsible for space activity should, instead, look to import sustainable values and try to create a shared understanding that becomes codified through regulation, rather than derived from it. Fundamentally, if space activity is to be sustainable for future generations, the different values that underpin state activity and commercial activity will need to be reconciled with the need for respect for the fragile space environment.

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[1] John S. Lewis, *Mining the Sky: Untold Riches from the Asteroids, Comets, and Planets* (Perseus Publishing 1997)

[2] For detailed discussion on the increased awareness of this area in the early years of the 21st Century see Mark Williamson, *Space: The Fragile Frontier* (American Institute of Aeronautics and Astronautics 2006)

[3] Gerard Brachet, "Protecting our space interests", ROOM - The Space Journal, Winter 2017 (#4 (10) 2017)
[4] See, for example, Carmen Pardini & Luciano Anselmo, "Assessment of the consequences of the Fengyun-1C breakup in low Earth orbit", (2009) 5 Advances in Space Research 545-557
[5] https://swfound.org/media/6575/swf_iridium_cosmos_collision_fact_sheet_updated_2012.pdf (accessed Feb 12 2017)
[6] Mark Williamson, "Space Ethics and Protection of the Space Environment" (2003) 19 Space Policy 47-52
[7] Mark Williamson, "Can Musk Achieve his Mars Dream?" Engineering & Technology, Nov 2016, 18-19
[8] United Nations Office for Outer Space Affairs (2016) 'Guidelines for the long-term sustainability of outer space activities'. Available at: http://www.unoosa.org/oosa/oosadoc/data/documents/2016/aac.1052017c.1l/aac.105c.1l.354_0.html (Accessed: 6 November 2016)]
[9] See, for example, Andrew Chaikin, *A Man on the Moon* (Penguin, 1998), p578
[10] William Kramer, "Extraterrestrial environmental impact assessments - A foreseeable prerequisite for wise decisions regarding outer space exploration, research and development." (2014) 30 Space Policy 215-222, 215
[11] Rachel Carson, *Silent Spring* (Houghton Mifflin, 1962)
[12] Paul R. Ehrlich, *The Population Bomb* (Sierra Club/Ballentine Books, 1968)
[13] Garrett Hardin, "The Tragedy of the Commons", (1968) 162 Science 1243
[14] For further discussion of the notion of governance of the commons see Elinor Ostrom, *The Evolution of Institutions for Collective Action*, (Cambridge University Press, 1990).
[15] World Commission on Environment and Development. Our Common Future. Oxford University Press. Oxford. UK, 1987 quoted in Pope J, Annandale D, Morrison-Saunders A. "Conceptualizing sustainability assessment." (2004) 24 Environmental Impact Assessment Review 595-616.
[16] http://swfound.org/our-focus/space-sustainability/
[17] Christopher J. Newman, "Seeking Tranquility: Embedding Sustainability in Lunar Exploration Policy" (2015) 33 Space Policy 29-37
[18] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies: 610 UNTS 205; 1968 UKTS 10, Cmnd. 3519; 18 UST 2410, TIAS 6347; (1967) 6 ILM 386; (1967) 61 AJIL 644. It was adopted by the General Assembly of the United Nations on 19th December 1966 and opened for signature on 27th January 1967 in London. It entered into force on 10th October 1967.
[19] See for further details on the historical origins of the Outer Space Treaty see, inter alia, Joanne Gabrynowicz "Space law: Its Cold War origins and challenges in the era of globalization." (2004) 37 Suffolk U L Rev 1041
[20] Francis Lyall and Paul B Larsen, *Space Law: A Treatise* (Ashgate 2009) 57
[21] ibid 58
[22] Evidence for the broad acceptance of the principles within the OST can be seen in a number of places. This includes wide spread incorporation within domestic law of the need for licensing and supervisory provisions as required by Art VI OST (for example ss.4-5 Outer Space Act 1986). The prohibition on the stationing of Nuclear weapons in outer space, contrary to Art IV of the OST has been manifestly observed by nuclear powers. Finally, discussions on the question of space resources are dominated by the legality of distributing any such resource in light of Art II of the OST.
[23] Lyall and Larsen (n20) 59
[24] PJ Blount, "Renovating space: the future of international space law." (2011-2012) 40 Denv J.Int'l L&Pol'y, 515-532, 516
[25] Indeed, the first in-orbit explosion occurred quite early in the Space Age, on 29 June 1961, when the *Able Star* upper stage used to launch the Transit 4A satellite produced 296 catalogued pieces of debris; significantly, 191 pieces were still in orbit in 2001, see for further details: Anz-Meader, Phillip D et al,

"History of On-Orbit Satellite Fragmentations" (12th edition, JSC29517, July 31, 2001) NASA Lyndon B. Johnson Space Center Orbital Debris Program Office

[26] Nicholas Welly, "Enlightened State Interest: A legal framework for protecting the "Common Interest of All Mankind" from Hardinian Tragedy." (2010) 36 J Space L 273-313

[27] Phillip Slann, "Space Debris and the need for space traffic control." (2014) 30 Space Policy 40-42 and for a detailed discussion on the broader environmental problems facing the space environment see Williamson (n2) and Lotta Viikari, *The environmental element in space law* (Martinus Nijhoff Publishers 2008)

[28] Donald J. Kessler & Burton G. Cour-Palais, "Collision frequency of artificial satellites: The creation of a debris belt." (1978) 83 (A6) J Geophys Res, 637–2646

[29] In-orbit explosions and collisions do not confine themselves and their effects to a single orbital track at a given altitude and inclination: depending on the trajectory of the ensuing debris, a wide variety of orbital altitudes and inclinations may be affected

[30] For consideration of the legal implications of Space Debris see *inter alia* Stephan Hobe, "Environmental Protection in Outer Space: Where we stand and what is needed to make progress with regard to the problem of space debris." (2012) 8 Indiana Journal of Law and Technology, 1-10

[31] Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space as annexed to UN do. A/62/20, Report of the UNCOPUOS (2007), no 1, para 1. This paragraph also speaks of the potential risk of damage on the ground if uncontrolled debris survives the re-entry through the atmosphere of the Earth

[32] See, for example Williamson (n2) and Viikari, n27.

[33] Hobe (n30) 3

[34] Michael C Mineiro, "FY-1C and USA-193 ASAT Intercepts: An assessment of legal obligations under Article IX of the Outer Space Treaty" (2008) 34 J Space L 321-356

[35] See Christopher J. Newman, "The Undiscovered Country: Establishing an ethical paradigm for space activities in the 21st Century." In Alan Lawton, Leo Huberts and Zeger van der Wal (eds), *Ethics in Public Policy and Management* (Routledge 2015), 311

[36] *Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space,* as annexed to UN doc. A/62/20, Report of the UNCOPUOS (2007), no. 1,para. 1.

[37] In addition to the IADC, ESA coordinates European research into orbital debris via the ESA Space Debris Office. NASA has established the Orbital Debris Program Office at the Johnson Space Center, which conducts research into all aspects of the management, mitigation and remediation of orbital debris

[38] See for details Stephan Hobe and JH Mey "UN Space Debris Mitigation Guidelines", (2009) 58 ZLW 388-403, 402

[39] Newman (n35) 312

[40] For further details on the difficulties faced in this area, Jer-Chyi Liou, "An active debris removal parametric study for LEO environment remediation", (2011) 11 Advances in Space Research 1865-1876

[41] JAXA has recently launched the Kounotori mission to the ISS seeking to utilize an experimental tether to remove redundant satellites and debris from orbit. See https://phys.org/news/2016-12-japan-space-junk-collector.html for details (accessed Feb 12 2017 at 14:37)

[42] For a full discussion on the legal dimensions to this issue, see Michael Listner, "Addressing the challenges of space debris, part 2: liability." The Space Review, Dec 17, 2012, available at: http://www.thespacereview.com/article/2204/1 (Accessed Feb 12 2017)

[43] See above (n38)

[44] The work of the IADC and the UN Debris Mitigation guidelines has established accepted norms regarding measures to be taken in reducing the amount of debris created by new missions. For example, the requirements that need to be met before the UK Government will grant a licence under s.5 of the Outer Space Act 1986 includes a requirement that end of mission de-orbit measures are considered by the operator.

[45] For details of the current problems in describing GEO space debris environment see: Wang Dongfang, Pang Baojun, Xiao Weike and Peng Keke, "GEO objects spatial density and collision probability in the Earth-centred Earth-fixed (ECEF) coordinate system" (2016) 118 Acta Astronautica 218-223

[46] Williamson (n2) 248

[47] See, for example Steve Hoeser, "Getting back to the historic sequence of opening our space frontiers." The Space Review, Feb 6 2017, available at: http://www.thespacereview.com/article/3165/1 (Accessed Feb 12 2017)

[48] There is evidence that this mindset is now changing with the plans of Elon Musk and Space X for the settlement of Mars. See, for example, Jeff Foust, "Musk unveils revised version of giant interplanetary launch system", Space News (Sep 29 2017), available at http://spacenews.com/musk-unveils-revised-version-of-giant-interplanetary-launch-system/ (Accessed Feb 19 2018).

[49] Agreement Governing the Activities of States on the Moon and other Celestial Bodies, UN Doc. A/34/664. New York (UN) 5 December 1979. Both the OST and Moon Treaty are available at http://www.oosa.unvienna.org/pdf/publications/ST_SPACE_061Rev01E.pdf

[50] For details see inter alia, Virgiliu Pop, Who Owns the Moon? Extraterrestrial Aspects of Land and Mineral Resources Ownership (Springer 2008) and Fabio Tronchetti, "The Moon Agreement in the 21st Century: Addressing its potential role in the era of commercial exploitation of the natural resources of the Moon and other celestial bodies", (2010) 36 J Space L 489-524

[51] Mark Williamson, *Spacecraft Technolongy: The Early Years*, (IEE 2006) 360

[52] See Williamson (n2) Chapter 4 for details of the damage to the delicate lunar environment.

[53] Jeff Foust, "Google Lunar X Prize teams await word of their fate", Space News (Dec 30 2016), available at: http://spacenews.com/google-lunar-x-prize-teams-await-word-of-their-fate/ (Accessed Feb 12 2017)

[54] For further details on all aspects of the Chinese Lunar exploration programme see M P Hilborne, "China." (2016) 37 Space Policy 39-45, 40

[55] Williamson (n2) 105

[56] http://www.planetaryresources.com

[57] Kenneth Chang, "Elon Musk's Plan: Get Humans to Mars, and Beyond", New York Times, Sept 27 2016 available online at https://www.nytimes.com/2016/09/28/science/elon-musk-spacex-mars-exploration.html?_r=0 accessed Feb 12 2017

[58] For a discussion of some of these issues see, inter alia, Albert A. Harrison, Spacefaring, (University of California Press 2001) and Christopher J. Newman, "'The Way to Eden': Environmental legal and ethical values in interplanetary space flight", in Tony Milligan and James Schwartz (eds), *The Ethics of Space Exploration* (Springer 2016)

[59] For a broader consideration of Sustainability from a Chinese perspective see Rong Du, "China's approach to space sustainability: Legal and policy analysis." (2017) 42 Space Policy 8-16

[60] Newman (n17) 33

[61] For a more optimistic vision of how the Moon Treaty can be resurrected see Stephan Hobe, "The Moon Agreement – Let's Use the Chance!" (2010) 59 ZLW 372-381

[62] Art. 7 of the Moon Treaty provides the environmental provisions

[63] Viikari, (n27) 55

[64] Timothy G Nelson, "The Moon Agreement and Private Enterprise: Lessons from Investment Law" (2011) 17 ILSA J Int'l & Comp 393-416, 395

[65] This act was part of the Commercial Space Launch Competitiveness Act (HR 2262).

[66] For the full text of the Space Resource Exploration and Utilization Act 2015 see; https://www.congress.gov/bill/114th-congress/senate-bill/976/text

[67] Article II of the OST provides that 'Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.'

[68] See: Ravi Jain, *Environmental Impact of Mining and Mineral Processing*, (3rd Ed, Butterworth-Heinemann, 2015)

[69] James Schwartz & Tony Milligan, "The Scope and Content of Space Ethics" in Schwartz & Milligan (n57) 2

[70] Eugene Hargrove (ed), *Beyond Spaceship Earth: Environmental Ethics and the Solar System* (Sierra Club Books 1986)

[71] Quoted in Schwartz & Milligan, (n57) 2

[72] ESA (2016) 'Citizens' space debate: the main findings and the future', ESA Press Release N°49-2016, Paris, 28 November 2016. Available at: http://www.esa.int/For_Media/Press_Releases/Citizens_space_debate_the_main_findings_and_the_future (Accessed: Nov 28 2016).

[73] See, *inter alia*, Nelson (n63), Cesar Jaramillo, "The multifaceted nature of space security challenges" (2015) 33 Space Policy 63-66. For a balanced assessment of the operation of the OST and its suitability to deal with the onset of resource extraction see Ram S. Jakhu, Joseph N. Pelton and Yaw Out Mankata Nyampong, *Space Mining and its Regulation* (Springer Praxis, 2016).

[74] Christopher D. Johnson, "The Outer Space Treaty at 50." The Space Review, 23 Jan 2017 available at http://thespacereview.com/article/3155/1 accessed 12 Feb 2017

[75] See Tanja Masson-Zwaan and Bob Richards, "Op-Ed: International Perspectives on Space Resource Rights." Space News, December 8, 2015. Available at http://spacenews.com/op-ed-international-perspectives-on-space-resource-rights/ accessed Feb 12 2017

[76] Gennady M. Danilenko, "International law-making for outer space" (2016) 37 Space Policy 179-183, 183

[77] See, for example the US and India space agreement of 2014 http://www.bbc.co.uk/news/science-environment-29439256 accessed Feb 12 2017

[78] Horikawa, Y. (2014), 'ICoC and Long Term Sustainability of Outer Space Activities' In: R. Rajogopalan and D. Porras, ed., 'Awaiting Launch: Perspectives on the Draft ICoC for Outer Space Activities', 1st ed. www.orfonline.org: Observer Research Foundation, pp.19-25 at p.25

[79] For detailed consideration of the application of Environmental Impact Assessments in outer space activity see William Kramer, "In Dreams Being Responsibilities -- Environmental impact assessment and outer space development" (2017) 19 Environmental Practice 128-138.