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Fostering multi-stakeholder collaboration for space sustainability through an incentive-based mechanism

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Abstract

The proliferation of debris in the space environment, congesting the Low Earth Orbit (LEO), constitutes a major challenge to the safety and sustainability of space missions and operations. Policymakers at the national, regional and international levels are developing and implementing legal and binding frameworks to address the concerns of space debris. The processes require increased coordination and collaboration and are likely to take a number of years before entering into force.

However, as the sense of urgency calls for immediate innovative, multi stakeholder solutions with a global scope, private actors from the space industry can fill the current void by undertaking initiatives which would foster voluntary and inclusive action for the long-term sustainability of outer space. The Space Sustainability Rating (SSR) presents a compelling example, with the aim of incentivising space operators to encourage space actors to design and implement sustainable space missions and operations while enabling other key stakeholders from the space ecosystem to become part of this collaborative effort.

In particular, the SSR provides a new way to address space debris mitigation through a two-pronged approach: 1. It provides a rating system usable by satellite manufacturers and operators informed by transparent and comprehensive assessment to get a clear picture of where a specific mission stands on sustainability and against best practices. 2. It hosts an action-focused platform in which all actors from the space sector can engage, including throughout the value chain. In other terms, the SSR can serve as an action arm for the implementation of the current and future guidelines for space sustainability.

This article will present how space actors, with a focus on satellite operators, are using the SSR. By showcasing an example of rating process and lessons learned with EnduroSat's Platform-1, it will analyse its effectiveness to incentivise space actors to implement sustainable behaviours and list the benefits they can derive from using the rating system. Furthermore, the experience of satellite operators from the other side will also be described. The potential future developments to strengthen the incentive-based mechanism of the SSR will be explored, and ultimately how its promotion among stakeholders, and potential spill-over can lead to a wider adoption of the rating system (for operators, stakeholders from the space ecosystem and policymakers).

Keywords: (maximum 6 keywords)
Space Sustainability, Mission Rating, Incentive, LTS, STM, Rating Advantages

Acronyms/Abbreviations

ADOS	Application of Design and Operation Standards
COLA	Collision Avoidance Capabilities
DIT	Detectability, Identification and Trackability
DS	Data Sharing
EO	Earth Observation
ES	External Services
LEOP	Launch and Early Operations Phase
LTS	Long-Term Sustainability
SSR	Space Sustainability Rating
UN COPOUOS	United Nations Committee on the Peaceful Uses of Outer Space

1. Introduction

"Due to the lack of opportunity to properly assess the risk it could pose to the astronauts, teams have decided to delay the spacewalk planned for Tuesday, November 30 (2021), until more information is available," NASA said in a statement[1]. These types of announcement are more and more frequent as the space debris population is growing every year in an exponential manner. As per the ESA environmental report 2023, at the end of 2022 more than 32,000 objects larger than 10 cm are orbiting the earth, and ITU filings show plans for millions of satellites to be sent into space[2]. In addition, on average over the last two decades, 11.2 non-deliberate fragmentations continue to occur in the space environment every year[3]. These numbers do not promise a sustainable evolution of the space environment.

Sustainability is a broad concept and therefore in the frame of this paper, the authors considers the one from UN COPOUS as a reference:
“The long-term sustainability of outer space activities is defined as the ability to maintain the conduct of space activities indefinitely into the future in a manner that realizes the objectives of equitable access to the benefits of the exploration and use of space for peaceful purposes, in order to meet the needs of the present generations while preserving the out-space environment.”

The proliferation of debris in the space environment congesting the Low Earth Orbit (LEO), constitutes a major challenge to the safety and sustainability of space missions and operations. Policy makers at the national, regional and international levels are developing and implementing legal and binding frameworks to address the concerns of space debris. The processes require increased coordination and collaboration and are likely to take a number of years before entering into force.

The Space Sustainability Rating (SSR) is on a mission to encouraging space actors to design and implement sustainable and responsible space missions for the long-term sustainability of the space environment. The association supports space actors, such as governments, space agencies, and commercial companies in understanding the impact of their activities on the space environment, identifying opportunities to minimize those impacts, and taking an active role in making space safer and more sustainable for all.

The SSR is a new way to incentivise safer conditions for operating in space. It is an initiative that seeks to foster voluntary actions by satellite operators to reduce the risks related to space debris and on-orbit collisions providing: 1. A rating system informed by transparent, data-based assessments of the level of sustainability of space missions. 2. Practical guidance on how to improve sustainability performance and practices; and 3. A platform for action-focused collaboration centred on the rating system to support research and leverage best practices.

After a short overview of the SSR, this paper will showcase the rating performed with Endurosat on their Platform-1, describing the process, the inputs provided and the rating outcome. As a co-author of this paper, Endurosat will also present their experience of the rating process and the added value for them. Then in the section, the authors will explore different paths to identify how to use the SSR to incentivise sustainable behaviour in space.

2. Overview of the SSR

1.1 Short description of the SSR

The rating is a voluntary system and operators are invited to pay a fee to receive a set of ratings during the membership years, the rating process includes the technical analysis and recommendations on how to improve the rating. In order to complete a rating, an operator must complete a questionnaire and provide technical data about the mission. The rating is higher if the operator provides validation information, including technical documentation and third-party verification of information related to the rating.

Finally, the SSR is an association organized in Switzerland and has members and a steering committee

The SSR framework consist of six modules:
1. Mission Index which measures the impact of the mission on the space environment;
2. Collision Avoidance Capabilities (COLA) 0: the ability of the mission to perform collision avoidance manoeuvre and the associated processes;
3. Data Sharing (DS)[14];
4. Detection Identification and Tracking (DIT) [15] which measures the ability of the mission to be detected, identified and tracked;
5. Application of Design and operation Standards (ADOS) [16]; and
6. External Services (ES) [17], which assess the capability of the mission to be compatible with future On-orbit servicing missions.

While the DIT and Mission Index are computational, based on numerical parameters that will then output a score, the other four modules are questionnaire based. The External Module is a bonus module, giving only additional points that are outside the core assessment. More information is available under the following sources. [7][8][10][9] [11][12]

1.2 Main Achievement from June 2022 to October 2023

The following chapter will present the main achievements from June 2022 to October 2023 [4] . In total, four ratings have been performed and two are underway, including three constellations and three nano to mini single satellite missions[1]

As the team performed ratings, several questions were addressed regarding the process, documentation, as well as on the technical methodology

As the rating process needs to be clear and well understood by rated entities, the team has focused its effort from the beta-testing feedback to assemble all the necessary documentation to perform a rating in a single rating data-pack. This data-pack provides the SSR applicants a better understanding of the rating process, references, but most importantly, of the technical methodology through:

Module handbooks;

- Tutorial documents explaining how to compute critical input values (such as the so-called “mitigated collision risk”, input to the mission index allowing to quantify the efficiency of a given collision avoidance strategy based on the accepted risk).
- Additional tools allowing to approximate certain rating values based on simplified assumptions. These tools are especially useful for missions in pre-design, in order to be able to play with mission parameters and preview an approximated score for certain modules.

2022 allowed the team to efficiently test the rating on a large variety of missions, enabling them to significantly enhance the model’s accuracy for particular mission cases such as constellations, and for challenging concepts of operations, including orbit raising, parking orbits at intermediate altitudes, and low-thrust propulsion.

This rating computation capability increase is also driving new development, as the aforementioned mission aspects are not yet implemented in the RATE SPACE web-based interface.

As the hand-over from the SSR consortium to the EPFL Space Center was performed, the ownership of the computation method of the Detectability, Identification, and Trackability (DIT) module was performed between the Space Enabled Research Group at MIT and the SSR team. This transfer allows a faster computation timeline, as well as more score analysis capabilities.

Finally, additional work for future enhancement of the rating have been performed notably on the life cycle assessment single score and the Dark and Quiet skies modules. They will not be described in this paper but further references are available there [6] [6]

3. “Platform-1” mission rating:

This section provides an example of a rating use case, considering the different perspectives from the satellite operator and rating issuer.
The rating described in this section is a mission encompassing one satellite manufactured and operated by EnduroSat. The technical work on the rating (excluding contractual work to sign agreements) took place between August 18 and November 11, 2022. Here below is a list of key dates and milestones in the

[1] Spacecraft mass classes in accordance with definitions of the FAA The Annual Compendium of Commercial Space Transportation: 2018, Table 11 (p. 100).

rating process, providing an example of the time required to perform a rating. The timeline below encompasses three formats: a calendar date, "D+…" for the calendar days elapsed and "WD+…" for the working days elapsed[2]:

- August 18 / D0 / WD0: Technical documentation is sent by the SSR team, allowing the rating technical process to begin.
- August 23 / D+5 / WD+3: Kick-off meeting including a description of the SSR material, clarification of some rating inputs.
  August 26 / D+8 / WD+6: First version of inputs list provided by the applicant to the SSR issuer.
- September 6 / D+19 / WD+13: First iteration of inputs list review containing comments from the SSR issuer and further verifications to provide by the applicant.
- September 14 / D+27 / WD+19: Second iteration of input list review based on previous comments and answer from applicant.
- October 3 / D+46 / WD+31: First score computation performed and issued alongside a preliminary set of score improvement measures, mainly focussed on justification of compliance to some rating criteria.
- October 4 / D+47 / WD+32: Decision from EnduroSat to provide further justification, improving the verification levels of provided inputs, allowing them to achieve a higher score.
- October 7 / D+50 / WD+35: Meeting to discuss score improvement based on issued score improvement measures.
- October 26 / D+69 / WD+48: Justifications provided by the SSR applicant, second score computation is performed.
- October 31 / D+74 / WD+51: Technical report issued and provided to the applicant showing score status and further recommendations to improve the score.
- November 11 / D+85 / WD+60: Closure meeting including technical report presentation and feedback from operator on the rating process.

The technical process involved the SSR operation officer and one engineer from EnduroSat. The work was not performed full-time but rather through regular exchanges to clarify requested inputs and expected justification. It must be noted that some computation setbacks were experienced during this rating due to a licence procurement issue that delayed the process. At the same time, it was the second official rating delivered, and process improvements have been implemented since, making the process more efficient.

[2] Accounting for September 19, 2022 being a bank holiday in Switzerland.

3.1 Description of EnduroSat Platform-1

EnduroSat's Platform-1, a 6U CubeSat, built for Earth Observation (EO) applications, was launched on May 25, 2022. This satellite incorporates advanced sensors, including Visible and Near-Infrared (VNIR) hyperspectral imagers and Infrared (IR) spectrometers, enabling a range of applications from air quality monitoring to environmental assessment. In addition to its optical payload, Platform-1 showcased edge computing capabilities, catering to the needs of commercial customers such as IBM and Red Hat. Following a well-executed launch and the thorough implementation of the Launch and Early Operations Phase (LEOP), extensive subsystem testing and telemetry data collection were conducted to validate both the satellite bus and payload functionality. Notably, the Electric Power System (EPS) ensured a consistent and reliable power supply, while the Attitude Determination and Control System (ADCS) demonstrated its unwavering reliability in orbit. This is of paramount importance, especially for EO missions, where precise targeting of specific areas on the ground is imperative.

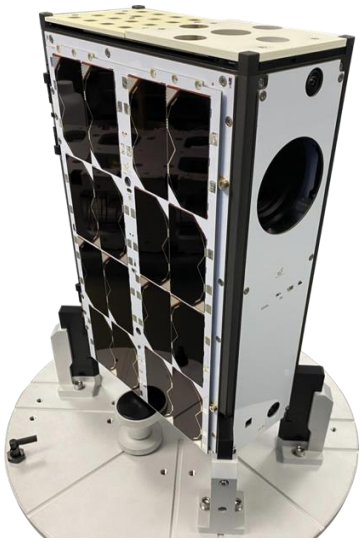

Figure 1: PLATFORM-1 6U CubeSat with optical camera payload (right hand side).

The combination of advanced sensor technology and computing capabilities on Platform-1 represents a substantial leap forward in satellite technology. It not only expands the horizons of scientific research but also opens doors to a multitude of practical applications. The successful deployment of VNIR hyperspectral imagers and IR spectrometers underscores the satellite's versatility in addressing pressing environmental concerns. Moreover, the integration of edge computing capabilities is a testament to its adaptability for modern commercial demands. Platform-1's journey from launch to rigorous in-orbit testing stands as a testament to its robustness and potential to revolutionize EO missions and satellite-based research endeavours.

3.2 Rating outcome

Disclaimer: The rating was issued for the "Platform-1" **mission** during the operational phase. Computing a rating implies evaluating operational parameters considering the orbit a spacecraft operates in, best practises for data sharing, and compliance to guidelines implemented by the spacecraft operator. As a consequence, similar platforms can score differently based on the set of parameters above and the rating outcomes presented in this work does not represent the sustainability of a given platform, but rather the overall results for the **mission**.

Based on the performed evaluation, the computed tier score for Platform-1 mission is 72.7%, with a bonus score of 38.56%, resulting in a **gold rating with one bonus star** (Figure 2, Figure 3). The score details are displayed in Table 1**.**

Table 1: Platform-1's rating individual module scores, aggregated tier and bonus score

Modules	Score
Mission Index	82.37%
COLA	80.56%
Data Sharing	45.27%
DIT	63.89%
ADOS	61.88%
External Services	25%
Tier Score	**72.7%**
Bonus Score	**38.56**

Figure 2: Platform-1 mission badge - Gold, one bonus star

Figure 3: Platform-1 mission rating certification, mentioning the rating level and operational phase of the mission

While the exact content of the SSR technical report shall not be disclosed, it is important to explain how this score was achieved:

- The satellite orbit allows a re-entry by natural decay compliant with the currently advised practises for de orbiting. Coupled with a low spacecraft cross-sectional area, the aggregated collision risk over the lifetime is low, even though no propulsive manoeuvre for collision avoidance can be performed;
- Several Space Situational Awareness providers are contracted, providing conjunction screening, accurate and periodical orbital state knowledge monitoring, data sharing of spaceflight related data with other satellite operators. These aspects impact the score positively on the Collision Avoidance capabilities, Data Sharing and DIT modules;
- The spacecraft is considered highly detectable based on the DIT module criteria[3];
- The mission complies with most space debris mitigation guidelines and standards;
- As presented in previous work ([7], [8], [35]), the data verification process has a substantial

[3] As a side note, even though Dark and Quiet Skies are not yet part of the SSR assessment, Platform-1 rating shows a visual magnitude allowing detection but not impacting too much astronomical observation by remaining dimmer than threshold of apparent visual magnitudes recommended by the International Astronomical Union (section B.2.Reco.5).

impact on the SSR assessment. Most data provided in the scope of this mission's rating were either supported by technical documentation, or could be verified by third party entities, as shown in Figure 4, resulting in a mean level of verification[4] of 78.6%.

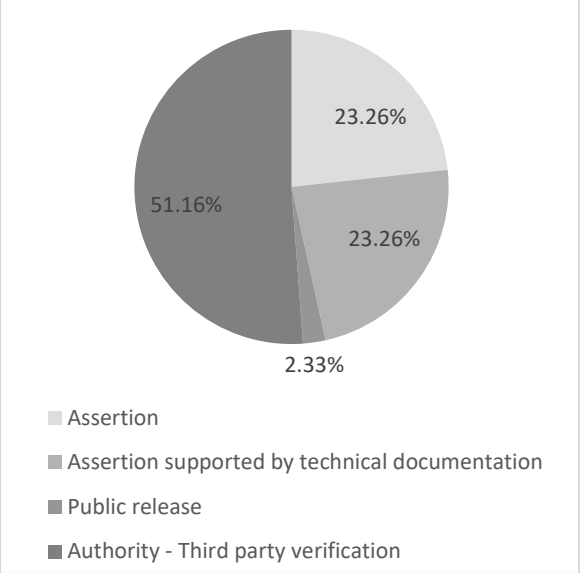

Figure 4: Level of data verification for the Platform-1 mission

3.3 Recommendations

While the Platform-1 mission incorporates most current sustainability practices, showing consideration for the orbital environment in design and operation of mission, recommendations were nevertheless issued by the SSR issuer. Such recommendations, as the mission was already launched, were mainly focussed on operational aspects, and in particular with respect to the data sharing practises, hence showing the high score improvement potential in this module as shown in Figure 5 and Table 2. The implementation of the measures identified by the SSR issuer shows a score above the 80% platinum threshold. While implementing the measures identified by the SSR issuer is not necessarily straightforward, is shows that the aspirational target of a platinum rating can be achieved by Platform-1 if strictly complying to the highest rating standards. The recommendations are hence provided as an incentive for further efforts both for the future of the Platform-1 mission, but also as a baseline for future missions.

[4] Mean value from the verification level of each compliant inputs, considering the following weighting for each verification level: "Assertion" 0.5, "Assertion supported by technical documentation" 0.6, "Public release of the technical documentation" 0.8, "Authority – third party verification" 1. Levels of verification further detailed in **Error! Reference source not found.**.

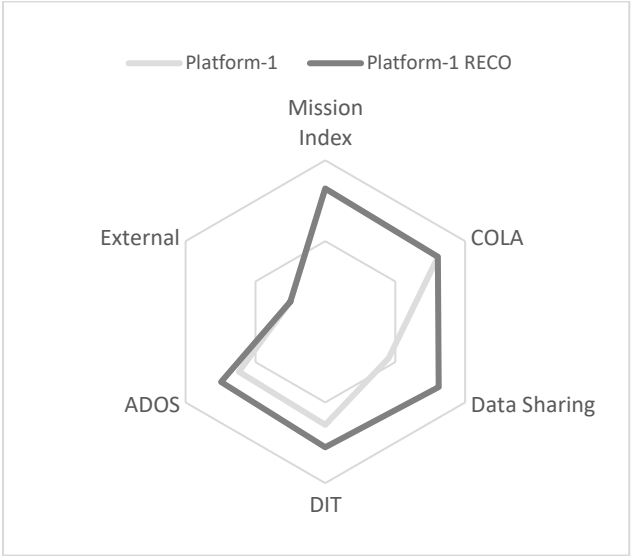

Figure 5: Web chart of module scores for Platform-1 rating and projected score if the issued recommendations are implemented

Table 2: Module scores for Platform-1 rating and projected scores if the issued recommendations are implemented

Modules	Platform-1	Platform-1 RECO
Mission Index	82.37%	82.52%
COLA	80.56%	80.56%
Data Sharing	45.27%	81.08%
DIT	63.89%	77.78%
ADOS	61.88%	74.63%
External Services	25%	25%
Tier Score	**72.7%**	**81.00%**
Bonus Score	**38.56**	**57.23%**

3.3 Perspective of the operator

The awarding of a Gold rating from the SSR for EnduroSat's Platform-1 represents a significant boost to the company's business prospects. This prestigious recognition not only validates EnduroSat's commitment to responsible and sustainable space practices, but also enhances the company's reputation as a trustworthy and environmentally conscious player in the satellite industry. A Gold rating underscores EnduroSat's dedication to mitigating space debris and minimizing the potential for collisions in the

increasingly crowded orbital environment. It resonates with clients, investors, and partners alike, signalling EnduroSat's proactive approach toward ensuring the long-term sustainability of outer space. As a result, the golden rating not only fosters trust among existing customers but also positions EnduroSat favourable for future collaborations and contracts, thus strengthening the company's foothold in the competitive space technology market and promoting responsible behaviour while conducting space activities.

The strong imperative to work with the SSR and obtain a space sustainability rating is multifaceted and brings several key advantages:

Enhancing Reputation and Trust: Obtaining a favourable rating demonstrates a commitment to responsible space practices, which enhances a company's reputation in the industry and among stakeholders. This, in turn, builds trust with customers, partners, and investors.

Competitive Advantage: A high sustainability rating can be a unique selling point for a company. In a competitive marketplace, it differentiates the business from competitors and can influence potential clients to choose the rated company for their satellite services or products.

Attracting Investors: Responsible space practices are increasingly important to investors who want to align their investments with sustainable and ethical principles. A high rating can attract socially responsible investors, potentially increasing access to capital.

Regulatory Compliance: As space becomes more congested, some governments may introduce regulations or incentives related to space sustainability. A good rating demonstrates compliance with potential future requirements.

Risk Mitigation: Good space sustainability practices reduce the risk of collisions and space debris creation, which could otherwise lead to operational disruptions, satellite damage, or loss, saving the company from potentially significant financial losses.

Long-term Viability: Space sustainability measures contribute to the long-term viability of space operations. Companies with a strong rating are better positioned to operate successfully in space over the long haul.

Marketing and Public Relations: A good sustainability rating can be leveraged in marketing and PR efforts, demonstrating a company's commitment to ethical and responsible practices, which can resonate positively with customers and the public.

In essence, obtaining a space sustainability rating is not just a matter of compliance or ethics; it is a strategic business move that can yield tangible benefits by improving reputation, competitiveness, and overall resilience in the rapidly evolving space industry. This has been confirmed through conversation with EnduroSat stakeholders throughout 2023.

Furthermore, a space sustainability rating can significantly improve satellite operations in the following ways:

Enhanced Collision Avoidance: A higher rating reflects a commitment to responsible space practices, which includes actively working to prevent satellite collisions. By implementing collision avoidance measures and adhering to best practices for orbital debris mitigation, satellite operators reduce the risk of costly collisions that could disrupt operations.

Longer Mission Lifetimes: Responsible space practices, such as end-of-life disposal and avoiding risky manoeuvres, contribute to longer mission lifetimes. Satellites can continue to operate effectively, providing valuable services for a more extended period, which can increase the return on investment.

Reduced Operational Risks: By adhering to space sustainability guidelines, satellite operators can minimize operational risks associated with space debris. This, in turn, reduces the likelihood of satellite damage or loss due to collisions or other debris-related incidents**.**

In conclusion, the participation in the SSR offers numerous advantages for satellite operators like EnduroSat. It strengthens operational efficiency by reducing collision risks, extending mission lifetimes, and enhancing regulatory compliance. Moreover, it fosters trust among stakeholders and opens doors to collaborations. With these benefits in mind, EnduroSat remains committed to prioritizing responsible space practices and will continue to seek ratings for its platforms.

5. *Developing incentives to perform a space sustainability rating*

When operators and large system integrators are developing the business case for performing a rating, they are also seeking incentives. It is therefore important to see the potential future developments to

strengthen the incentive-based mechanism of the SSR, and ultimately how its promotion among stakeholders, and potential spill-over, can lead to a wider adoption of the rating system (for operators, stakeholders from the space ecosystem, and policy makers).

Rathnaspabathy and David [24] presented the following options for incentives:

- Financial and economic incentives; (Incentive A)
- Support for current and potential regulations; (Incentive B)
- Altered procurement processes; (incentive C)
- Public perception; and (incentive D)
- Marketing and environmental, social and governance-style corporate reporting. (incentive E)

To understand how SSR adoption could be incentivised, the following actions have been taken:

- Research Project funded by the Swiss Secretariat of Research Education and Innovation in relation to the OECD Space forum: Addressing earth-space sustainability: An analysis of policy options for the long-term uses of satellite infrastructures
- IAA Working group: Opportunities for National Government to Foster Space Traffic Management using the Space Sustainability Rating.
- Student Project on ESG governance in Space
- Participation in international working group (ESA Zero Debris Charter Paris Peace Forum Net Zero Space initiative, UN LTS working group)

All these efforts are currently on-going and the following chapter will present the status in October 2023. Specific papers will follow-up.

5.1 Incentives and actors

In order to understand and map the different incentives, it is important to identify to whom they would benefit and by whom they are requested.

The different types of stakeholders are identified:

Spacecraft Operators and Large System Integrator (LSI): They build and operate satellites and constellation. An operator can be an LSI as well, for some missions an LSI will hand over the satellite to the operator after the launch and early operation phase. Finally, sometimes the owner of the constellation is a third party. For the rest of the paper, owners, developers and operators of the mission will be considered as spacecraft operators.

Licensing authorities (national and international): Licensing a launch, a mission or radio-frequency can be from a national organism (FAA in the US, CNES in France or ITU for international radio-frequency).

Procurement authorities (public and private): Procurement authorities are the agencies that lead the procurement of a space system, it can be a public entity

Sustainability actors: In this paper, Sustainability actors are the new business emerging providing services such as on-orbit servicing, active space debris removal and space situational services. They are the actors that promote and act for a more sustainable space environment. While this is the core of their business, they are driven by impact. In this area, the paper also considers researchers that develop technologies, frameworks to serve space sustainability.

Investors: The role of investors is increasing in the space sector, in particular in the commercial sector. While investors seek a return on investment within a certain timeframe, they also want to address the success of their venture. In general, studies are emerging showing that sustainability is an indicator of success for a small share of them. There is no data on how this would be the case for the space industry.

Insurers: When mentioning the SSR, the role of insurers is raised by operators. An aspect of space sustainability is strongly linked with space safety and the risk to space debris collision. In that matter, insurers have a strong interest to have a sustainable space environment. However, little public information is available on the insurance fees value in comparison to the total cost of the mission and how insurers would consider third party rating to link it to their fees.

Citizens or the general public: Often left out from the space sustainability debate, the general public is the "end customer" of the space-based infrastructure and benefit from the socio-economic benefit. However, they can also be the first victims or an unsustainable space activity (loss to key service such as connectivity but also victim of re-entry objects, etc…). Finally, the citizens should be informed on how the services they are using is procured and which impact it has on the space environment.

The next table shows which type of incentives would be impacting each actor. Operators will be interested and impacted by all incentives type from financial and economic, up to the marketing and CSR communication. They are at the core of the debate and can have the most impact. Licensing authorities have an impact on how they define the condition for delivering licenses, they can decide whether to add a clause related to sustainability. These requirements could be linked or not to a third-party assessment. Procurement authorities have the most impact on the altered procurement processes and can act upon the implementation of sustainability criteria in the evaluation/criteria of their tenders. This is similar to adding diversity criteria for grant calls in research. Similar to the operators, the sustainability actors will also have a strong interest in all the incentive types as their services can also be linked to the incentives. Investors will more interested in the financial and economic incentives, as they might be more prone to invest in sustainability (as per the definition of this paper) and also the public perception would impact the value of the company on the market share as well as the perception on their funds. Insurers would be interested in the financial incentives as they could also link the level of their premium to sustainability performance. Finally, citizens would be impacted mostly the public perception and the reporting as this is for them the visible part of the sustainability performance of the space ecosystem.

	Operators	Licensing authorities	Procurement authorities	Sustainability actors	Investors	Insurers	Citizens
Financial and economic incentives;	x			x	x	x	
Support for current and potential regulations;	x	x		x			
Altered procurement processes;	x		x	x			
Public perception	x			x	x		x
Marketing and ESG style corporate reporting	x			x			x

Table 3: Incentives and actors maps

5.2 On-going studies

This chapter will address on-going studies to validate policies that could be developed alongside the use of the SSR at the national and international level, addressing the Option A, B and C. The formats are one research project led by Dr. Yap and one IAA Study Group led by Prof D. Wood.

Addressing Earth-space sustainability: Policy options for satellite infrastructures under three scenarios by 2030 (incentive A, B, C)

This subsection reports on an ongoing project at EPFL and SSR [23] as part of a larger research campaign led by the OECD Space Forum.

The OECD Space Forum [19] is investigating the economics of space sustainability and seeks to encourage leading-edge academic research in this new domain. The OECD and 11 space agencies are offering researchers and students the opportunity to join an international project. PhD, post-docs and Master's students as well as academic staff from universities and research organisations from around the world are invited to tackle the same research questions and join an international community of practitioners

This is the second edition of a truly multidisciplinary project with participants from around the world asked to develop and present solutions based on the same initial statements of work (participants may pick one or multiple statements of work to research):

1. Understanding the value of space-based infrastructure (e.g. specific segments of the infrastructure such as earth observation, satellite telecommunications, human spaceflight infrastructure)

2. Evaluating the impacts of space debris incidents, including impacts on society (e.g. denial of service) and specific users (e.g. operators themselves, government users)

3. Identifying the effects of policy options for addressing space debris (e.g. taxation, insurance, active debris removal, etc.).

The proposed project between EPFL and SSR is under the third pillar and mobilizes the notion of 'earth-space sustainability', which emphasizes the importance of using space infrastructures for sustainability purposes on Earth while simultaneously ensuring space

sustainability [20][21]. More specifically, the current project explores policy options for the long-term uses of satellite infrastructure by taking the SSR as an example. The project focuses on three types of satellite infrastructures critical for sustainable development: Earth observation, satellite navigation, and internet satellite constellations.

The SSR is currently a promising policy option considering the lack of a strong, legally binding governance regime at the international level. However, empirical research is needed to better understand under what conditions stakeholders, policymakers, and satellite operators will be driven to adopt the SSR[22]. To do so, this study conducted a qualitative discourse analysis of secondary news data on the three selected infrastructure sectors, a scenario-building workshop, as well as follow-up interviews.

The discourse analysis derives a comprehensive view of actors shaping the rapid development of the sectors and allows the study to anticipate the development trends of the satellite infrastructure sectors. This analytical step serves as a basis to project into the future by providing the contextual conditions or factors for building the narratives of potential scenarios. More specifically, the study identified three plausible scenarios by 2030 based on how space governance might evolve: Scenario A: space governance led by individual state governments; Scenario B: space governance led by private actors; and Scenario C: space governance led by international organizations or multilateral fora. The three scenarios were presented at a workshop held at Politecnico di Milano on 8 June 2023 for further development.

Participants of the workshop jointly discussed how each of the different scenarios may pose opportunities and challenges to future Earth-space sustainability. This includes whether the space physical environment would be stable (i.e., the collision risk is controlled, satellites can be operated without significant risks in most orbits); how will the different scenarios impact the diffusion of satellites infrastructures; and whether or not a scenario is desirable and for whom (which actor types and considering less developed countries).

In Scenario A, intensified geopolitics will lead to increasing militarisation of space in LEO and GEO, with anti-satellite tests, jamming that can lead to the loss of control of assets and other catastrophic events which potentially cause more space debris. In addition, a state-driven approach in this scenario reduces the likelihood of a more efficient diffusion of technologies, such as active debris removal, that need an international collaborative framework that ensures business feasibility. Overall, this scenario is deemed the least desirable in particular for commercial actors, as their operations in the orbital region will be impacted. This scenario would also hinder developing/ less developed countries as they become increasingly reliant on space infrastructure services provided by the leading spacefaring countries engaged in geopolitical competition. The scenario, however, might be desirable for individual states that prefer global institutional fragmentation and it might cause a delay in forming global consensus.

Scenario B is also expected to lead to a less sustainable orbital region as the increase in private satellite operators does not guarantee all operators would follow sustainable practices. Participants drew on the example that 5,000 satellites of large private players could pose less risk than 2,000 satellites of smaller private players that do not have the technological maturity to conduct best practices. This also impacts equitable access to space as it is on a first-come-first-served basis. However, considering the lack of effective international fora at the moment, participants in this break-out group believed that Scenario B – a scenario whereby space governance is led by private actors as they self-coordinate to a large extent – is perhaps still the best solution. This is because private actors are efficient in making decisions based on cost and benefit analysis, which in this case collectively ensuring orbital sustainability among themselves will help ensure the long-term functioning of their respective satellite operations. Scenario B could therefore lead to two opposing outcomes in terms of the distribution of socio-economic benefits: (i) more competition among private actors in more advanced countries might prohibit participation of companies from latecomer countries; and (ii) satellite constellations efficiently managed by private actors could offer great potential in offering global connectivity that can bring high socio-economic benefits to developing/ less developed countries.

The orbital environment is deemed to be relatively sustainable by 2030 under Scenario C as some international framework for Space Traffic Management/Space Domain Awareness might emerge. This might be plausible through bottom-up, international institutional approaches. Meanwhile, other international fora such as the ITU continue to review and revise its regulatory framework through the World Radiocommunication Conference. Despite this, Scenario C is deemed the most desirable among a majority of workshop participants and interviewees, it is also discussed as rather unrealistic or progressing too slowly given the current state of international affairs.

Based on the alternative scenarios, participants discussed the opportunities and challenges for SSR under each scenario. Some guiding questions also included what might be a potential incentive package that SSR could offer, e.g. integrating SSR into the licensing process at the national and international level, integrating SSR into the procurement policies for space infrastructures, etc. As mentioned earlier, procurement policies can incorporate considerations for space sustainability and the SSR can be used to help assess the performance criteria of the infrastructure service providers.

As scenario A is undesirable for emerging nations and private actors, it is also unlikely to have an international framework for STM/SDA. In that context, the SSR would need to be managed at the national level and main regional powers will want to own the rating process and adapt it to its own set of values and models. For example, the mission index is based on models developed by the European Space Agency, and it is unlikely that another powerful nation would rely on models to which they do not have the full ownership. The SSR would then be a model actor that can be replicated and adapted (by re-developing some modules) to fit national regulations and constraints. In this context, the SSR might be linked to public procurement policies and licensing processes.

Scenario B is led by private actors. In that context, the SSR should emphasise on how to create more value to the operators and large system integrators. In that way, the SSR could develop a value package that involves investment funds and insurance companies. The SSR would be a business-oriented entity. However, to avoid any critics on the validity of the rating, the transparency on the process is key. In this scenario the aspect of sustainability focuses on space safety and therefore preventing the loss of use of outer space is a key driver.

Finally, effective international fora under Scenario C will provide a solid ground for the SSR to be implemented as all member states are likely to reach the consensus on sustainable behaviour in space. In this scenario, the SSR can address the risk of having international institutional progress outpaced by technological development due to bureaucratic procedures. The SSR would need to have an agile structure to capture the best practises in some regions (such as the US FCC challenging the 25-year disposal rule and implementing the 5-year rule instead) and therefore being an early adopter of the best-in-class technologies, procedures and standards in in-space sustainability. In addition, the standardisation by the SSR has to proactively consider that the rules and guidelines are fair to all new spacefaring nations (including less developed states). In this scenario, the SSR should also initiate communications with the citizens (i.e. users and consumers of space services) about the importance of knowing the sustainability performance of those service providers in space.

To conclude, the workshop also generated cross-cutting implications to SSR across all scenarios. Here, participants of the study (both workshop and interviewees) raised opinions that SSR as an incentive-based policy option is encouraging given that the SSR can serve as a transparent, credible third party. Operators expressed their reservation concerning the impact of the rating to their corporate reputation. Being able to keep track of on-going results of the rating process will be key to convince these actors. Overall, participants consistently emphasized the importance of incorporating an insurance model into the SSR package as well as creating more financial incentives such as access to corporate loans or other funding. The feasibility and advantage of formulating such a package, however, still requires further research.

Opportunities for National Governments to Foster Space Traffic Management using the Space Sustainability Rating, IAA Study Group. (incentive A, B, C)

A Study group led by Prof. Danielle Wood was launched in 2022 on the topic of “Opportunities for National Governments to Foster Space Traffic Management using the Space Sustainability Rating ” The Study Group is pursued under the Space Traffic Management Committee of the International Academy of Astronautic

The proposed study asks how national governments can use the SSR as part of their domestic regulation and authorisation of space launches and operations. What would the implications be if national governments required a certain level of performance based on the SSR for operators applying for approval to launch? Is it more effective for governments to require minimally sustainable actions or to incentivise spacecraft operators to identify innovative ways to be as sustainable as possible? This study will draw insights from engineering, policy and economics to address these and related questions. The results will recommend to national governments how they can make use of the SSR as a tool to increase the sustainable behaviour of space actors.

This study is the first institutional study interviewing national actors on how they could implement SSR in their national legislative framework.

The following questions are addressed in the working group:

- What approaches is your country currently taking to address the long-term questions related to managing space debris, promoting space sustainability and preparing for future Space Traffic Management?
- How might your country apply the methods from the six SSR modules in their work to promote space sustainability?
- How might your country apply the overall concept of using an incentive to promote sustainable behaviour in their work to promote sustainability, to licence space missions, and to provide continuous supervision?

The study is currently on-going and main outcomes will be presented in a paper. During a future IAC or related event.

5.3 Future work

Other studies are currently on-going led by other entities that allows to test the hypothesis of this paper: SSR and how ESG governance in space could also influence the adoption of SSR by private companies. They address the option D and E.

Future work on the ESG governance in space and how space companies handle this aspect. (incentive D, E)

In this context, we see a lot of interest in discussions on how ESG regulations and CSR can apply to the space sector and the specificities.

Environmental, social and governance (ESG) is a framework used to assess an organisation's business practices and performance on various sustainability and ethical issues.

Large companies and entities have to face their responsibilities towards society when it comes to environmental, social, or economical aspects. In recent years, many of them have started working on the definition of strategies to harmonise and reinforce their commitment in terms of corporate responsibility, for instance with corporate social responsibility (CSR) reports.

The project will be performed with a student. The goal is to identify how SSR fits in the ESG reporting required by space companies in Europe.

Finally, SSR team and members of the Steering committee are involved in many international initiatives to promote a safe, secure and sustainable use of outerspace such as the Paris Peace Forum working groups and the ESA Zero Debris Charter.

6. Conclusions

To conclude, this paper has presented the main updates from the Space Sustainability Rating from October 2022 to October 2023, with the focus on presenting the rating outcome with Endurosat and the process applied. Then incentive options are described and the work performed to validate the hypothesis.

Endurosat Plateform-1 is a 6U CubeSat, built for Earth Observation (EO) applications that was launched on May 25 2022. The rating process lasted almost three months from the beginning of input gathering until the release of the rating. During these three months, the operator benefited from a feedback loop that allowed them to increase the score by implementing measures such as data sharing practises. Endurosat benefited from the rating process and sees the following values for its business case: Enhancing Reputation and Trust, Competitive Advantage, Attracting Investors, Regulatory Compliance, Risk Mitigation, Long-term Viability, and Marketing and Public Relations. Furthermore, a space sustainability rating can significantly improve satellite operations in the following ways: Enhanced Collision Avoidance, Longer Mission Lifetimes, and Reduced Operational Risks.

When operators and large system integrators are developing the business case for performing a rating, they are also seeking incentives to perform the exercise. The following incentives are identified and are also in line with the ones enumerated by Endurosat.

- Financial and economic incentives;
- Support for current and potential regulations;
- Altered procurement processes;
- Public perception; and
- Marketing and environmental, social, and governance-style corporate reporting.

Several projects are on-going at EPFL and with partners to explore and validate the feasibility of such incentives were presented in the paper. Two main

studies are on-going on how SSR can go along with policy development for Earth-space sustainability and how national governments can use the SSR while developing their space traffic management framework. Finally, in the fall 2023, a specific project on how ESG/CSR is addressed by space companies and how can the SSR help space companies fill their requirements is taking place.

The SSR association is looking for more members and partners to continue this academic work and support the international effort to have a coordinated space traffic management framework at the international, regional and national levels.

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