
FLAGSHIP STUDIES

Camila ACQUARONE* – Giuliana ROTOLA** –
Yana YAKUSHINA***

Space Solar Power: A Sustainable Solution or an Environmental Dilemma?

ABSTRACT: *Space-Based Solar Power (SBSP) involves collecting solar energy in space and transmitting it to Earth, ensuring continuous power generation. Though an old concept, SBSP is gaining renewed interest, with projects such as the European Space Agency's (ESA) SOLARIS targeting deployment by 2030. Consulting firms have confirmed its cost-benefit viability. However, numerous legal, economic, and regulatory challenges arise. Key questions include space environmental considerations, such as orbital light pollution, as well as ground-based environmental concerns, particularly regarding the size of the rectenna required to capture space laser beams. The deployment of massive SBSP systems could also contribute to an increase in space debris if the maintenance and decommissioning of such large structures are not addressed during the design phase. Beyond environmental aspects, the commercialisation of SBSP raises issues concerning the ESA's role as an energy producer, the impact of facility location on energy resale, and the classification of space solar energy or orbital slots for SBSP installation as space resources. These considerations will raise challenges regarding the ownership and business model of the energy produced, in accordance with the provisions of the Outer Space Treaty. International energy distribution presents additional complexities, particularly in ensuring equitable access for developing nations. Within the European Union, SBSP integration would require significant grid upgrades, pose the risk of market saturation, and necessitate navigating diverse national regulations. Despite its transformative potential, SBSP faces significant legal, technical, and economic challenges, all of which are explored in this paper, inviting a transversal and comprehensive reflection.*

KEYWORDS: *space law, solar power, sustainability, energy law, space resources.*

* PhD graduate, University of Paris (France), Faculty of Law, Department of European, Public and International Law; ca.spacelaw@outlook.com

** PhD Student, Sant'Anna School of Advanced Studies (Italy); giuliana.rotola@santannapisa.it

*** Research Fellow, University of Ghent (Belgium), Faculty of Law and Criminology, Department of European, Public and International Law; ya.yakushina@gmail.com, <https://orcid.org/0000-0001-6907-4890>.



1. Introduction

The concept of space-based solar power (SBSP) or space solar power (SSP) involves collecting solar energy in outer space using solar power satellites (SPS) and distributing it to Earth.¹ In other words, SBSP systems convert sunlight into another form of energy, such as microwaves, which can then be transmitted through the atmosphere to receivers on the Earth's surface.

The advantages and cost-benefit of SSP projects have been confirmed by several consulting firms, such as Franzer-Nash² and Roland Berger.³ Among the benefits is continuous, 24/7 power generation throughout the year, potentially reaching gigawatt levels for baseload energy and green hydrogen production for the transport sector. These projects promise to enhance security and resilience against political or terrorist actions, ensure long-term fuel supply security, and offer affordable energy for households and industries.

According to the Franzer-Nash Consultancy report,⁴ SBSP can be readily integrated into existing grid infrastructures, providing low intermittency, high predictability, and dispatchable power with a high load factor. It aligns with net-zero goals, with plans for an orbital demonstrator by 2031 and operational systems by 2040, and is scalable to supply a substantial proportion of energy. Additionally, it offers flexible energy solutions, export opportunities, and power for humanitarian disaster relief and space operations.

Space-based solar power has gained significant attention over the past four years; however, the concept itself has longstanding origins. This concept was introduced by K. E. Tsiolkovsky, a Soviet rocket scientist and astronautics pioneer. In his works, he proposed various ideas of reflective surfaces with black, transparent, or mirror coatings to provide maximum or minimum temperatures depending on the task. The mirrors focus on heating boilers, where radiant energy is continuously concentrated, reaching unprecedented temperatures.⁵ Since then, the SBSP concept has continued to evolve and has been implemented in various real-world projects.

Since the 1980s, several space agencies, including the Japan Aerospace Exploration Agency, have initiated the development of SBSP systems.⁶ Significant advancements were observed starting in the 2020s, marking the beginning of a new ambitious era of SSP projects. For instance, the European Space Agency's (ESA) SOLARIS project and plans to deploy a space power plant by 2030 marked notable milestones.⁷ Addi-

1 European Space Agency Space-Based Solar Power, 2022.

2 Franzer-Nash, 2021.

3 Berger, 2022.

4 Franzer-Nash, 2022.

5 Tsiolkovsky, 1933.

6 Japan Aerospace Exploration Agency, n.d.

7 European Space Agency "SOLARIS," n.d.

tionally, recent commercial initiatives such as Virtus Solis aim to develop the world's first commercial SBSP.⁸

Space-based solar power projects are regarded as the future of renewable energy and may play a key role in supporting global and national policies in shifting towards carbon-neutral solutions.⁹ Consequently, the ESA referred to the SBSP concept to support the European Union's (EU) transition to carbon neutrality by 2050.¹⁰ However, is everything as green and sustainable as it appears?

The introduction of such new technologies poses several risks and raises concerns related to potential adverse impacts both on Earth and in space. The ambitious goal of launching the first SBSP system by 2030 is approaching rapidly, requiring thorough consideration of the potential risks associated with such projects, as every new sustainable solution has the potential to introduce new environmental challenges.

Several drawbacks of SBSP projects have been identified and discussed.¹¹

To expand the existing analysis of concerns associated with the deployment of SBSP projects, this paper provides brief insights into the potential environmental and sustainability challenges, thereby contributing to a pragmatic and critical perspective on the deployment of such a project and facilitating discussions on possible risks of such projects among researchers, stakeholders, and experts.

This paper discusses the following aspects of SBSP: (1) potential impacts on the space environment; (2) potential effects on the natural environment on Earth; (3) issues related to the ownership and distribution of the generated energy; and (4) space sustainability concerns. To address these issues, we draw on examples from existing SBSP projects and analyse current political initiatives and regulatory frameworks, using both international and EU regulations to inform the discussion.

2. Space-Based Solar Power: Orbital Environmental Considerations

Pre-phase studies on SBSP projects primarily focus on environmental impacts in the context of climate change, such as an assessment of carbon footprints from energy production, issues related to the potential increase in Earth's temperature and energy efficiency, and space debris mitigation, with other important environmental considerations receiving insufficient attention. Such preliminary reports suggest, for instance, that thousands of SBSP systems delivering approximately 15,000 GW would likely cause a 0.006°C rise in Earth's temperature, which is much smaller than the warming

⁸ Virtus Solis, 2023.

⁹ European Commission, 2019.

¹⁰ ESA, 2022.

¹¹ New Space Economy, 2024.

effects of producing the same power using fossil fuels.¹² However, even minor increases in the Earth's temperature can lead to irreversible changes in the climate, exacerbating the pressures already exerted by existing contributors to climate change.¹³ Therefore, further consideration should be given to minimising potential temperature increases, for example, by reducing the number of solar panel satellites used.

Despite the negative consequences associated with a relatively small increase in temperature, overall, SBSP systems are largely viewed as carbon-neutral energy with a minimal greenhouse gas emission footprint. Another consideration is the mitigation of space debris. The need to include such considerations is driven by current space practices, recommendations, and policy discussions aimed at building more sustainable space activities, complementing the existing international legal framework governed by major treaties, such as the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies – Outer Space Treaty (OST).¹⁴

More specifically, space sustainability concerns are discussed in Section 4. Since most SBSP projects are still in the early stages, the primary focus is on understanding how to ensure manoeuvrability in order to prevent collisions with other space objects or debris and address decommissioning issues. In addition, further research on other environmental impacts that may be caused by SBSP systems is important.

Particular attention should be given to the reflectivity of solar panel satellites, as it may contribute to increased orbital light pollution and may have potential effects on the Earth's environment, including impacts on biodiversity. Orbital light pollution is driven by the rapid commercialisation of outer space, particularly due to the proliferation of numerous mega-constellation satellites launched into Earth's orbit over the past decade. This form of pollution is primarily caused by the high reflectivity of satellite surfaces. As more satellites are launched, the cumulative effect of their combined light reflections results in a noticeable increase in sky brightness.¹⁵

The negative effects of orbital light pollution extend across multiple areas, from its obvious impact on astronomical observations to its potential adverse effects on biodiversity. Obstacles to astronomy include the practical impossibility of ground-based space exploration due to the constant presence of satellite trails. Regarding the impact on biodiversity, studies suggest that visible space objects rapidly moving across the night sky may affect species' orientation and migration patterns, as many species rely on celestial bodies and their movements for navigation.¹⁶

¹² Mankins and Nobuyuki, 2011.

¹³ Intergovernmental Panel on Climate Change, 2018.

¹⁴ European Space Agency (2023).

¹⁵ International Astronautical Union (IAU), Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference, 2024.

¹⁶ Gaston et.al., 2023.

Thus, reflectivity issues should be considered when planning SBSP systems. Solutions include the use of anti-reflective coatings, optimisation of satellite orientation, and implementation of optical shielding. Addressing these concerns ensures efficient energy transmission while minimising environmental and operational risks. In addition, regarding the environmental impacts of SBSP systems, outer space should be considered an integral component of the natural environment. This approach will enable the application of international environmental principles and national environmental legislation to outer space activities, further protecting the outer space environment from impacts such as orbital light pollution and space debris.¹⁷ It will also facilitate the implementation of environmental measures, including binding environmental impact assessments for space projects, concerning not only the Earth's environment but also the outer space environment.

This is already briefly reflected in the provisions of Article 9 of the OST,¹⁸ indicating that countries shall avoid harmful contamination of space and celestial bodies and is more developed in the currently adopted space sustainability recommendations. Considering outer space as a form of the environment will prompt a broader examination of how space objects can impact the natural environment beyond Earth, providing for the application of stricter environmental protection of space.¹⁹ Finally, although it is suggested that overall SBSP production is likely to be environmentally friendly, further studies on the environmental impact across the entire lifecycle of SBSP systems are necessary to prevent potential negative effects on the orbital environment and enable conformity with developing regulatory frameworks.²⁰

3. Space-Based Solar Power: Ground-Based Environmental Considerations

Even though the preliminary study reports consider that SBSP could be a practical tool to “avoid” land allocation for terrestrial technologies (since SBSP rectennas would use only 5m² of land per MWh), the environmental and social impact of deploying such a giant structure on Earth from a practical perspective should be considered. The terrestrial receiver would need to span several kilometres in diameter (approximately 20–35 km), adding complexity and cost to its implementation on the ground, while also potentially generating negative societal externalities.²¹

17 United Nations Office for Outer Space Affairs, 2021.

18 United Nations Office for Outer Space Affairs, 1967.

19 Miraux, Wilson, et.al., 2022.

20 Mankins and Nobuyuki, 2011.

21 Dakora et al., 2021.

Which state would agree to install this rectenna and face potential complaints and legal actions from environmental associations and local residents? Should it be left alone to deal with this complexity? In this context, raising awareness about space-related matters and the benefits of this operation is essential. Second, and more obviously, this giant rectenna will have an environmental impact on the area, which must be considered.²² Large solar power plants already exist, such as the Bhadla Solar Park in India, which covers an area of 57 km² with a production capacity of 2.7 gigawatts.²³ Even if the sizes of the Earth-based receiver and traditional ground-based solar farm are similar, the effects of the different technologies used to transmit space energy (such as microwaves) on flora, fauna, and the atmosphere, as well as carbon intensity, should be understood.²⁴

Additionally, similar to solar panel satellites, it is crucial to consider the reflectivity of receivers, which could potentially contribute to an increase in ground-based light pollution. This pollution is caused by increased, unwanted, and misdirected artificial light at night (ALAN) levels and other sources, including reflective surfaces such as solar panels. Ground-based light pollution has significant adverse effects on biodiversity, habitats, and ecosystems, necessitating the prevention of such effects in future projects. An environmental impact assessment of SBSP systems must be conducted, as with traditional solar power installations, while also considering the coexistence of the rectenna with other productive activities such as agriculture or farming, a best practice that could be imported and democratised for large terrestrial solar power plants, which rarely integrate multiple activities with energy production.²⁵ Answering Elon Musk, who affirms that it is much easier to have solar power on the ground than in orbit, Ian Cash, Chief Engineer of International Electric Company Limited, who is developing the Cassiopeia project, asks, *'Is the easiest place, necessarily the best place?'*²⁶

4. Ownership, Consumption, And Distribution of Photovoltaic Energy

When analysing the central issue of implementing SBSP systems, namely the production of electricity, two aspects must be considered.

First, the ownership of photovoltaic energy, a resource that can be collected both in space and on Earth, raises several issues. On the one hand, it could be argued that this energy is not a "space resource" as such; on the other hand, the slot in the orbit

²² Cash and Eng, 2021.

²³ Futura Science, 2024.

²⁴ Frazer-Nash, 2022.

²⁵ Faucon et al., 2023.

²⁶ 'Agrivoltaics: Advantages and disadvantages of installing solar panels in the field', n.d.

required to build the solar power plants necessary for electricity production could fall within this definition.²⁷

The concept that Earth's orbit is a finite resource is highlighted by the growing congestion in Low Earth Orbit (LEO) and Geostationary Orbit (GEO), as these regions become increasingly crowded with the rising number of satellites.²⁸

In the specific case of the Constant Aperture, Solid-State, Integrated, Orbital Phased Array (CASSIOPEA) Solar Power Satellite, which has a diameter of 2 km—hundreds of times larger than the ISS—it is crucial to consider solar energy and the orbital space where the SBSP system is situated as valuable resources. This consideration is essential for determining the conditions under which the generated electricity can be effectively utilised and sold on Earth.

Space resource activities fall under the category of “use” of outer space, as defined in Article I of the OST. This paper explicitly allows state parties to utilise “outer space, including the Moon and other celestial bodies,” which covers activities such as the direct utilisation of resources in space. While this primarily refers to the in-space use of resources such as fuel, oxygen, or water, it likely extends to the extraction of resources intended for use on Earth once such processes become feasible.²⁹ The potential benefits of utilising space-extracted resources include reducing the energy required to transport additional materials to space for in-situ use and exploring possible applications on Earth.³⁰ As observed, the definitions of “use” and “space resources” can be broad enough to cover energy production activity.

Additionally, Article I stipulates that outer space should be explored and used “for the benefit and in the interests of all countries, regardless of their level of economic or scientific development”; yet, the implementation of these principles remains uncertain and could lead to tensions, though precedents such as the sharing of lunar samples might be interpreted as fulfilling this obligation.³¹

The most significant challenge for space resource activities lies in the principle of non-appropriation outlined in Article II of the OST, which applies equally to governmental and commercial space resource activities and is further reinforced in Article 11(2) of the Moon Agreement, which governs the activities of states on the Moon and other celestial bodies.

The debate over whether a distinction can be made between the appropriation of an entire celestial body and the appropriation of resources extracted from it is central to the legal framework governing space activities. If such a distinction is recognised, then the principle of non-appropriation under Article II of the OST would only prohibit

²⁷ Nozari, 1973.

²⁸ De Man, 2010.

²⁹ United Nations, 1967.

³⁰ McKinsey & Company, 2022.

³¹ de Zwart et al., 2023.

states and private entities from claiming sovereignty over an entire celestial body, rather than extending this prohibition to extracted resources.

This interpretation would open the door to commercial space mining and other resource utilisation activities, making them legally viable. However, the legal status of this distinction remains unsettled, with different states interpreting it differently.

The significance of this distinction extends beyond space mining to other space-based commercial activities such as SBSP. If the principle of non-appropriation is interpreted narrowly – prohibiting ownership of celestial bodies but allowing the use of extracted resources – then questions arise about how similar logic applies to SBSP.

Specifically, if a European SBSP system, such as the SOLARIS project, were to collect and distribute solar energy from space, legal mechanisms would need to be established to ensure equitable access among European member states. This is because SBSP, while technically an extracted resource, could be viewed as monopolising access to solar energy at a particular orbital position, potentially leading to legal and political challenges.

Furthermore, deploying a large-scale SBSP system could raise concerns about the fair allocation of this resource and its alignment with the principles of the OST, which emphasise free access to space for all nations and equitable sharing of space benefits.

If a single entity or group of nations dominates the collection of solar energy from space, it could be argued that this contravenes the OST's intent by creating exclusive control over a space-based resource. Additionally, SBSP could disrupt existing energy markets, which are traditionally regulated at the national level.

This perspective raises numerous questions that could pose significant challenges during the operational phase of SBSP deployment.

For example, can the ESA be considered an energy producer within the framework of the SOLARIS project? In which national market can this energy be sold? Does the location of Earth-based facilities affect the resale of energy on Earth? More specifically, if the facility is located in Spain (or in any other country), must the energy be sold according to Spanish market regulations? How is the price of this electricity determined? Will the energy be sold on the general grid, or can it be purchased by a private or public entity through a corporate power purchase agreement (PPA)?³² These questions become even more technical when we analyse energy distribution at an international level, particularly if the purpose is to ensure that developing countries benefit equally from this “new” space resource, as outlined in the OST.

From a practical standpoint, selling solar energy from space-based facilities across Europe or on a global scale presents several challenges. Grid integration can be difficult because of the large and variable influx of energy, necessitating significant

³² Power Purchase Agreement (n.d.).

upgrades to transmission infrastructure and energy storage systems. Unlike traditional Earth-based facilities, the continuous flow of space-generated energy can create energy storage challenges when solar production exceeds consumption.³³

Economically and commercially, market saturation could lead to price fluctuations, thus affecting the profitability of space-based solar power,³⁴ highlighting the need for political and economic coordination among countries to ensure fair distribution and pricing.³⁵

Navigating the complex regulatory landscape across Europe and other countries is crucial for ensuring compliance with national and EU regulations; however, these challenges are even more pronounced from an international perspective.

Corporate power purchase agreements could facilitate the transfer of SBSP across European countries by providing direct, stable, and flexible contracts between private companies, offering price stability and risk management, both of which are crucial for emerging technologies such as SBSP. As PPAs are private agreements, they can facilitate cross-border transactions and help integrate energy from different sources into a unified market, aligning with European efforts to create a single energy market.

Even if these practical considerations are addressed much later in the development process of SBSP, as the power plant is not yet in space and the first kilowatt may only be produced in ten years, it is important to anticipate the legal framework that will enable the commercialisation of SBSP energy.

5. Space Sustainability vs. Space-Based Solar Power

Space sustainability can be 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 outer space for peaceful purposes in order to meet the needs of the present generations while preserving the outer space environment for future generations.”³⁶

This includes minimising the creation of space debris, preventing orbital congestion, and ensuring that space remains accessible for future generations. In this context, SBSP presents both opportunities and challenges for space sustainability.

³³ Green Match, 2024.

³⁴ Green Match, 2024.

³⁵ European Network of Transmission System Operators for Electricity, 2024.

³⁶ United Nations Office for Outer Space Affairs, 2021, p. 2.

As discussed above, one of the key sustainability concerns for SBSP is the orbital impact of large structures, as the deployment of massive solar arrays in GEO presents significant challenges given the limited nature of GEO. Indeed, the placement of large SBSP stations in this region could limit the availability of slots for other critical services, such as communications and navigation satellites. Moreover, unlike LEO, where satellites can be spaced apart at different altitudes, GEO satellites must be located on a narrow belt 35,786 km above the equator, resulting in limited available “slots”.³⁷ Any new SBSP system could occupy these valuable orbital positions, creating competition and challenges for allocating these positions under international agreements such as the International Telecommunication Union’s frequency and orbital slot coordination mechanisms. As more nations and private entities enter the space arena, ensuring fair and sustainable access to GEO will require extensive cooperation and further regulation.

Another issue arises from the maintenance and decommissioning of such large structures. Given the remote location and size of SBSP systems, maintaining these systems over their operational lifespan could prove difficult. Unlike smaller satellites, which are occasionally serviced or deorbited at the end of their lifecycle, SBSP systems would require advanced, possibly autonomous, on-orbit maintenance capabilities to ensure that they do not become hazardous. Failure to manage these systems effectively could lead to the creation of large debris if malfunctions or collisions occur, thereby exacerbating the already significant problem of space debris.

The risk of debris production is also particularly relevant, as GEO does not have a natural “cleanup” mechanism such as atmospheric drag, which helps remove debris from lower Earth orbits. If an SBSP system were to fail, it could remain in orbit indefinitely, posing a long-term threat to other operational satellites. Despite collision risks being lower than those in other orbits,³⁸ there is still a pressing need to develop robust end-of-life strategies for SBSP infrastructure, such as moving defunct systems to “disposal” orbits far above GEO to avoid obstructing future space operations.

Finally, as already stated, from a regulatory standpoint, the deployment of SBSP systems will require careful coordination under international space law. The OST obligates countries to ensure that activities in space, whether by governmental or non-governmental entities, do not cause harmful contamination. As SBSP systems would operate in GEO, a limited and valuable orbital region, questions arise about prioritising orbital slots and preventing the monopolisation of GEO resources. Current frameworks such as the United Nations Committee on the Peaceful Uses of Outer Space *Guidelines for the Long-Term Sustainability of Outer Space Activities*³⁹ offer guid-

³⁷ European Space Agency *Types of orbits* (n.d.).

³⁸ Roberts and Bullock, 2020.

³⁹ Roberts and Bullock, 2020.

ance; however, they may need to be adapted to accommodate the unique challenges posed by large-scale SBSP systems.

5.1. Maintenance, reparability, and decommissioning

Maintaining and repairing large-scale SBSP infrastructure is a major engineering challenge. Owing to their large size and complexity, any required maintenance must be conducted remotely, possibly autonomously. This adds layers of technical difficulty, as no current technology offers a comprehensive solution for maintaining such massive structures in GEO. While some advancements have been made in on-orbit servicing (such as Northrop Grumman's MEV-1 mission, which successfully extended the life of a GEO satellite),⁴⁰ these are singular operations and far from the regular, large-scale maintenance that SBSP systems might require, considering that low-cost space transportation also remains a challenge for SBSP's economic viability.⁴¹ Furthermore, decommissioning SBSP systems would be critical to prevent them from becoming long-term debris hazards. Geostationary Orbit satellites are typically moved to "graveyard" orbits when their operational life ends; however, the size of SBSP systems means that they would need specialised end-of-life plans to avoid obstructing future GEO operations.

5.2. Debris mitigation and long-term risks in GEO

The deployment of SBSP systems is strongly associated with long-term risks concerning debris generation. Geostationary Orbit satellites already face increasing risks from collisions with ageing space objects, defunct satellites, and smaller debris, even over a longer time scale than LEO risks from collisions.⁴² However, introducing SBSP systems, which are larger and more complex than most existing GEO assets, increases the likelihood of accidental damage and long-lasting debris fields. Moreover, because SBSP systems are meant to operate continuously over long periods, their failure or fragmentation could lead to widespread debris creation, which, because of the physical characteristics of GEO, could remain there for centuries, posing a threat to vital telecommunications and navigation satellites.⁴³ Therefore, comprehensive debris mitigation strategies are essential.

40 Wikipedia *Mission extension vehicle* (n.d.).

41 National Space Society (n.d.).

42 National Space Society (n.d.).

43 Dongfang et al., 2017.

6. Conclusions

In conclusion, SBSP presents promising opportunities as well as significant environmental and social challenges that require more thorough investigation.

Preliminary research must go beyond simple cost-effectiveness or energy efficiency analyses to encompass broader environmental impact assessments. This should not only focus on Earth's environment but also treat outer space as an integral part of it. The two systems are inherently interconnected, and space projects, particularly on the scale of SBSP, must recognise this relationship.

Impacts such as increased orbital and ground-based light pollution, potential harm to biodiversity, and the long-term sustainability of both orbital and terrestrial environments require critical consideration. The evolving concept of space sustainability requires a shift towards treating Earth and space as interconnected systems. As we venture further into space for energy solutions, it is fundamental to establish environmental frameworks that ensure the protection of both environments. Only by adopting a holistic Earth-space system approach can SBSP systems be truly efficient and sustainable.

Moreover, the concept of space resources should encompass solar energy produced in space, promoting equitable access to this valuable resource. The energy transition should not be an exclusive privilege of wealthy countries but should be of "benefit and in the interest of all countries". A space-based solar power system could provide an opportunity for developing countries to participate in the benefits of space technology and contribute to a global sustainable energy transition. This opportunity should not be missed, and the shared benefits of SBSP should be carefully addressed in the final phase of its development.

Bibliography

- Cash, I., Eng, M. (2021) 'Cassiopeia- Sps: Space-based solar power for net zero' [Online]. Available at: https://www.researchgate.net/publication/356915218_CASSIOPEIA_SPS_Space_Based_Solar_Power_for_Net_Zero (Accessed: 30 November 2024).
- De Man, P. (2010) 'The exploitation of outer space and celestial bodies – A functional solution to the natural resource challenge', *Working Paper No. 54*. Catholic University of Leuven.
- De Zwart, M., Henderson, S., Neumann, M. (2023) 'Space resource activities and the evolution of international space law', *Acta Astronautica*, 211, pp. 155–162 [Online]. Available at: <https://doi.org/10.1016/j.actaastro.2022.10.005> (Accessed: 30 November 2024).
- Dongfang, W., Baojun, P., Wei, X. (2017) 'GEO space debris environment determination in the Earth-fixed coordinate system' in *Proceedings of the 7th European Conference on Space Debris*. Harbin: Hypervelocity Impact Research Center, Harbin Institute of Technology, PR China [Online]. Available at: <https://conference.sdo.esa.int/proceedings/sdc7/paper/304/SDC7-paper304.pdf> (Accessed: 30 November 2024).
- ENTSO-E (2024) 'ENTSO-E strategic roadmap: Prepare the future and manage the present' [Online]. Available at: https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/Publications/ENTSO-E%20general%20publications/entso-e_strategic_roadmap_WEB_240215.pdf (Accessed: 30 November 2024).
- European Commission (2019) 'The European Green Deal', Publications Office of the European Union [Online]. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN> (Accessed: 30 November 2024).
- European Space Agency (2023) 'Space Debris Mitigation Requirements', *ESSB-ST-U-007 Issue 1* [Online]. Available at: https://technology.esa.int/upload/media/DGHKMZ_6542582e18e33.pdf (Accessed: 30 November 2024).
- European Space Agency (n.d.) 'SBSP history' [Online]. Available at: https://www.esa.int/Enabling_Support/Space_Engineering_Technology/SOLARIS/SBSP_history (Accessed: 30 November 2024).
- European Space Agency (n.d.) 'SOLARIS', *Enabling & Support* [Online]. Available at: https://www.esa.int/Enabling_Support/Space_Engineering_Technology/SOLARIS/SOLARIS2 (Accessed: 30 November 2024).
- Faucon, M.-P., Legras, M., Gloaguen, R. (2023) 'Agrivoltaics: Advantages and disadvantages of installing solar panels in the field', *Unilasalle* [Online]. Available at: <https://www.unilasalle.fr/en/actualites/agrivoltaics-advantages-and-disadvantages-installing-solar-panels-field> (Accessed: 30 November 2024).

- Frazer-Nash Consultancy (2020) '*Space Based Solar Power as a Contributor to Net Zero Phase 1: Engineering Feasibility Report*', FNC 004456-51057R Issue 1.0. Prepared for Department for Business, Energy and Industrial Strategy (BEIS), 3 December.
- Frazer-Nash Consultancy (2021) '*Space Based Solar Power: De-risking the pathway to Net Zero*' [Online]. Available at: <https://www.fnc.co.uk/media/e15ing0q/frazer-nash-sbsp-executive-summary-final.pdf> (Accessed: 29 November 2024).
- Frazer-Nash Consultancy (2022) '*Study on Cost-Benefit Analysis of Space-Based Solar Power (SBSP) Generation for Terrestrial Energy Needs*', *Final Report*, 014843-101, 53886R Issue: 1.0. Prepared for: European Space Agency.
- Gaston, K. J., Anderson, K., Shutler, J. D., Brewin, R. J., Yan, X. (2023) '*Environmental impacts of increasing numbers of artificial space objects*', *Frontiers in Ecology and the Environment*, 21(6), pp. 289–296.
- Green Match (2024) '*Space-Based Solar Power: The Future Source of Energy?*', *Green Match* [Online]. Available at: <https://www.greenmatch.co.uk/blog/2024/07/space-based-solar-power-the-future-source-of-energy> (Accessed: 30 November 2024).
- IPCC (2018) '*Global Warming of 1.5°C: An IPCC Special Report*' [Online]. Available at: <https://www.ipcc.ch/sr15/> (Accessed: 30 November 2024).
- Mankins, J.C., Nobuyuki, K. eds. (2011) '*Space Solar Power: The First International Assessment of Space Solar Power: Opportunities, Issues and Potential Pathways Forward*', *International Academy of Astronautics (IAA)* [Online]. Available at: https://nss.org/wp-content/uploads/sg311_finalreport_solarpower.pdf (Accessed: 30 November 2024).
- McKinsey & Company (2022) '*The role of space in driving sustainability, security and development on Earth*' [Online]. Available at: <https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/the-role-of-space-in-driving-sustainability-security-and-development-on-earth> (Accessed: 30 November 2024).