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Space-Based Solar Energy: Economic Viability in the Context of Global Competition

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ABSTRACT

The development of space-based solar energy (SBSP) in the last decade goes beyond scientific and technical experiments and acquires the features of an emerging sector of the global economy. In contrast to the works focused on technological aspects or the environmental agenda, the study considers SBSP as an area of intersection of long-term investment strategies, national priorities of energy security and new market opportunities. **The subject** of the analysis is the country models of SBSP development, their institutional design and economic parameters determining the prospects for the orbital stations' commercialization. **The purpose of the work** is to identify the dominant national strategies in the sphere of space energy and to determine the threshold values of indicators ensuring its economic feasibility. The relevance of the topic is due to the intensification of programs in the United States, China, Japan, India, Russia and the European Union, which consider SBSP as a tool for reducing dependence on traditional energy carriers and consolidating technological leadership. **The methodological framework** includes comparative country analysis, modeling with the decomposition of factor influences on LCOE, as well as analysis of strategic documents and reporting data. **The scientific novelty** of the study lies in the classification of national approaches to the development of CSE, built on the basis of the analysis of financing sources and mechanisms, as well as in the adaptation of the levelized cost of energy (LCOE) methodology to the specifics of space projects. **The results of the study** allow us to identify six strategic paradigms, from the American synergetic model based on private initiative to the conservative evolutionary position of Russia. Quantitative analysis confirms the main barrier to commercialization is not the efficiency of photovoltaic cells but the cost of launching a payload into orbit, setting benchmarks for long-term investment policy and technological development.

Keywords: space-based solar power (SBSP); levelized cost of energy (LCOE); orbital solar stations (OSS); investment strategies; installed capacity utilization rate (ICUR); economic feasibility; energy security; commercialization of space energy

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ОРИГИНАЛЬНАЯ СТАТЬЯ

Космическая солнечная энергетика: экономическая целесообразность в условиях глобальной конкуренции

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АННОТАЦИЯ

Развитие космической солнечной энергетики (КСЭ) в последнее десятилетие выходит за рамки научно-технических экспериментов и приобретает черты формирующегося сектора глобальной экономики. В отличие от работ, сосредоточенных на технологических аспектах или экологической повестке, проведенное исследование рассматривает КСЭ как область пересечения долгосрочных инвестиционных стратегий, национальных приоритетов энергетической безопасности и новых рыночных возможностей. **Предметом анализа** выступают страновые модели развития КСЭ, их институциональное оформление

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и экономические параметры, определяющие перспективы коммерциализации орбитальных станций. **Цель работы** — выявить доминирующие национальные стратегии в области космической энергетики и определить пороговые значения показателей, обеспечивающих ее экономическую целесообразность. **Актуальность темы** обусловлена активизацией программ США, КНР, Японии, Индии, России и Европейского космического агентства, рассматривающих КСЭ как инструмент снижения зависимости от традиционных энергоносителей и закрепления технологического лидерства. **Методологическая база** включает сравнительный страновой анализ, моделирование с декомпозицией факторных влияний на нормированной стоимости энергии (LCOE), а также анализ стратегических документов и отчетных данных. **Научная новизна** исследования заключается в классификации национальных подходов к развитию КСЭ, построенной на основе анализа источников и механизмов финансирования, а также в адаптации методологии нормированной стоимости энергии к специфике космических проектов. **Результаты исследования** позволяют выделить шесть стратегических парадигм — от американской синергетической модели, опирающейся на частную инициативу, до консервативно-эволюционной позиции России. Количественный анализ подтверждает, что основным барьером коммерциализации выступает не эффективность фотоэлементов, а стоимость вывода полезной нагрузки на орбиту. Достижение целевых показателей в диапазоне 20–50 долл./кг способно обеспечить паритет КСЭ с наземными источниками генерации, что задает ориентиры для долгосрочной инвестиционной политики и технологического развития.

Ключевые слова: космическая солнечная энергетика (КСЭ); нормированная стоимость энергии (НСЭ); орбитальные солнечные станции (ОСС); инвестиционные стратегии; коэффициент использования установленной мощности (КИУМ); экономическая целесообразность; энергетическая безопасность; коммерциализация космической энергетики

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1. Introduction

The evolution of approaches to the use of solar energy in outer space is a classic trajectory of technological development: from solving the narrowly focused problem of powering an individual spacecraft to realizing the potential of technology as a driver of systemic changes in the global economy. At the initial stage, photovoltaic systems acted exclusively as an onboard power source determining the resource and efficiency of space missions.[1] The current stage of development is characterized by a conceptual shift towards the creation of orbital solar stations (OSS) capable of contactless transmission of energy to ground-based receiving complexes. However, the real conceptual upheaval is associated with the transition to the idea of space-based solar power plants (CSPs) capable of transmitting energy to Earth. Peter Glaser originally proposed the idea of orbital solar stations (OSS) in 1968 as a solution to energy scarcity, and it is now transforming into a factor of economic sovereignty and a tool for long-term investment planning. In the context of the growing volatility of global commodity markets and increased competition for energy resources, access to extraterrestrial energy sources ceases to be an exclusively technological task and moves to the plane of ensuring economic security and the formation of new markets.

Three interrelated factors, far beyond the challenges of decarbonization, drive the current interest in OSS.

Formation of a new architecture of the global energy market. A state or a coalition of countries that is the first to ensure the commercially efficient operation of the OSS will get the opportunity not only to diversify its own energy balance but also to form a fundamentally new segment of the world energy market — space generation. Unlike traditional hydrocarbons, energy transmitted from orbit is characterized by zero marginal production costs after the commissioning of capacities and the absence of reference to territorially localized resource bases. These properties form the prerequisites for the emergence of new business models and financial instruments: from long-term contracts for the supply of "orbital energy" to the creation of international energy pools with the participation of sovereign funds and institutional investors. The active investment

[1] NASA Technology Roadmaps. Space Based Solar Power. NASA Official site. 11.01.2024. URL: https://ntrs.nasa.gov/api/citations/20230018600/downloads/OTPS%20SBSP%20Report%20Final_Tagged_Approved_1_5_24.pdf (accessed on 18.11.2025).

policy of China,[2] which declares its intention to launch a demonstration station by 2028 [2], and US program initiatives within the framework of the Defense Advanced Research Projects Agency of the US Department of Defense (Defense Advanced Research Projects; DARPA)[3] testify to the understanding by the world's leading economies of the strategic potential of the OSS as a tool for influencing the redistribution of global energy flows in the emerging multipolar world. A recent study by He, Che, and Liu [3] published in Joule provides quantitative economic validation for this potential, demonstrating that SBSP could become a commercially viable component of large-scale power systems under specific cost reduction scenarios.

The role of OSS as a basic element for the production infrastructure in space. The OSS's economic potential extends beyond merely exporting energy to Earth. The possibility of creating production clusters in space based on orbital energy platforms is of key importance from the point of view of long-term economic growth. Providing energy to lunar settlements, refueling complexes for interplanetary flights, and, most importantly, orbital factories for the production of materials with unique properties in microgravity opens up prospects for the formation of new industries with high added value. In this context, OSS should be considered not an end product but an infrastructural asset creating conditions for the emergence of a number of related markets and ensuring the transition to a qualitatively new model of economic development based on the use of extraterrestrial resources. The lack of a reliable power supply beyond Earth is a critical limitation for any scenario of commercial exploration of the Moon, Mars, or deep space flights.

Investments in technological sovereignty and their multiplicative effect. The deployment of the OSS acts as a catalyst for the development of a wide range of critical dual-use technologies: autonomous robotics for the assembly of large-sized structures in space, the creation of materials with fundamentally new characteristics, wireless power transmission systems (laser and microwave) with high efficiency advantages in related sectors: telecommunications, the defense industry, transport, forming a stable multiplier effect for national economies. At the same time, the motivation of the participating countries is differentiated: if for the United States and China the priority is to consolidate leadership in high-tech processing stages, then for Japan, characterized by critical dependence on energy imports, the OSS is a tool for ensuring long-term economic security and reducing country risks associated with the volatility of world hydrocarbon prices.[4]

The scientific novelty of this study lies in the substantiation of the thesis about the need to rethink the OSS projects in the categories of economic efficiency, investment attractiveness and market potential, as opposed to the technical-engineering or military-political discourse dominating in the literature. The paper attempts to assess the Russian scientific and technical potential through the prism of its conversion into competitive advantages in the context of the emerging global space energy market, based on the premise of "stimulating technological development as the main driver of economic growth" [4, p. 109].

The practical significance of the work lies in the formation of a conceptual framework for the integration of OSS projects into the system of strategic planning and investment policy at the national and corporate levels. The proposed approach allows us to consider OSS not only as an engineering project but also as a new class of long-term infrastructure assets requiring the development of specialized methods for financial modeling, risk assessment and management of investment portfolios of energy and high-tech companies.

To achieve the purpose formulated in the abstract — identifying dominant national strategies in space energy and determining the threshold values for economic feasibility — the study sets the following research objectives:

- To identify and classify country-specific models of SBSP development based on an analysis of funding sources, institutional architecture, and strategic priorities.
- To adapt the levelized cost of energy (LCOE) methodology to the specifics of space projects and

[2] The National Center for Science Technology Innovation (NCSTI). China looks set to build space solar power station. URL: https://en.ncsti.gov.cn/home/gridview/202406/t20240613_164551.html (accessed on 20.11.2025).

[3] A Glimpse at the Future of Space-Based Solar Power/Energy and Technology. 11.08.2025. URL: https://www.ncsc.coop/content/solutions/en/stories/energy-tech/a-glimpse-at-the-future-of-space-based-solar-power.html (accessed on 22.11.2025).

[4] Japan Basic Plan on Space Policy. URL: https://www8.cao.go.jp/space/plan/plan-eng.pdf (accessed on 25.11.2025).

determine the threshold values of key parameters (launch cost, capacity factor, operational lifetime) that ensure the economic viability of SBSP.

• To assess the risks and opportunities for countries with different strategic approaches, including Russia, in the context of the emerging global space energy market.

2. Materials and methods of research

Research methodology is based on a comparative analysis of open data, official strategic documents, scientific publications and reports of analytical agencies.

Existing studies, as a rule, consider OSS either in a narrow technical way [5–7] or through the prism of green energy [8–11]. The review by Cifone et al. (2025) [12] takes a broader perspective, synthesizing recent technological demonstrations and assessing the economic viability of SBSP, thereby bridging the gap between technical feasibility and commercial potential. Despite the growing interest in OSS, their study in the context of geopolitical competition and the formation of new space infrastructure is fragmentary [13, 14]. The key issues of economic feasibility and analysis of the market potential of OSS in the new multipolar model of the space economy remain insufficiently explored, and only a few recent studies [15] are starting to address these aspects. However, the main driving forces behind the creation of OSS are not so much environmental factors as the desire for energy dominance, the formation of long-term competitive advantages and the creation of not only a technological but also an investment basis for the next stage of economic space exploration.

The information basis of the study. The empirical foundation of the work consists of three groups of sources, identified according to the criteria of reliability, representativeness and chronological relevance. The first group consists of official strategic documents and policy statements determining the vectors for the development of leading powers' space activities. Among them are the U.S. Space Act (U.S. Space Act, 2015),[5] roadmaps of the National Aeronautics and Space Administration (NASA, 2024),[6] program documents of the China National Space Administration (CNSA),[7] reflected in the XIV Five-Year Plan (2021–2025),[8] the Basic Space Law of Japan (Basic Space Law, 2008)[9] and the JAXA Strategic Roadmap,[10] as well as the Federal Space Program of Russia and the Fundamentals of State Policy in the Field of Space Activities until 2030.[11] The second group of sources is represented by analytical reports and feasibility studies by reputable organizations: NASA,[12] the National Security Technology Accelerator (NSTXL),[13] the LAZARD Laboratory (2025),[14] the European Space Agency (ESA SOLARIS),[15] and the National Center for Scientific Research and Innovation of China (NCSTI).[16] The third group includes peer-reviewed scientific literature, consisting of fundamental works laid the conceptual foundations of the problem: from N. Tesla's experiments on wireless power transmission [16] and the civilizational hypothesis of N.S. Kardashev

[5] U.S. Space Act, 2015. U.S. Public Law 114–90. URL: https://www.congress.gov/114/plaws/publ90/PLAW-114publ90.pdf (accessed on 10.11.2025).

[6] NASA Technology Roadmaps. Space Based Solar Power. NASA Official site. 11.01.2024. URL: https://ntrs.nasa.gov/api/citations/20230018600/downloads/OTPS%20SBSP%20Report%20Final_Tagged_Approved_1_5_24.pdf (accessed on 18.11.2025).

[7] Policies and Announcement. China National Space Administration official site. URL: https://www.cnsa.gov.cn/english/n6465645/n6465648/index.html

[8] The 14th Five-Year Plan of the People's Republic of China. URL: https://www.adb.org/publications/14th-five-year-plan-high-quality-development-prc (accessed on 10.11.2025).

[9] Japan's legal framework: Basic Space Law (2008) and CSE Strategic Roadmap. URL: https://global.jaxa.jp/about/law/index.html (accessed on 13.11.2025).

[10] Research on Space Solar Power Systems (SSPS). JAXA. 2025. URL: https://www.kenkai.jaxa.jp/eng/research/ssps/ssps-ssps.html (accessed on 10.11.2025).

[11] Fundamentals of State Policy in the Field of Using the Results of Space Activities in the Interests of Modernizing the Economy of the Russian Federation and the Development of Its Regions for the Period up to 2030. Electronic fund of legal and regulatory and technical documents. URL: https://docs.cntd.ru/document/560853771(accessed on 10.11.2025). Hereinafter referred to as Cosmos Policy Fundamentals-2030.

[12] Rodgers E., Gertsen J., Stroup T., et al. Space-Based Solar Power: Technology Assessment and Economic Analysis. Washington: NASA Office of Technology, Policy, and Strategy; 2024. 98 p. URL: https://ntrs.nasa.gov/api/citations/20230018600/downloads/OTPS%20SBSP%20Report%20Final_Tagged_Approved_1_5_24.pdf (accessed on 18.11.2025).

[13] Reducing the Cost of Space Travel with Reusable Launch Vehicles. Analytical Report (NSTXL, 2024). URL: https://nstxl.org/reducing-the-cost-of-space-travel-with-reusable-launch-vehicles/ (accessed on 21.11.2025).

[14] Lazard's 2025 LCOE+ Report, June 2025. URL: https://www.lazard.com/media/5tlbhyla/lazards-lcoeplus-june-2025-_vf.pdf (accessed on 03.12.2025).

[15] ESA Annual Space Environment Report. URL: https://www.esa.int/Space_in_Member_States/United_Kingdom/ESA_accelerates_the_race_towards_clean_energy_from_space (accessed on 13.11.2025).

[16] The National Center for Science Technology Innovation (NCSTI). China looks set to build space solar power station. URL: https://en.ncsti.gov.cn/home/gridview/202406/t20240613_164551.html (accessed on 20.11.2025).

[17] to the classic work of P. Glaser, who was the first to formulate the principles for the creation of orbital solar stations [1]. Special attention is paid to modern publications reflecting the current stage of the discussion development, including studies by Russian researchers [18–20] and foreign authors [2, 8]. For example, a review conducted by Cifone et al. [12], assessing the economic viability of the SBSP, concludes, despite significant obstacles remaining, recent advances in wireless power transmission and light photovoltaic systems make it much easier to achieve commercial feasibility for investment in orbital stations. To verify the conclusions about the industry's transition to the experimental development phase, materials on practical tests were used, including successful demonstrations by the Japan Aerospace Exploration Agency (JAXA)[17] and data on the deployment of a test site in Chongqing (China) [2].

Methods of collecting and processing information. At the initial stage, the collection, systematization and primary processing of open data from the listed sources was implemented. To identify key semantic parameters in strategic documents and policy statements, content analysis is used.

Methods of comparative and country analysis. To compare the approaches of six key players (the United States, China, Japan, India, Russia, and the European Space Agency), this study employed a comparative analysis. This comparison relied on a single matrix of criteria: the institutional architecture for managing CSE programs, the prevailing sources and mechanisms of funding, the degree of private sector involvement, the availability of publicly stated targets and timeframes, and the position on international legal regulation of the use of space energy. The differences identified made it possible not only to streamline national strategies, but also to explain the difference in their dynamics.

Methods of Economic Analysis and Modeling. To provide a quantitative assessment of the prospects for Space-Based Solar Power (SBSP), this study employs a techno-economic analysis decomposing the Levelized Cost of Electricity (LCOE). The base-case LCOE formula included the following parameters: capital expenditures (It), encompassing the cost of developing and manufacturing photovoltaic modules, payload launch expenses (the main economic barrier), the creation of power transmission systems, and ground-based receiving infrastructure; operating expenses (Ot), associated with orbital maintenance, space debris countermeasures, and station upkeep; the volume of energy produced (Et), deriving from the uniquely high capacity factor in geostationary orbit (35.8 thousand km); the discount rate (r), reflecting a combination of technological and country-specific risks; and the estimated service life (n). Modeling based on the parameter ranges documented in the NASA (2024) and NSTXL (2024) reports has enabled the identification of threshold values for launch costs ($20–$50/kg). At these costs, the LCOE of SBSP becomes competitive with terrestrial energy sources. Furthermore, a sensitivity analysis of the final generation cost to key variable changes identifies critical leverage points for achieving economic feasibility. The approach to LCOE decomposition developed in this study aligns with contemporary methodological approaches to assessing technological development [21], allowing SBSP to be considered not in isolation, but in the context of its position within a somewhat expanded technological core of the global economy.

Case analysis method. This research employed the method to examine technological solutions in the context of their commercial potential. For the examples, author selected projects significant to the future SBSP economy: JAXA's wireless power transmission experiments in Japan (2015), the development of Roll-Out Solar Arrays (ROSA)[18] in the United States, and the establishment of a testing ground in Chongqing, China. The analysis confirms the conclusion the industry is moving from a theoretical stage to a practical one — this fact is an important signal for attracting investment and the possibility of intensive commercialization. Unlike studies focused on the operational applicability of SBSP for niche applications [22, 23], the present study conducts a decomposition analysis of LCOE, which has made it possible to identify the cost of payload delivery as the most critical parameter for commercialization. Achieving the threshold value of $20–$50/kg would make SBSP competitive with

[17] JAXA's experiment on wireless power transmission from the Konotori spacecraft. Source: JAXA press release of March 12, 2015 "Successful Operation of Wireless Power Transmission Technology for SSPS". URL: https://www.mhi.com/news/1503121879.html (accessed on 16.11.2025).

[18] Experimental solar panels deployed on the ISS. Clean Energo News Portal. 26.06.2017. URL: https://www.cleanenergo.ru/2017/na-mks-razvernuli-eksperimentalnye-solnechnye-batarei/ (accessed on 20.11.2025).

terrestrial generation and provide clear benchmarks for long-term investment policy.

This study has several restrictions. The most significant one is the closed character of information on some national programs (particularly those of China and Russia). This situation necessitated the use of only open data and the opinions of reliable experts. To all given above, the prediction of LCOE is scenario-dependent and sensitive to assumptions about technological changes. The findings take these restrictions into account, admitting the probabilistic characters of results requiring further correction as new information will be gotten.

3. Results

3.1. SBSP economics: National strategies and models

By comparing national approaches to space-based solar power, the author discovered the fact that the key differences between countries are primarily characterized not by their levels of technological readiness but rather by their fundamental strategic goals and the possible financing models they use.

3.2. USA: Synergetic model of public-private partnership and use of market mechanisms for CBSP development

The American method of space-based solar power development is linked to the "New Space" phenomenon. This paradigm concentrates on the construction of economic synergies between government customers and private high-technology enterprises. Within this framework, NASA has transformed from a sole developer into an integrator of the growing innovation ecosystem as technologies evolve and are implemented. The development and testing of flexible Roll-Out Solar Arrays (ROSA) provide an illustrative example.[19] This technology, developed with significant government backing, moved relatively quickly to commercialization, finding applications on the International Space Station and in other projects [24]. In doing so, it created a precedent for a "dual-use technology" possessing both near-term and long-term value.

Private companies, most notably SpaceX, play a pivotal role in stimulating demand for innovation. By deploying massive low-orbit satellite constellations such as Starlink, the company generates sustained market demand for solar panels that are not only efficient and reliable but also cost-effective. This market dynamic, in turn, fuels further technological progress. It helps reduce the cost of producing each unit. At the same time, the major players like Northrop Grumman[20] and Lockheed Martin,[21] are increasing their engagement with the SBSP sector. They bet strategically on its long-term prospects and anticipated expansion.

A project's ability to attract investment depends heavily on its legal framework. By enacting the Space Act in 2015,[22] the United States created a definitive legal basis for commercial space resource utilization, including solar power. This gave private investors the certainty they need for long-term, high-risk ventures. The resulting American model focuses on a self-sustaining ecosystem: government sets direction and removes barriers, while business finds commercial niches and pursues cost reductions.

3.3. China: State planning and resource mobilization for SBSP

China treats space solar power as a national priority. Technological goals fit directly into the country's broader plans for economic and social development.

Two main institutions lead the work: CNSA, the space agency, and CASC, the aerospace contractor. They operate as a single unit, following directions from political leadership through a strict chain of command.

Progress in space solar technology follows a clear pattern. First, China studies existing designs. Then it improves them. Finally, it builds its own systems. This approach has helped the country catch up with American technology quickly.[23]

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[19] Experimental solar panels deployed on the ISS. Clean Energo News Portal. 26.06.2017. URL: https://www.cleanenergo.ru/2017/na-mks-razvernuli-eksperimentalnye-solnechnye-batarei/ (accessed on 20.11.2025).

[20] Solar Array Products. Northrop Grumman — Official site. URL: https://www.northropgrumman.com/what-we-do/space/mission-enabling-products/solar-array-products (accessed on 21.11.2025).

[21] Small Satellite Solar Arrays. Lockheed Martin Corporation. Official site. URL: https://www.lockheedmartin.com/en-us/products/smallsat-solar-arrays.html (accessed on 29.11.2025).

[22] U.S. Space Act, 2015. U.S. Public Law 114–90. URL: https://www.congress.gov/114/plaws/publ90/PLAW-114publ90.pdf (accessed on 10.11.2025).

[23] The National Center for Science Technology Innovation (NCSTI). China looks set to build space solar power station URL: https://en.ncsti.gov.cn/home/gridview/202406/t20240613_164551.html (accessed on 21.11.2025).

However, speed is not the sole factor that distinguishes China. The scale of resources it can bring to bear matters just as much. Unlike countries where SBSP advances through debate and market signals, China has already started building a major test site in Chongqing. The facility will test two critical technologies: assembling large structures in space and transmitting power wirelessly [2]. Money for this work comes through the 14th Five-Year Plan (2021–2025),[24] which gives the project the weight of a state assignment. Companies with majority government ownership must deliver.

The official target calls for a pilot megawatt-level orbital station by 2035. This is not just a statement of ambition. It serves as a tool for long-term planning and focusing resources. The Chinese model follows a direct path to its goal. Market forces play little role during research and development. Instead, the government provides what amounts to unlimited funding. It directs engineering talent where needed. And there is no pressure to make short-term profits.

This approach lets China overcome investment barriers that still make SBSP economically unattractive in market-driven economies.

3.4. Japan: A strategy of technological specialization and a model for monetizing core competencies

Japan has a long-standing interest in alternative energy sources. The country faces objective constraints in the form of limited domestic resources, and this situation has long made energy security a central concern of national policy. Space-based solar power fits into that broader picture.

The Japanese response to SBSP differs markedly from the American or Chinese models. Rather than pursuing scale or self-sufficiency across the entire technological spectrum, Japan has chosen to focus its efforts.[25] The logic is straightforward: with finite resources, attempting to compete across the board would likely result in mediocrity across the board. A different approach is called for.

That approach centers on wireless power transmission. This method is widely regarded as one of the most technically demanding elements of the entire SBSP enterprise. It is also capital-intensive. JAXA, together with industrial partners such as Mitsubishi Heavy Industries, has made this project the focus of its work.

The strategic rationale deserves attention. Japan cannot match the budgetary scale of American programs or the mobilization capacity of Chinese ones. This is simply a fact. But by concentrating resources on a single critical technology, Japan can achieve something else: it can become indispensable. Future international SBSP projects, whatever their scale and whoever leads them, will require efficient wireless power transmission. If Japan controls that technology, it controls a vital piece of the puzzle. The country positions itself not as a competitor in scale but as a supplier of necessary capability.

Evidence that the technology works has already been produced. During the "Kounotori" mission to the International Space Station, JAXA successfully demonstrated microwave power transmission under space conditions. This was not merely a laboratory exercise. It was a practical validation of a technology with clear commercial applications. The groundwork has been laid for future revenue streams: licensing intellectual property, providing engineering services, and entering into collaborative arrangements with partners who bring other capabilities to the table.

The Japanese case suggests that there is more than one path to relevance in emerging technological domains. Scale is one option. Specialization is another.

The Japanese "Strategic Roadmap for Space Solar Power Development"[26] formalizes this approach. Unlike many national documents that remain aspirational, this roadmap carefully charts the progression from basic research to market deployment. It sets out both the technological benchmarks that must be reached and the economic targets required to attract private investment. The underlying logic is clear. Japan pursues global significance not by scaling up, but by dominating a vital technological segment. From that position of strength, the country can

[24] The 14th Five-Year Plan of the People's Republic of China. URL: https://www.adb.org/publications/14th-five-year-plan-high-quality-development-prc (accessed on 10.11.2025).

[25] Research on Space Solar Power Systems (SSPS). JAXA. 2025. URL: https://www.kenkai.jaxa.jp/eng/research/ssps/ssps-ssps.html (Japan's Legal Framework: Basic Space Law (2008) and the Strategic Roadmap for Space Solar Power (SSP). (accessed on 10.11.2025).

[26] Japan's Legal Framework: Basic Space Law (2008) and the Strategic Roadmap for Space Solar Power (SSP). URL: https://global.jaxa.jp/about/law/index.html (Japan's Legal Framework: Basic Space Law (2008) and the Strategic Roadmap for Space Solar Power (SSP). (accessed on 13.11.2025).

monetize its advantage through licenses, collaborative ventures, and technology transfers — a model that turns constraint into competitive strength.

3.5. India: A strategy of incremental development and a model of budget efficiency

The Indian space paradigm demonstrates a consistent, long-term strategy focused on fundamental scientific research and national economic pragmatism. Although India currently operates with budgets that are not comparable to those of the leading spacefaring nations, the Indian Space Research Organization (ISRO) is methodically constructing the technological and institutional foundation necessary for a future breakthrough in SBSP.

India's principal strength does not lie in radical technological breakthroughs per se, but rather in its capacity to formulate a coherent strategy and pursue defined objectives with remarkable consistency, all while rigorously containing costs at every stage. The successful soft landing of Chandrayaan-3 on the lunar surface offered a striking demonstration of India's emerging capabilities. Shchedrov and Topyckanov in their article [25] noted that the achievement stood out all the more when placed alongside the setbacks experienced by Japanese and Russian lunar programs during the same period. Speaking after the mission, India's Minister of State for Space, Dr. Jitendra Singh, made a point that resonated widely: the mission proved that India can execute complex space operations without the budgets normally associated with such undertakings.[27] What Russia spent on its own, ultimately unsuccessful attempt exceeded India's expenditure by a factor of more than twenty-six.[28] The contrast reveals something fundamental about how the two countries approach resource allocation.

For India, SBSP is not simply a technological ambition. It speaks to more immediate concerns. The country faces real pressure on its energy system. Population growth continues. Dependence on imported hydrocarbons remains high. In this context, space-based solar power takes on a different character. It becomes a long-term infrastructure asset, something that can reduce exposure to external shocks and move the country closer to genuine energy independence. The economic logic is consistent with what Chandrayaan-3 demonstrated: outcomes depend not only on how much is spent but also on how resources are deployed. India's low-cost approach to space projects creates favorable conditions: with funding similar to other nations, India can achieve higher returns on investment. The Indian paradigm therefore shows that when one cannot compete through investment scale, one can compete through investment efficiency.

3.6. Russia: A conservative-evolutionary strategy and the risks of missed opportunities

Russia's position on space-based solar power reflects the broader institutional characteristics of its national space industry: reliance on technological heritage, a strong foundation in "classical" areas, and caution toward capital-intensive innovations with uncertain payback horizons. The primary developer, the Russian Space Systems holding company, has presented a project for a low-power (up to 100 kW) space solar power station utilizing a laser channel for energy transmission to Earth. As the project initiator, M. Barkova, notes, the pilot version of such a station targets remote and hard-to-reach regions and deliberately does not position itself as a competitor to conventional generation [26].[29] This niche-oriented approach aligns with more recent and broader economic findings: Chen, Wang, and Li, in their article [27], demonstrate that even at intermediate launch cost reductions, SBSP can become viable for niche applications and remote markets before achieving full-scale commercial competitiveness.

A key feature of the Russian approach lies in the absence of SBSP integration into the system of national priorities. Key policy documents — the Federal Space Program and the Fundamentals of State Policy in Space Activities until 2030 — contain no direct mention of SBSP.[30] Research proceeds

[27] Chandrayaan-3 translates to "Lunar Craft-3" (author's note).

[28] Chandrayaan-3 has proved India's capability for cost-effective Space missions. Indian Government Press Information Bureau. 26.08.2023. URL: https://www.pib.gov.in/PressReleasePage.aspx? PRID=1952448 (accessed on 27.11.2025).

[29] Solar energy to be transmitted to Earth via laser beam. Scientific and business portal "Atomic Energy 2.0". 28.01.2022. URL: https://www.atomic-energy.ru/news/2022/01/28/121373 (accessed on 29.11.2025).

[30] Fundamentals of State Policy in the Field of Utilizing the Results of Space Activities for the Purposes of Modernizing the Economy of the Russian Federation and Developing Its Regions for the Period up to 2030. Electronic Fund of Legal and

sporadically within broader power systems studies, lacking dedicated funding and institutional responsibility.

The Law "On Space Activities"[31] enshrines the dominant role of the state, which, in the absence of expressed political interest in SBSP, creates an institutional vacuum for private initiatives. Under conditions where the state serves as the sole customer and regulator yet does not generate demand for innovation, projects with long payback horizons and a high degree of uncertainty become investment-unattractive both for private capital and for state corporations focused on fulfilling approved plan targets.

One can characterize the Russian paradigm as "conservative-evolutionary" — it entails gradual improvement of proven solutions and a wait-and-see stance toward technologies that advance beyond the current stage of development. However, as other nations move from conceptual discussion to practical implementation and targeted investment, such a strategy carries risks of missed opportunities. By postponing entry into the new technological wave, Russia risks finding itself in a catch-up position at a stage when key patents, competencies, and market niches have already been allocated and the cost of entering the industry has multiplied.

3.7. Europe (ESA): A rational-waiting strategy and the economic costs of multilateral governance

The European approach to space-based solar power development exhibits the characteristic combination, typical of the European Space Agency (ESA), of high scientific and technological potential alongside institutional complexity in decision-making — a complexity arising from the need to align investment priorities among ESA member states. European companies such as Airbus[32] and Thales Alenia Space[33] — possess world-class competencies in creating highly efficient photovoltaic systems for scientific missions in extreme environments, including the BepiColombo spacecraft mission to Mercury.[34] However, the mere existence of technological capabilities does not automatically guarantee a transition to their commercial exploitation.

The ESA SOLARIS initiative[35] represents a classic "rational-waiting" paradigm. Its goal involves not the immediate launch of development work but a comprehensive assessment of technical feasibility, economic viability, and environmental implications of SBSP. This strategy minimizes early-stage investment risk, but the trade-off is clear: it significantly slows the move from research to demonstration.

Europe operates under institutional constraints that are not easily set aside. Because decision-making requires consensus among member states, and because those states bring different priorities, budget realities, and energy strategies to the table, building agreement takes time. It also consumes resources that might otherwise go directly into program execution. These transaction costs matter more in a context where technology moves quickly. The danger is that Europe finds itself responding to developments shaped elsewhere rather than helping to shape them.

There is a broader lesson in the European experience. Advanced technology is necessary for a major SBSP program, but it is not enough on its own. Two other conditions must be met. The first is political: someone must have the will to concentrate resources behind a shared objective. The second is commercial: there must be a credible account of how the venture will generate returns and attract sustained investment. Without these elements, even strong scientific and industrial capabilities may never find their way into operational form. In the absence of these elements, even high scientific potential risks remaining commercially unexploited, yielding ground to the more decisive and coordinated actions of other global players. The diagram below summarizes six national models of SBSP development described above (see *Figure*).

Regulatory-Technical Documents. URL: https://docs.cntd.ru/document/560853771(accessed on 10.11.2025).

[31] Law «On Space Activities» No. 5663–1, with amendments and additions as of July 7, 2025. URL: https://base.garant.ru/136323/ (accessed on 10.11.2025).

[32] Solar power beams: a step towards cleaner energy. Airbus. Official site. URL: https://www.airbus.com/en/newsroom/news/2022–09-solar-power-beams-a-step-towards-cleaner-energy (accessed on 22.11.2025).

[33] Thales Alenia Space Official site. URL: https://www.thalesaleniaspace.com/en/space-alliance (accessed on 22.11.2025).

[34] BepiColombo, Investigating Mercury's mysteries. European Space Agency URL: https://www.esa.int/Science_Exploration/Space_Science/BepiColombo (accessed on 22.11.2025).

[35] ESA Annual Space Environment Report. URL: https://www.esa.int/Space_in_Member_States/United_Kingdom/ESA_accelerates_the_race_towards_clean_energy_from_space (accessed on 13.11.2025).

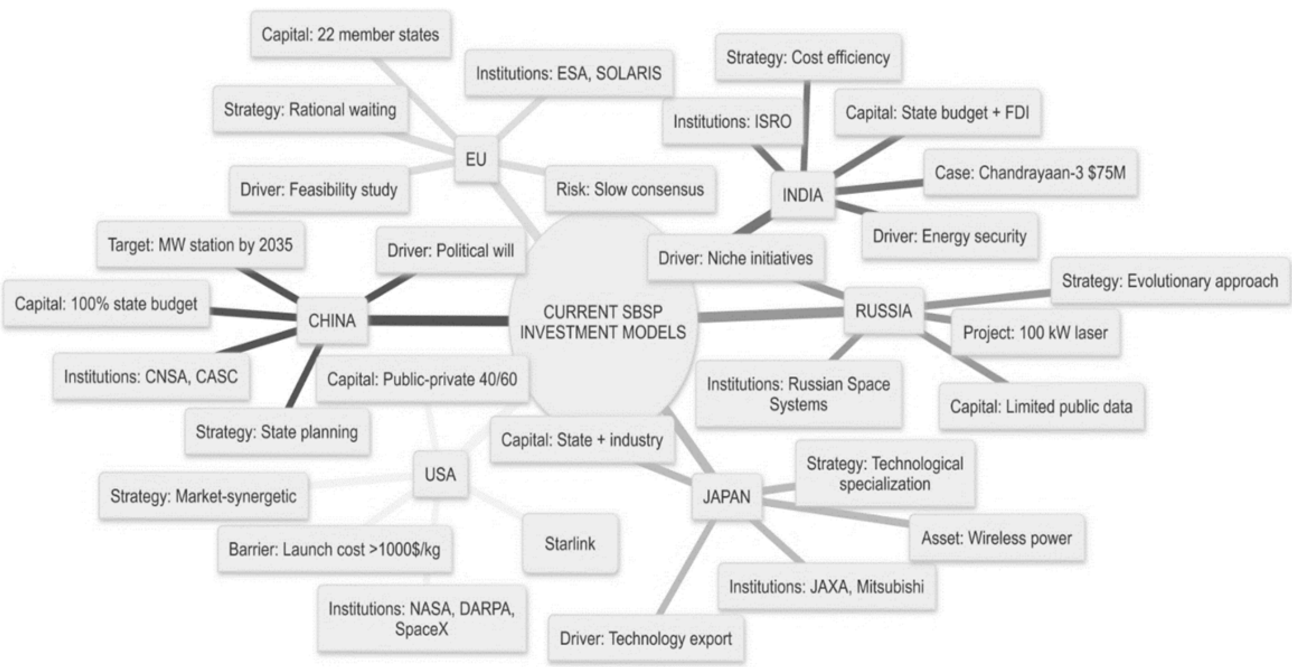

Fig. **National strategies and models of SBSP economics**

Source: Structured and built by the author in the Mermaid program.

Six national models of SBSP development are distinguished not primarily by technological maturity, but by strategic objectives and funding sources — ranging from the market-oriented US approach and China's state-mobilization model to Japan's specialization strategy, India's budget-efficient paradigm, Russia's conservative-evolutionary stance, and Europe's rational-waiting approach. The key differentiating factor is the balance between state planning and market mechanisms.

4. The legal dimension of SBSP: National regimes and economic risks

The legal environment for SBSP remains in a formative stage, with national approaches diverging and thereby influencing the investment climate and project financing models. The conditions for private investment entry and the fundamental parameters of SBSP economic models depend on how legislation defines rights to space resources and regulates capital participation.

The United States created a legal precedent by permitting private companies to appropriate and sell space resources (Space Act, 2015).[36] This represents a cornerstone for the future commercialization of SBSP.

China[37] and India[38] integrate SBSP legal regulation into the broader frameworks of their national space programs and five-year plans [28].

Japan enacted the Basic Space Act (2008),[39] establishing a legal framework for utilizing space for national prosperity, thereby paving the way for projects such as SBSP.[40]

Given the limited availability of open official data on Russia, forming well-founded conclusions about legal regimes in the SBSP sphere proves problematic.[41]

Table 1 below provides a comparative summary of the relevant country–specific documents.

At the international level, the 1967 Outer Space Treaty remains the foundational instrument. Ar-

[36] U.S. Space Act, 2015. U.S. Public Law 114–90. URL: https://www.congress.gov/114/plaws/publ90/PLAW-114publ90.pdf (accessed on 10.11.2025); U.S. Commercial Space Launch Competitiveness Act, Public Law 114–90 (full text). URL: https://www.govinfo.gov/content/pkg/PLAW-114publ90/html/PLAW-114publ90.htm (accessed on 10.11.2025).

[37] China unveils new measures to boost private investment. (The State Council of People's Republic of China). URL: https://english.www.gov.cn/policies/latestreleases/202511/11/content_WS691283b2c6d00ca5f9a07766.html (accessed on 10.02.2026).

[38] Press Information Bureau, Government of India. (2025, March 12). Parliament Question: Foreign Direct Investment in the Space Sector. URL: https://www.pib.gov.in/Pressreleaseshare.aspx? PRID=2110835

[39] Basic Space Law, 2008 URL: https://global.jaxa.jp/about/law/index.html (accessed on 10.11.2025).

[40] Japan Basic Plan on Space Policy URL: https://www8.cao.go.jp/space/plan/plan-eng.pdf (accessed on 13.11.2025).

[41] Roscosmos proposed sending solar energy from Space. February 22, 2022. URL: https://myseldon.com/ru/news/index/342187687 (accessed on 13.11.2025).

Table 1

National approaches to space activity regulation

Country	Legal framework / strategy	Key provisions of significance for SBSP
USA	U.S. Commercial Space Launch Competitiveness Act (SPACE Act)[1], Public Law 114–90 (2015), Section 51303	By granting private companies' ownership and sale rights over extracted space resources, the law protects future revenues and reduces investor uncertainty
Japan	Basic Space Law (Law No. 43 of 2008)[2]	Article 16 — Tax and financial incentives for private investment. Article 4 — Space Development for International Competitiveness
India	FDI policy amendment (March 2025)[3]	Differentiated FDI limits in the space sector draw foreign investment while keeping state control over strategically sensitive segments
China	State Council Policy on Private Investment (2025)[4]; Commercial Space Action Plan (2025–2027)[5]	The 15th Five-Year Plan includes commercial space among its strategic clusters. Private capital can now engage in commercial space ventures. The government is also establishing a National Fund for the Development of Commercial Space
Russia	Open official sources contain no evidence of dedicated legal frameworks specifically addressing SBSP[6]	Ongoing initiatives (including the space solar power station project by the "Russian Space Systems" holding company) remain fragmentary in nature and do not integrate into strategic document

Source: Compiled by the author.

Notes: [1] U.S. Commercial Space Launch Competitiveness Act, Public Law 114–90 (full text). URL: https://www.govinfo.gov/content/pkg/PLAW-114publ90/html/PLAW-114publ90.htm (accessed on 10.11.2025). [2] Japan's Legal Framework: Basic Space Law (2008) and the Strategic Roadmap for Space Solar Power (SSP). URL: https://global.jaxa.jp/about/law/index.html (Japan's Legal Framework: Basic Space Law (2008) and the Strategic Roadmap for Space Solar Power (SSP). (accessed on 13.11.2025). [3] Press Information Bureau, Government of India. (2025, March 12). Parliament Question: Foreign Direct Investment in the Space Sector. URL: https://www.pib.gov.in/Pressreleaseshare.aspx? PRID=2110835. [4] China unveils new measures to boost private investment. (The State Council of People's Republic of China). 11.11.2025 URL: https://english.www.gov.cn/policies/latestreleases/202511/11/content_ WS691283b2c6d00ca5f9a07766.html (accessed on 10.02.2026). [5] China's "Action Plan for Promoting the High–Quality and Safe Development of Commercial Space (2025–27)". Chinese Laboratory of Space Research. URL: https://www.lsr.hku.hk/china-targets-2027-milestone-for-its-commercial-space-sector-development/ (accessed on 10.02.2026). [6] Fundamentals of State Policy in the Field of Using the Results of Space Activities in the Interests of Modernizing the Economy of the Russian Federation and the Development of Its Regions for the Period up to 2030. Electronic fund of legal and regulatory and technical documents. URL: https://docs.cntd.ru/document/560853771 (accessed on 10.11.2025).

ticle I of the Treaty proclaims the freedom of exploration and use of outer space. Article II, however, prohibits the national appropriation of space and celestial bodies. From a legal perspective, an important question therefore remains open: can a geostationary orbital slot — the most effective position for transmitting energy to Earth — be considered an object falling under this prohibition? And does the prohibition extend to energy collected in orbit? From an economic standpoint, this legal uncertainty creates tangible risks for investors, which in turn increases the cost of capital.

5. The economics of SBSP: LCOE and commercialization thresholds

The Levelized Cost of Electricity, or LCOE, provides an essential metric for evaluating the economic feasibility of SBSP [29]. The structure of this metric reveals the parameters that most critically determine the ultimate cost of generating power in orbit and transmitting it to Earth-based receivers.

5.1. Structural analysis of the LCOE formula as applied to SBSP

To assess the economic viability of SBSP, one must begin with the standard expression for levelized cost of electricity. The formula (1) takes the following form:

$$LCOE = \frac{\sum_{t=1}^{n} * \frac{I_t + O_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} * \frac{E_t}{(1+r)^t}}, \qquad (1)$$

where I_t — Capital expenditures, the dominant cost item for CSEs. It includes:

• Manufacturing costs for photovoltaic modules. Although the cost of terrestrial solar panels has dropped sharply, space-grade counterparts require expensive materials (gallium arsenide) and technologies to ensure radiation resistance and durability [20]. However, the recent work of foreign researchers [30] presented a new system design with increased efficiency, thus reducing the overall cost of launching a spacecraft into orbit.

• Launch and orbital deployment costs constitute the main economic barrier. At current launch costs of approximately $1,000–$3,000/kg[42] deploying a gigawatt-capacity station weighing thousands of tons appears economically inconceivable.

• Costs of developing power transmission systems (antennas, transmitters).

• Costs of the ground-based receiving rectenna (rectenna).

O_t — Operating expenses, encompassing maintenance and repair of the orbital platform. For SBSP, these will prove exceptionally high due to the need to combat component degradation from radiation, perform orbit corrections, and — critically — actively counter space debris. This creates demand for a new industry — orbital servicing — which in itself represents an investment challenge.

F_t — Fuel costs are almost zero, which is a fundamental advantage of CSPs over fossil power plants.

E_t — Energy output represents the key economic rationale and advantage of SBSP. The capacity factor for SBSP in geostationary orbit can reach 0.9–0.95 (90–95%), whereas for the best terrestrial solar plants it does not exceed 0.25–0.3 (25–30%) [31–33]. This means that at identical peak power, an SBSP system will generate 3–4 times more energy annually. Extending research in this direction, Wilson and Vasile in [34] (2025) demonstrate through multi–objective optimization that strategically designed satellite constellations can enhance the economic efficiency of an orbital energy system.

r — The discount rate. For projects carrying high technological, political, and commercial risks, the discount rate will be very high, increasing the cost of capital and requiring the state or institutional investors to provide risk mitigation mechanisms in the early stages.

n — Lifespan determined by the durability of components in the harsh conditions of space. The target of 15–30 years is achievable only with breakthroughs in the creation of appropriate materials and protection from cosmic radiation, which directly affects the return on investment.

[42] Reducing the Cost of Space Travel with Reusable Launch Vehicles. Analytical Report (NSTXL, 2024). URL: https://nstxl.org/reducing-the-cost-of-space-travel-with-reusable-launch-vehicles/ (accessed on 21.11.2025).

Table 2

Comparative cost of electricity for different generation technologies (2024)

Energy Production Technology	LCOE (USD/MWh)
Terrestrial industrial solar power plant	24–96
Wind energy	24–75
Natural gas power plant	39–155
Nuclear Power	141–221
Space–based solar power (estimated)	More than 1000

Sources: Compiled by the author based on National Security Technology Accelerator, 2024; LAZARD Laboratory, 2024; NASA Report, 2024.

5.2. The condition for SBSP's economic competitiveness

Achieving competitiveness between SBSP and ground–based solar power requires satisfying a simplified version of the condition expressed in formula (2). For purposes of illustration, discounting does not enter into this approximation:

$$\left(I_{\text{space}} + O_{\text{space}}\right) \le \le \left(I_{\text{terrestrial}} + O_{\text{terrestrial}}\right) \cdot \frac{ICUR_{\text{space}}}{ICUR_{\text{terrestrial}}}. \quad (2)$$

Substituting the capacity factor values discussed above yields:

$$\left(I_{\text{space}} + O_{\text{space}}\right) \le \left(I_{\text{terrestrial}} + O_{\text{terrestrial}}\right) \cdot \frac{0.9}{0.25} \approx \approx \left(I_{\text{terrestrial}} + O_{\text{terrestrial}}\right) \cdot 3.6. \quad (3)$$

The calculations in formula (3) lead to the following conclusion: even assuming that total capital and operating costs for SBSP prove 3.6 times higher than for terrestrial solar plants, the higher capac-

Table 3
Key LCOE parameters for SBSP: Current values and commercialization targets

Parameter	Current situation for SBSP	Target for competitiveness	Impact on LCOE
Cost of launch	$1,000–$3,000/kg	$20–$50/kg	Reducing the numerator — capital expenditures
Power transmission efficiency	5–10% (In laboratory conditions)	15–20%	This increases the denominator of the LCOE formula — the volume of energy transmitted to Earth
Installed capacity utilization rate (ICUR)	–	90–95% (In potential)	This increases the denominator of the basic LCOE formula — annual energy output
Operational lifetime (n)	Not Confirmed	>20 years	This increases the denominator of the LCOE formula — the energy generation period
Discount rate (r)	Very high	Mitigation through risk reduction	Reduces the final LCOE value

Sources: Compiled by the author based on National Security Technology Accelerator, 2024; LAZARD Laboratory, 2024; NASA Report, 2024.

ity factor allows SBSP to produce energy cheaply enough to achieve parity. The problem lies in the fact that today, the gap in space segment costs exceeds 3.6 times — it runs to orders of magnitude greater, primarily due to launch costs.

5.3. Comparative analysis of LCOE and commercialization targets

A comparison of SBSP's levelized cost of electricity (LCOE) with traditional and renewable generation sources vividly illustrates the scale of the economic challenge facing SBSP (*Table 2*).

The existing cost difference, which is more than an order of magnitude higher than the cost of terrestrial alternatives, confirms the non-competitiveness of SBSPs. But a comprehensive comparative station life cycle assessment [35] argues that while SBSP is currently inferior to onshore renewables in strict cost metrics, its unique advantage lies in providing real baseload power without the disruption issues associated with onshore solar and wind installations. Breaking down the LCOE into its constituent elements makes it possible to determine exactly which parameters need to change and by how much in order to achieve commercial profitability (*Table 3*).

Recent advances in wireless power transmission, as reviewed by Mori and Sasaki [36], suggest efficiency targets of 15–20% are achievable with current technology trends, and further improvements could push these figures even higher. These efficiency gains have direct economic implications: they reduce the required generating surface area, lower launch mass and associated costs, and ultimately improve the return on investment for SBSP infrastructure.

The key conclusion from the analysis presented: today, the main driver of SBSP economics is not photovoltaic efficiency but the cost of access to space. This component of capital expenditures creates a gap that even the uniquely high-capacity factor (3–4 times higher than terrestrial) and zero fuel costs cannot offset.

Achieving the target range of $20–$50/kg would reduce capital expenditures to a level where SBSP's LCOE becomes comparable to terrestrial generation sources. Recent progress in developing reusable launch vehicles (e.g., SpaceX Starship) provides grounds for cautious optimism, yet the required cost reduction spans orders of magnitude beyond what has been achieved to date. Meeting these target parameters sets benchmarks for long-term investment policy and technological development: without a radical reduction in the cost of delivering payloads to orbit, SBSP commercialization will remain a theoretical prospect.

6. Conclusion

Conducted research allows to systematize the key findings regarding the economic viability of space-based solar power (SBSP) in the context of global competition.

This study establishes that space-based solar power (SBSP) has moved from the phase of theoretical concepts into the realm of strategic planning and long-term investment. An analysis of national approaches — from the market-oriented U.S. model to the state-directed strategies of China and India, Japan's technology-niche positioning, and Russia's conservative-evolutionary approach — has revealed fundamental differences in objectives, stages of readiness, and methods of implementing space energy programs.

The primary driver of SBSP development lies not so much in the environmental agenda as in the pursuit of energy independence and the creation of foundational infrastructure for the future space economy. Orbital power platforms can supply not only energy to Earth but also power for lunar bases, orbital manufacturing facilities, and interplanetary missions — in other words, they can become the foundation for emerging high-value-added markets. This fundamentally shifts the investment logic: SBSP projects merit consideration not as "green energy" but as long-term infrastructure assets that enable a whole range of related industries. For pioneering nations, this approach opens an opportunity not only to diversify their own energy mix but also to secure technological leadership, shape the standards and rules of a new sector, and ultimately control key elements of space logistics and manufacturing.

The cost of access to space remains the key economic barrier. LCOE decomposition confirms that even the uniquely high potential capacity factor (up to 90–95%) and zero fuel costs cannot compensate for the current gap in capital expenditures — a gap orders of magnitude wider than what would allow price parity with terrestrial generation. Achieving the target payload delivery cost of \$20–\$50/kg could fundamentally change this situation, thereby setting a clear benchmark for investment in reusable transportation systems and orbital infrastructure.

For Russia, the current landscape presents challenges requiring strategic reflection. With no information in open sources about specialized legal mechanisms or targeted programs in the SBSP sphere, initiatives such as the low-power space solar power station project proceed in a fragmentary manner, lacking integration into the system of national priorities. As other spacefaring nations move from conceptual discussion to practical implementation and targeted investment, a wait-and-see position risks the loss of competencies by the time the market takes shape. Integrating SBSP into the long-term strategy for space activity development and the orbital energy sector could serve as a tool for strengthening technological sovereignty, since participating in SBSP technology development today creates a foundation for the future competitiveness of national companies in the global market.

The findings presented here offer practical value for shaping national space initiatives, guiding energy sector investment decisions, and supporting ongoing research to refine SBSP's economic metrics as operational projects yield new data.

The implications of the findings differ for the stakeholders involved.

For governments and those shaping strategy. The choice between a state-led model and a market-driven one affects not only how quickly SBSP advances but also whether a country can help set standards in this field. Delaying decisions now risks ending up as a follower in a market that will have already taken shape without you.

For private investors. The study provides clear benchmarks: it shows under what conditions investment in space-based solar energy becomes viable. It also makes clear that early stages will require mechanisms to share risks between government and business.

For the international legal framework. As long as there is no clarity on how to use geostationary orbit and transmit energy from space under international law, financing such projects will remain difficult. Uncertainty simply raises costs for investors.

For researchers. The classification we have developed, together with the LCOE methodology adapted for space projects, can serve as a foundation for further work — at the intersection of space economics, energy policy, and institutional theory.

Based on the limitations of this study, further research should pursue the following interrelated directions: dynamic LCOE models and expanding the country sample.

Overall, SBSP's progression to a commercial level will depend on factors shaping the project's investment attractiveness: reducing payload delivery costs, creating an orbital services market, lowering risks (and thus the cost of debt capital), and finally, establishing a predictable international legal environment — without which private investment in such capital-intensive projects will remain in question.

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