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SPACE-BASED SOLAR POWER (SBSP) GEOPOLITICAL CONNOTATIONS AND IMPLICATIONS FOR INDIA

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Abstract

The global search for clean, renewable energy resources has led to the concept of producing solar power in the Earth's orbit and relaying it to the Earth. SBSP, other than its environmental and economic advantages, may also accrue certain military advantages including providing electricity at remote locations for the military in ships and isolated bases, wireless sensor networks, satellite-to-satellite power transmission, offensive space capabilities, and beaming electricity to power drones to virtually unlimited flight endurance. SBSP has tremendous potential. However, the technology is not ripe yet and faces obstacles such as high cost of production and technological challenges which are yet to be resolved. However, various studies suggest that costs will come down in future due to better and cheaper technology and greater scale. Amongst the leading space powers, China and the US have made significant progress in this domain. Japan has also been researching SBSP since the 1980s, aiming for commercial space-to-solar power by 2025. India is collaborating with the US as part of the joint Kalam-NSS Indian-American Energy Initiative However, this collaborative effort has seen little progress.

China is fast emerging as a potential global SBSP provider. This will provide the Chinese with windfall financial gains, and also provide diplomatic leverage and geopolitical dominance. Moreover, China's proclivities towards exploiting the military capabilities of SBSP to achieve dominance in space, particularly in the region of Geosynchronous Earth Orbit (GEO), raise concerns about India's national security in the domain of space. India needs to focus on SBSP technology development, collaborate internationally, and address security concerns in the evolving space landscape.

INTRODUCTION

A recent report titled International Energy Outlook 2023 published by the U.S. Energy Information Administration of the US Govt suggests that the global consumption of primary energy would increase from the current 640 quadrillion B.T.U. to around 850 quadrillion B.T.U. This increase in demand and consumption of energy will primarily be met by nuclear and renewable energy resources. Solar and other renewable energy consumption would cumulatively increase from the current 86 quadrillion B.T.U. to around 206 quadrillion B.T.U. Such a growing demand for clean energy resources has spurred global research on newer, more efficient means to tap solar energy, of which Space-Based Solar Power (SBSP) has found the most traction. Conceptually, it envisages placing an array of solar panels in the earth's orbit, converting the incident solar energy into microwave and transmitting it securely to earth. At the Earth receiving stations, this microwave would be converted into electricity and further integrated into a nation's power grid.

GENESIS

The idea of a solar power plant orbiting the Earth was first proposed by Peter Glaser in a 1968 paper titled "Power from the Sun: Its Future".[1] [2] The broad concept is to launch satellites housing massive solar arrays into space that would receive continuous intense solar energy uninterrupted by the terrestrial cycles of day and night and the lowering of solar intensity due to weather and atmospheric conditions etc. The light energy thus absorbed by the photovoltaic cells of the solar panel would be converted into microwave by the satellite in space and then radiated back to receiving earth stations. The receiving stations would then convert it to electricity. In July 1971, Glaser applied for patenting "Method and Apparatus for Converting Solar Radiation to Electrical Power" and obtained the patent in 1973.[3] Major spacefaring nations have been conducting extensive research on developing these capabilities for several decades.

BASIC WORKING OF SBSP

A standard SBSP system consists of a group of large satellites that orbit the Earth in the GEO. These satellites have lightweight solar panels and mirrors that focus the sunlight on to the panels, each producing approximately 3.4 GW of energy. The electrical energy thus produced is then converted into microwave radiation. The microwave frequency used is generally 2.45 GHz, which can pierce through moisture and the atmosphere. Finally, a net power of 2.9 GW is transmitted to a fixed point on the ground using a receiving antenna. To ensure the accuracy of the transmission, a guiding beam is transmitted by the earth-based stations to the satellite to enable the microwave beam to lock onto the correct point. The rectifying antenna at the earth-station, also known as 'rectenna', is a net structure that contains small dipoles designed to capture radio wave energy. This energy is then converted into electricity amounting to approximately 2 GW and transferred to the power grid. Due to the relative of motion of the SBSP spacecraft with respect to the Sun and the Earth, the mirrors of the solar panels have to be constantly facing the sun and the microwave transmitter has to be facing the fixed ground station on earth. This allows the system to provide full power levels day and night, in all weather conditions and throughout the year. The microwave is transmitted at an intensity level of around 240 Watts/ metre^2, which is only about 25 percent of the intensity of mid-day sunlight. As a result, this system is not harmful to life on Earth.[4] This intensity can however be altered in case the beam needs to be repurposed for damaging an adversary's space-based/ ground-based critical infrastructure.

Laser beam power transmission is being explored as an alternative to microwave power transmission technology. The incident solar radiation is intensified into a monochromatic laser beam which is then directed at the designated ground receiving station. The photovoltaic receiver at the receiving station then converts the incident laser beam into electricity."[5]

BENEFITS OF SBSP

Environmental and Economic Advantages

- SBSP will provide a virtually endless source of clean energy and contribute to our energy security, lowering dependence on fossil fuels and reducing our carbon footprint. As a part of a bouquet of emerging clean energy solutions, it offers a technologically and commercially viable option for our efforts towards net zero.
- The main advantage of SBSP over earth-based solar power and wind, tidal or geothermal power is the ability to produce energy day and night without interruption, all year long irrespective of the weather. The intensity of the solar light beams are 40 percent stronger in space than on the Earth's surface.[6] In space solar beams do not face interruptions due to clouds, atmosphere, and night downtime due to the earth's rotation. So solar arrays in space would provide a steady flow of current at a higher efficiency.
- With the source of the power generated being steady, there is the least likelihood of a surge, fluctuations, or even interruptions. It is therefore safe for integrating seamlessly into the nation's power grid. Several such plants can be deployed in space to meet the increasing power requirements in a grid. SBSP not only contributes towards a nation's energy security but it can also be exported for commercial purposes and also as humanitarian or diplomatic endeavours.

- Since solar power is not vulnerable to geographic and geopolitical upheavals, the cost of the power generated will remain stable, unlike fossil fuels.
- SBSP systems placed in a suitable orbit could even provide power to future lunar bases etc. or spacecraft for cislunar travel.

Military Advantages

- SBSP will enhance the movement capability and deployment of military forces by providing energy automatically at Forward Operating Bases, Ships and other large sea-borne platforms etc.
- Wireless Distributed Sensor Networks (WDSN) that are deployed in remote locations and used to perform a variety of surveillance functions can be provided power through SBSP obviating the requirement of using time-limited battery power.
- SBSP can provide satellite-to-satellite power transmission.
- SBSP can provide power to UAVs for extended flight endurance.
- In case conventional power plants are degraded due to enemy action, SBSP could act as a reserve source of power feeding the power grid.
- The solar arrays might also be used as Directed Energy Weapons for space targeting.
- SBSP could also supply power to existing dual-use RPO satellites for executing kinetic attacks in space or to DEW satellites for EM attacks in space, enhancing their endurance capability for space-based offensive.
- Wireless Power Transmission (WPT), a crucial component of SBSP could also have terrestrial uses, such as beaming power from space to UAVs to enhance their endurance, beaming power from ship to landing troops

MAJOR CHALLENGES

- **Cost of SBSP.** The cost of production appears prohibitive at this stage, though with economies of scale and future advancements, it is fair to assume that SBSP will become financially viable. Recently European Space Agency commissioned two studies in 2022 to ascertain the commercial viability of SBSP as a source of clean energy on Earth.[7] One of these studies conducted by Frazer-Nash Consultancy Limited was ordered by the UK for the European Space Agency. The study report, published in September 2021, based on the CASSIOPeiA (Constant Aperture, Solid-State, Integrated, Orbital Phased Array) concept, estimated the Liberalised Cost Of Electricity (LCOE), including the end-to-end production, launch, assembly, operational service life, and decommissioning costs to be around £50 per megawatt hour with an investment hurdle rate of 20 percent and assuming this system is commissioned in 2040. In comparison, LCOE for large-scale solar power is estimated to be around £33 per megawatt hour and wind power to the tune of £40-£45 per megawatt hour while nuclear power and dedicated biomass would cost around £96-£98 per megawatt hour.[8] Another similar study by Roland Berger in Germany on behalf of European Space Energy concluded *"The competitiveness of SBSP vs. other clean energy sources was measured using the Value-Adjusted Levelised Cost of Electricity (VALCoE) introduced by the International Energy Agency (IEA). Based on the cost assumption of SBSP, the projected VALCoE could even reach 69 EUR/MWh for the first system. Applying a learning curve metric already shows cost reduction potential in the setup of the first 10 SPS station deployments, leading to an estimated VALCoE of 49 EUR/MWh. This means that SBSP has the potential to even become a cost-competitive renewable technology while also providing baseload generation capacity. Depending on the pace of climate target implementations and the state of energy supply, future electricity prices can range between 25 and 300 EUR/MWh."*[9] International collaboration in developing the technology could resolve the problems related to development funding/long ROI of the SBSP.

- **Technology Development.** There are significant technological and infrastructural issues that need to be overcome before the solar power generated can be made financially viable. The three major technological challenges that need to be addressed in the development of a massive electricity generator and the transmission of power generated from space include transporting the heavy electricity generator to geosynchronous orbit using a carrier rocket; completing the automatic assembly of the SBSP satellite in space; and, transmitting power from space to the earth. The energy losses incurred due to the conversion of solar energy into microwave and further into electricity and also due to transmission losses of the microwave need to be factored. Also, large areas to be occupied by the receiving stations for housing the rectennas and other terrestrial infrastructure might have environmental impacts.

COMPARISON OF STRATEGIC, SOCIETAL & ENVIRONMENTAL DIMENSIONS

Besides the economic dimensions that were considered in the previous paragraph, it is also necessary to compare various other cost dimensions of SBSP technology.

- **Strategic Dimensions.** Nuclear energy has high potential but is limited by technology and uneven distribution of resources. Floating bases for offshore wind turbines could be a game-changer for the nations with access to the sea. Solar PV and onshore wind are less efficient due to resource-intensive construction, location-dependent efficiency, and limited potential for further improvements. None of these however affect the SBSP construct.
- **Societal Dimensions.** Nuclear power plant construction, historically the biggest job generator, has lost public acceptance since the Fukushima disaster, due to opposition from green NGOs and political parties. Though renewable energy is popular, onshore wind farms face local community resistance due to visual pollution. SBSP space-based infrastructure is located too far away, in the GEO, for similar perturbations, while the ground-based receivers would hardly occupy enough physical or mind space for any viable societal impact.
- **Environmental Dimensions.** Nuclear power plants require less material input and have a limited impact on the environment, but safe disposal of nuclear waste remains a concern. Renewable power plants require more material input and have a high-energy, carbon-intensive manufacturing

process. While most materials used in wind turbines can be reused or recycled, the blades cannot be recycled. Solar PV recycling is more feasible than wind turbines, but currently only in general-purpose facilities with high recovery yield.

CHINA'S FORAY INTO SBSP

In February 2009, China's National Bureau of Statistics published a report which predicted a strategic shortfall in China's energy sector by the year 2050 and advocated for a rapid switch to renewable energy.[10] The Chinese government has planned to mitigate this energy gap and turn it into a strategic advantage through SBSP. In 2010, the China Academy for Space Technology (CAST) published a roadmap for developing SBSP in China. By 2010, the CAST planned to complete the entire Research & Design. The prototype of the SBSP was planned to be developed by 2019. By 2025, a space-based plant will be placed in the LEO which would produce 100kW electricity. By 2050, it is envisaged the GEO-based solar power plants would generate electricity for commercial purposes.[11] In 2019, China established the world's first SBSP manufacturing unit in the Bishan district of Chongqing. The Chongqing Collaborative Innovation Research Institute for Civil-Military Integration (CCIRICMI) is overseeing the construction of this manufacturing facility in collaboration with scientists from CAST, Chongqing University, and Xidian University. The SBSP plant has been testing various technologies, including WPT and the construction of SBSP satellites located in the GEO using automated assembly.[12]

The development program seems to be on track and may be launched in 2028, two years earlier than scheduled. An article in the refereed Chinese journal Chinese Space Science and Technology published in June 2022 states: *"a satellite will be launched to test WPT technology from an altitude of 400km (250 miles). The researchers explained that the satellite will transform solar energy into microwaves or lasers and direct the energy beams to various targets, including fixed locations on Earth and moving satellites. The generated power will be 10 kilowatts, which is enough to meet the needs of a few households. However, the technology can* *be scaled up significantly and become an effective contributor [to achieving] China's carbon neutrality goals."*[13]

Again in June 2022, Xidian University in Xi'an, North China released a statement declaring a successful test of a fully linked and integrated SBSP prototype. The work at this facility, designed to test and verify technology for the OMEGA system, was led by Academician Duan Baoyan, a leading Chinese expert in SBSP.[14] Researchers associated with the China Academy of Science and Technology (CAST) are hopeful that after a test satellite "*Space High Voltage Transfer and Wireless Power Transmission Experiment*" launch in LEO in 2028, a 10-megawatt power plant located in GEO will start sending energy to certain military and civilian users by 2035. By 2050, the station's power output is expected to rise to 2 gigawatts, and the cost reduced to commercially affordable levels.[15]

US EFFORTS AT DEVELOPING SBSP CAPABILITY

Northrop Grumman in collaboration with the Air Force Research Laboratory is leading the US efforts towards SBSP funded by a $180 million federal program. The primary purpose of the research, as stated in the AFRL's official website, is to provide power to the military from space during operations, thus obviating the threat to the long convoys and supply lines that are the usual methods to provide power.[16] The aim is "*to develop and demonstrate technology including lightweight sandwich solar panel PV/ RF modules, and lightweight extendable mirrors, under the SSPIDR (Space Solar Power Incremental Development And Research Project)*"[17] Six critical technologies that require further research and development will be validated in critical technology demonstrations:

- Space Power InfraRed Regulation and Analysis of Lifetime (SPIRRAL) experiment to test the thermal management technology will be conducted in the International Space Station this year.[18]
- The keystone flight experiment in the SSPIDR project, Arachne, will demonstrate the sandwich tile and its ability to collect solar energy, convert it to RF, and beam it to a rectifying antenna on the ground from

low earth orbit. A panel of nine sandwich tiles, under development by Northrop Grumman, will be flying on Arachne.[19] It will carry the Space Solar Power Radio Frequency Integrated Transmission Experiment (SSPRITE) payload, also being developed by Northrop Grumman, to collect and convert solar energy. Arachne will be based on the Helios bus manufactured by Northrop Grumman Space Systems. It is planned for launch in early 2025, followed by months of on-orbit demonstrations.[20]

Concurrently, a similar project by the California Institute of Technology (Caltech) named the Space Solar Power Project (SSPP) and funded by the philanthropist Donald Bren has worked on another prototype. In January 2023, in an article titled Beaming Power From Space: Caltech's Prototype Achieves Wireless Energy Transmission published by the California Institue of Technology in the journal Scitech, stated "A space solar power prototype, SSPD-1, has achieved wireless power transfer in space and transmitted power to Earth. The prototype, including MAPLE, a flexible lightweight microwave transmitter, validates the feasibility of space solar power, which can provide abundant and reliable power globally without ground-based transmission infrastructure." The other two main experiments as per the report are the "DOLCE (Deployable on-Orbit ultraLight Composite Experiment), a 6 feet by 6 feet structure that demonstrates the architecture, packaging scheme, and deployment mechanisms of the modular spacecraft; and ALBA, a collection of 32 different types of photovoltaic cells to enable an assessment of the types of cells that are the most effective in the punishing environment of space. The ALBA tests of solar cells are ongoing, and the SSPP has not yet attempted to deploy DOLCE."[21]

JAPAN'S ENDEAVOUR TOWARDS DEVELOPING SBSP

Research on SBSP has been happening in Japan since the 1980s. Japan has identified SBSP as a key focus area for its space program. According to a May 2023 article published by Igor Bonifacic in the journal 'Engadget', in 2015 "JAXA successfully beamed 1.8 kilowatts of power more than 50 meters to a wireless receiver. A Japanese public-private partnership will attempt to beam solar energy from space as early as 2025. The project, led by Naoki Shinohara, a Kyoto University professor who has been working on SBSP since 2009, will attempt to deploy a series of small satellites in orbit. Those will then try to beam the solar energy the arrays collect to ground-based receiving stations hundreds of miles away."[22] [23]

INDIA'S STATUS

The 'Kalam-NSS Indian-American Energy Initiative' – a joint US-Indian effort aimed at developing SBSP satellites was announced on 04 November 2010.[24] However, the project has not progressed further. The Indian Express reported on 08 July 2018, that, while "*delivering the 11th Air Chief Marshal LM Katre Memorial Lecture organised by the Air Force Association at the HAL Convention Centre on Saturday, [the then ISRO Chairman] Dr K Sivan made a strong pitch for creating a solar power satellite. Sivan said, "We need to have a solar panel on the spacecraft. It should be 30 kilometres in length and 10 kilometres in width. This spacecraft needs to be put into space and it will convert solar energy into electrical energy and then into microwave energy*".

GEOPOLITICAL CONNOTATIONS

The U.S. and China have made significant progress towards developing SBSP, through different technology routes, both focussing on the reliability and cost-effectiveness of the project. Various studies conducted on cost-effectiveness indicate that the project will be commercially viable in the longer term. The environmental dividend of the project and its military applications further bolster the viability of SBSP. SBSP will likely expand the current geopolitical competition to new astral heights. At this point, Chinese efforts towards SBSP make it the leading player in the domain, being closely followed by the U.S. The geopolitical rivalry of the terrestrial powers has already spilt over into space. It is possible that the realisation of SBSP could give Beijing a clear, unassailable lead in this race.

With a leadership position in SBSP technology, Beijing will dominate the global energy market and become the global provider of energy, especially to smaller or poorer countries that may not be able to afford the high development costs. SBSP and its allied space-based and terrestrial infrastructure will enhance Chinese hegemony. This is because China will be able to offer the cheapest and safest space launches, and hence most nations will contract China for their satellite launches. Also, the export of SBSP and profits thereof will give China an unassailable leading position in the financial world. SBSP will feed the global narrative of China as a benevolent superpower. Diplomatically they would control an easily redirected energy source that can be provided to anyone or taken away at will.

While denying a "global commons" approach, China aims to take ownership of space resources, asserting that space has a tangible geography and territory that can be claimed. Beijing's hegemonistic aspirations towards space are poorly disguised. In 2017, Ye Peijian, the head of China's lunar program said, "*The universe is an ocean, the Moon is the Diaoyu Islands, Mars is Huangyan Island*", referring to Mandarin names of the disputed Senkaku island in East China and the Pantang Shoal in the South China Sea, and equating these celestial bodies with disputed islands whose ownership China has been aggressively claiming.[25] Beijing's SBSP ambitions are articulated in the statement of Lt Gen Zhang Yulin, who as a member of the Central Military Commission of PLA said in 2016 - "*China will manage to exploit the space between Earth and the Moon for solar power and other resources after it builds a space station in 2020… The Earth-Moon space will be strategically important for the great rejuvenation of the Chinese nation*."[26]

The need for securing national economic interests in space, and the terrestrial geopolitical and military contestations have led to the increased militarisation of space. In China's case, this is more evident since China's space program is led by the PLA. In its 2015 defence white paper, *China's Military Strategy*, China designated outer space as a "critical military domain" and so, the Chinese military should be prepared for "*a wide variety of emergencies and military threats*" and "*prepare for military struggle in all directions and domains*."[27] Therefore, the military must "safeguard China's security and interests in new domains" and that "*threats from such new security domains as outer space* *and cyberspace will be dealt with to maintain the common security of the world community.*"[28] Therefore, "*China will keep abreast of the dynamics of outer space, deal with security threats and challenges in that domain, and secure its space assets to serve its national economic and social development, and maintain outer space security.*"[29] Chinese authors believe that future wars might begin in the outer space. Due to the increased pace of militarisation of space, "*competition has become increasingly intense, and the curtain of space confrontations has been drawn open. The several local wars that have recently occurred before our eyes have shown that whoever is strong in military spaceflight will rule the battlefield, that he in whose hands lies space superiority will master the initiative in warfare, and that with the support of 'space,' it is possible to win victory, but without the support of 'space' this is impossible.*"[30] Chinese geopolitical thoughts on space, therefore, evince its military intent to optimally exploit the offensive space capabilities offered by the SBSP.

China's untrammelled expansion into space including its efforts at establishing SBSP in the GEO are not merely to satisfy scientific curiosity or for economic considerations alone. It aspires for global domination by:

- Gaining unprecedented economic advantage and geopolitical leverage by dominating the global energy markets through SBSP.
- Developing offensive space capabilities in space, particularly in the GEO.
- Having a ready source of energy in GEO for powering the spacecraft en route to the moon and deep space destinations.

INDIA'S PERSPECTIVE

- **Technology Development.** Considering the critical strategic importance of SBSP, India's efforts towards developing its own SBSP technology will, in all probability, receive a boost in the next few years. As is New Delhi's wont, a graduated approach to developing the component technologies for SBSP is likely. The financial viability of the project is of paramount importance and initiation costs are expected to be high. However, the various studies ordered by reputed international agencies have concluded that the project is viable in the longer term. However, considering the forte of our scientists, especially the Indian Space Research Organisation (ISRO) in developing low-cost solutions for high-end technologies, an independent study group at the national level to assess the cost of a similar project needs to be appointed. This study group, though led by ISRO also needs to incorporate experts from the DRDO and academic institutions in the areas of photovoltaic cell technology, renewable energy domain and experts in power grid integration among others. Initial technology components with terrestrial/ dual-use that could be identified for prioritised development are:

- o **Investment in WPT Technology.** WPT, which is a critical component of SBSP technology, also has several earth-based applications like beaming power to UAVs to enhance their endurance. Prioritising research and development of the WPT technology would avoid risks and provide immediate benefits to Earth.
- o **Investment in Reusable Launch Technology.** Considering the massive tonnages required to be delivered in the GEO, the cost of launch will need to be reduced significantly. Ongoing research and development of reusable launch vehicles will lower the cost of launch, which in turn would help lower the costs for SBSP.

- **Funding the SBSP Program.** Research grants to develop component technologies awarded to reputed universities besides concerted projects by ISRO & DRDO would kickstart this effort. Since the initial development cost of the SBSP technology will be very high and the financial returns from the project will start only after several years, the government will need to fund the initial research efforts. Once the component technologies are adequately mature, these may be handed over to the private sector for further investment to refine the component technologies for achieving commercial viability.
- **International Collaboration.** The U.S. and India have a long history of space cooperation, which was further strengthened by the signing of the Artemis Accords. Already a signatory of the 'Kalam-NSS Indian-American Energy Initiative', U.S. endeavours towards SBSP would

therefore be beneficial for India. A similar collaboration could also be planned with Japan or the European Space Agency. Considering the enormity of the scale of SBSP, a multi-national coalition of like-minded space powers might take shape, akin to the Artemis Accords.

- **The China Angle.** However the same is not the case with the Chinese SBSP program. Considering the geostrategic competition between the two countries, and China's proclivities towards weaponisation of space, India needs to closely monitor the Chinese program and adapt to the new capabilities that China would acquire as a result. Of particular concern are the offensive space capabilities that could pose a threat to India's national security interests in space.

CONCLUSION

SBSP may in future resolve the global energy crisis by providing us with a virtually unlimited source of clean energy, which would be the ultimate solution to terrestrial energy problems. It could further facilitate deep space exploration and also supply electricity to future lunar bases. After overcoming the technological hurdles and the cost-related issues, the project will have to surmount other hurdles like the efficiency of WPT, the damage that the space debris might cause to the thin, lightweight solar arrays, and the long-term effect high-intensity microwave beams on the earth's atmosphere and on the people etc. Leading space powers like the U.S. and China have already taken a significant lead in this area. With the first movers advantage, China will dominate the global energy market. With windfall financial gains, it will be able to monopolise the world financial markets. SBSP capability will also enable China to militarily dominate space, particularly the region of the GEO. As a consequence, there would be increased militarisation of space to secure the expanded national security interests in space.

India needs to use the momentum gained by its successful lunar missions and upend its astrostrategic game to keep pace, in cooperation with other like-minded spacefaring nations. In the currently effervescent, if not volatile geopolitical scenario, the need to adopt a "global commons" approach to space and its resources is the way ahead. However, at present, Realism in space policy appears to be the driving force. Prudence demands that India maintains its strategic focus and prioritisation towards these contestations in space. New Delhi is seised of these growing challenges and opportunities in space. Measured steps are being taken towards fortifying India's national security interests in space.

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NOTES

1. Zhao Lei, Scientists envision solar power station in space, China Daily, 27 February 2019, https://www.chinadaily.com.cn/a/201902/27/WS5c75c8b3a3106c65c34eb8e3.html. Accessed on 17 November 2023.
2. Peter Glaser, Power from the Sun: Its future, New Series, Vol. 162, No. 3856 (22 November 1968), pp. 857-861, Published By: American Association for the Advancement of Science1968, https://www.jstor.org/stable/1725510. Accessed on 22 December 2023.
3. Leonard David, Peter Glaser Father of Solar-Power Satellite Idea Dies at 90, Space.com, https://www.space.com/26175-peter-glaser-solar-power-satellite-obituary.html#:~:text=Glaser%20envisioned%20harvesting%20solar%20radiation,obtained%20the%20patent%20in%201973. Accessed on 22 December 2023.
4. Space Based Solar Power, Space Energy Initiative, https://spaceenergyinitiative.org.uk/space-based-solar-power/. Accessed on 31 January 2024.
5. Venugopal R, Manjunath H. R, Raghu A. V. Overview of Space Based Solar Power. Mat. Sci. Res. India;19(2), https://www.materialsciencejournal.org/vol19no2/overview-of-space-based-solar-power/. Accessed on 31 January 2024.

6. Research on the Space Solar Power Systems (SSPS), JAXA Research and Development Directorate, https://www.kenkai.jaxa.jp/eng/research/ssps/ssps-index.html. Accessed on 22 December 2023.
7. Costs vs. Benefit Studies, European Space Agency, 2022, https://www.esa.int/Enabling_Support/Space_Engineering_Technology/SOLARIS/Cost_vs._benefits_studies. Accessed on 22 December 2022.
8. Space-Based Solar Power: De-risking the Pathway to Net Zero, Frazer-Nash Consultancy Limited, 2021, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1020631/space-based-solar-power-derisking-pathway-to-net-zero.pdf. Accessed on 22 December 2023.
9. Manfred Hader, Martin Hoyer, Helping Decarbonise Europe and Make it More Energy Resilient Thanks to Electricity Generated in Space, Roland Berger, 2022, https://www.rolandberger.com/en/Insights/Publications/Space-based-Solar-Power.html. Accessed on 22 December 2023.
10. Gao, Ji; Hou, Xinbin; and Wang, Li "Solar Power Satellites Research in China," *Online Journal of Space Communication*: Vol. 9: Issue 16, Article 6, 2021 https://ohioopen.library.ohio.edu/spacejournal/vol9/iss16/6/. Accessed on 17 November 2023.
11. Gao, Ji; Hou, Xinbin; and Wang, Li "Solar Power Satellites Research in China," *Online Journal of Space Communication*: Vol. 9: Issue 16, Article 6, 2021, https://ohioopen.library.ohio.edu/spacejournal/vol9/iss16/6/. Accessed on 17 November 2023.
12. Pan Zhaoyi, China Starts to Build World's First Space-Based Solar Power Plant, CGTN dated 18 February 2019, https://news.cgtn.com/news/3d3d514f34597a4e32457a6333566d54/index.html. Accessed on 02 November 2023.
13. Stephen Chen, China Plans to Start Building First-Ever Solar Power Plant in Space by 2028, South China Morning Post, 07 June 2022, accessed from https://www.scmp.com/news/china/science/article/3180627/china-brings-forward-plans-space-solar-power-plant?module=perpetual_scroll_0&pgtype=article&campaign=3180627. Accessed on 18 November 2023.
14. Guan Hongcai, The Full-Link, Full-System Space Solar Power Station Ground Verification System developed by Academician Duan Baoyan's Team Passed Acceptance, Xidian News Network, Xidian University, 14 June 2022 accessed from https://news.xidian.edu.cn/info/2106/220926.htm. Accessed on 17 November 2023.
15. Stephen Chen, China plans to start building first-ever solar power plant in space by 2028, South China Morning Post, dated 07 June 1922, https://www.scmp.com/news/china/science/article/3180627/china-brings-forward-plans-space-solar-power-plant. Accessed on 31 October 2023.
16. Space Power Beaming, The Air Force Research Laboratory, https://afresearchlab.com/technology/space-power-beaming/. Accessed on 19 December 2023.
17. Space Based Solar Power: De-risking the Pathway to Net Zero, Frazer Nash Consultancy, https://www.fnc.co.uk/media/e15ing0q/frazer-nash-sbsp-executive-summary-final.pdf. Accessed on 19 December 2023.
18. Space Power Beaming, AFRL, https://www.afrl.af.mil/Portals/90/Documents/RV/AFRL_SSPIDR_FS_0922.pdf?ver=VAE9L00LRfAtQkWmG9uDkQ%3D%3D. Accessed on 19 December 2023.
19. Ibid.
20. Theresa Hitchens, Next Step for AFRL's Space-Based Solar Power Quest: Energy Beaming, Breaking Defense, 26 May 2022, https://breakingdefense.com/2022/05/next-step-for-afrls-space-based-solar-power-quest-energy-beaming/. Accessed on 19 December 2023.

21. Robert Perkins, In a First, Caltech's Space Solar Power Demonstrator Wirelessly Transmits Power in Space, The Caltech Weekly, 01 June 2023, https://www.caltech.edu/about/news/in-a-first-caltechs-space-solar-power-demonstrator-wirelessly-transmits-power-in-space. Accessed on 19 December 2023.
22. Igor Bonifacic, Japan will try to beam solar power from space by 2025, Engadget, 19 May 2023, https://www.engadget.com/japan-will-try-to-beam-solar-power-from-space-by-2025-214338244.html?fbclid=IwAR1aapGj4WvaD_2R5XkksYd88P4wo62tOW4ZqLvd1K5RDhglKqCLArgg0ak&guccounter=1. Accessed on 19 December 2023.
23. Satoshi Kawahara, Japan to Try Beaming Solar Power from Space in Mid-Decade, Nikkei Asia, dated 27 May 2023, https://asia.nikkei.com/Business/Science/Japan-to-try-beaming-solar-power-from-space-in-mid-decade. Accessed on 19 December 2023.
24. Ajey Lele, Kalam-NSS Indian-American Energy Initiative, IDSA Comment, Manohar Parrikar Institute of Defence and Strategic Analysis, 09 November 2010, accessed from https://idsa.in/idsacomments/KalamNSSIndianAmericanEnergyInitiative_alele_091110. Accessed on 19 December 2023.
25. Gordon G.Chang, We're in a New Cold War in Space: China Plans to Take Over the Moon, Newsweek, 09 January 2023, https://www.newsweek.com/were-new-cold-war-space-china-plans-take-over-Moon-opinion-1772306#:~:text=%22The%20universe%20is%20an%20ocean,to%20which%20Beijing%20claims%20sovereignty. Accessed on 17 November 2023.
26. Exploiting Earth-Moon Space: China's Ambition After Space Station, Xinhua, chinadaily.com.cn dated 08 March 2016, https://www.chinadaily.com.cn/china/2016-03/08/content_23775949.htm. Accessed on 29 October 2023.
27. The Information Office of the State Council of PRC, *China's Military Strategy*, 2015, https://english.www.gov.cn/archive/white_paper/2015/05/27/content_281475115610833.htm. Accessed on 03 November 2023.
28. Ibid.
29. Ibid.
30. Jiang Lianju, "An Outline of Space Operations" Lectures on the Science of Space Operations, Military Science Press, January 2013, sourced from "In Their Own Words: China Aerospace Studies Institute", P 16, https://www.airuniversity.af.edu/Portals/10/CASI/documents/Translations/2022-08-12%20Lectures%20on%20the%20Science%20of%20Space%20Operations.pdf. Accessed on 03 November 3, 2023.