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An Economic Impact Analysis for Space-Based Solar Power Systems on the World's Economy

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Abstract

Space-based solar power (SBSP) has long been considered a promising solution for continuous and reliable energy generation. Beyond its technological feasibility, SBSP has the potential to drive significant socio-economic transformations on Earth's economy. This study conducts a techno-economic analysis of SBSP, tailoring the Levelized Cost of Energy (LCOE) methodology to account solely for the generation component of SBSP. The model incorporates key cost parameters, including manufacturing, launch, assembly, deployment, solar panel fabrication and encapsulation, maintenance (considering space-based wear and tear, launching, and assembly costs), fuel for deployment and orbit correction, end-of-life costs, and environmental impact. A probabilistic Monte Carlo analysis was conducted to estimate the cost of SBSP energy generation, yielding a range between 53/MWh and 158/MWh under scenarios that assume flexible technologies, particularly for launch. This places SBSP theoretically within the range of terrestrial solar power generation costs, which typically vary between 20/MWh and 60/MWh. Notably, this study's Levelized Cost of Space Energy (LCOSE) explicitly incorporates lifecycle emissions costs, unlike many terrestrial LCOE calculations, offering a more comprehensive assessment of environmental impact at the expense of higher overall cost figures. However, it excludes the costs of satellite structural components and ground infrastructure, which are typically included in terrestrial LCOE models. The findings highlight that launch costs overwhelmingly dominate SBSP's total cost, exceeding all other assessed categories combined. Consequently, reducing launch costs is the most effective strategy for improving SBSP's economic feasibility. Additionally, SBSP could provide dynamic energy allocation, allowing satellites to shift energy transmission between different terrestrial receivers in response to fluctuating demand across geographic regions. This capability has profound implications for global energy markets, particularly in regions with high variability in consumption patterns. The potential economic benefits of SBSP extend beyond energy markets. Its deployment could reduce dependence on terrestrial energy sources, drive innovation in renewable energy infrastructure, and create new economic opportunities in the space sector. Moreover, SBSP aligns with climate goals, offering a near-continuous renewable energy source unaffected by atmospheric conditions, which could play a critical role in achieving net-zero emissions targets outlined in the Paris Agreement. This study provides valuable insights for policymakers, industry leaders, and researchers, supporting informed decision-making on the viability of SBSP as a competitive and sustainable energy solution for Earth's future energy landscape.

Keywords: Space-Based Solar Power (SBSP), Global Energy Markets, Macroeconomic Impact, Space Economy, Organic Photovoltaic.

1. Introduction

The energy sector is the largest contributor to anthropogenic greenhouse gas (GHG) emissions, accounting for around 73.2% of global emissions in 2016 [1]. Meeting the Paris Agreement's objective of limiting warming to below 2 °C requires rapid decarbonisation of electricity generation [2]. While renewable sources such as solar photovoltaics (PV) and wind have seen remarkable cost declines and rapid capacity growth, their intermittency presents challenges for grid stability and alignment with growing global demand [3].

Space-Based Solar Power (SBSP) offers a promising solution by placing solar arrays in geostationary Earth orbit (GEO), where they can capture continuous solar radiation and transmit electricity to Earth using microwaves. In GEO, satellites experience near-constant sunlight, with eclipse periods representing less than 0.1% of the year [4]. This unique feature makes SBSP one of the few renewable options capable of providing baseload electricity at a global scale.

The concept was first articulated in the late 1960s [5] and further developed during the 1970s by NASA and the U.S. Department of Energy. Since then, several nations have advanced their own approaches: Japan has focused on modular lightweight designs [4], China has proposed multi-rotating joint architectures [4], and the United Kingdom has developed the CASSIOPeia concept employing concentrator mirrors [4]. SBSP remains constrained by high costs. Prior techno-economic assessments highlight that launch mass and in-orbit assembly dominate system budgets, often placing SBSP one to two orders of magnitude more expensive than terrestrial solar power [4].

By contrast, terrestrial solar PV has already reached cost-competitiveness, supported by decades of research and economies of scale. Module prices have fallen from 60–100 USD/Wp in the 1970s to below 0.2 USD/Wp in 2020, driving installed capacity from below 0.2 million MW in the 1990s to nearly 1 million MW by 2020 [6]. This has reduced the Levelized Cost of Electricity (LCOE) for utility-scale solar PV to 20–60 USD/MWh [3], as shown in Fig. *1*.

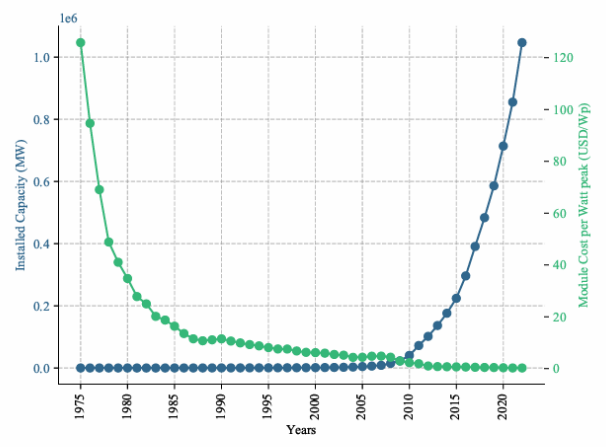

Fig. 1. The plot illustrates the installed photovoltaic (PV) capacity and system costs from 2000 to 2022. The data on installed capacity (measured in Megawatts, MW) shows a significant increase over the years, while the system costs (measured in USD per Watt-peak) have decreased substantially. Adapted by the author from Our World in Data from [6], CC BY 4.0.

This study addresses these challenges by developing a Levelized Cost of Space Energy (LCOSE) framework, an adaptation of conventional LCOE methodologies designed for SBSP applications. The model accounts for space-specific parameters, including:

- launch and deployment,
- in-orbit assembly,
- efficiency degradation under radiation and thermal cycling,
- fuel for orbit correction and deorbiting, and
- lifecycle emissions.

Unlike many terrestrial LCOE studies, the LCOSE explicitly incorporates environmental externalities, offering a more comprehensive measure of SBSP's sustainability. To capture uncertainty in future technology development and cost trajectories, the model employs a Monte Carlo simulation approach. This probabilistic method estimates cost distributions rather than single values, providing a robust assessment of SBSP's economic feasibility and its potential role in the global energy transition.

2. Methodology

Before constructing the LCOSE model, it was necessary to define the photovoltaic technologies considered in the analysis. Two technologies were selected: crystalline silicon (c-Si) and organic photovoltaics (OPV). c-Si was chosen because it is the most mature and widely used photovoltaic technology both on Earth and in space, with efficiencies of up to 26% in laboratory conditions and extensive operational data available [7, 8]. It therefore serves as a benchmark for the techno-economic feasibility of space-based solar power. OPV, on the other hand, was included because of its potential advantages for SBSP. Its lightweight, flexible, and low-material-consumption properties make it attractive in reducing launch mass, which is the dominant driver of overall system cost. Although OPV generally has lower conversion efficiency and higher degradation rates than c-Si, its specific power (W/kg) and stowability could lead to substantial cost reductions for large orbital arrays [9, 10, 11]. The comparison between a mature, high-efficiency but heavy technology (c-Si) and a lightweight, flexible, but less proven alternative (OPV) allows us to capture a realistic range of possible SBSP cost outcomes.

The analysis is limited to the generation component of SBSP and excludes transmission, ground infrastructure, and satellite structure. The system boundary is shown in **Error! Reference source not found.**, which illustrates the elements included in the LCOSE framework. These are: the solar panels themselves, launch to orbit, assembly and deployment, fuel for orbital correction and end-of-life manoeuvres, and environmental externalities. Transmission to Earth, rectenna ground stations, and satellite bus subsystems are excluded to isolate the cost of generation.

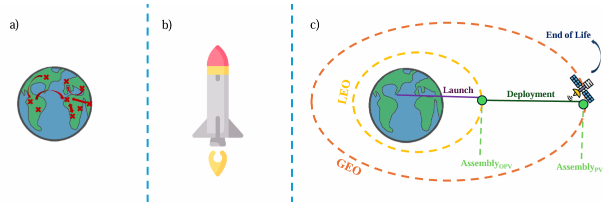

Fig. 2. Boundaries of the levelized cost of space energy (LCOSE) for space-based solar power (SBSP) Model. (a) Represents the Earth-based logistics, including the transport of raw materials, manufacturing, and preparation of modular systems before launch. This stage encompasses all activities necessary to prepare the SBSP system components for deployment. (b) Illustrates the launch phase, where the number of launches required is determined by the payload capacity, which is dependent on both the mass and stowability of the materials. This stage focuses on the transport of the SBSP components from Earth to space. (c) Depicts the space-based operations, highlighting the assembly points for both OPV and PV technologies, which differ based on their stowability and mass. This stage also encompasses the satellite's operational life in Geostationary Orbit (GEO), where the SBSP system will function until the end of its lifecycle.

2.1 Levelized Cost of Space Energy (LCOSE) Framework

The methodology adapts the conventional LCOE framework to the space domain, defining a LCOSE. The LCOSE represents the average cost per megawatt-hour of electricity transmitted to Earth, accounting only for the generation component of a space-based system.

The formulation is given as:

$$LCoSE = \frac{\sum_t^n \frac{I_t + M_t + F_t + C_t}{(1+r)^t}}{\sum_t^n \frac{E_t}{(1+r)^t}}$$

Where:

- I_t = include panel manufacturing, launch, in-orbit assembly, and deployment. Launch dominates this category, often exceeding all others combined [4]. For c-Si, the mass penalty makes launch disproportionately expensive, while OPV benefits from reduced mass and better stowability.
- M_t= covers replacement of modules, re-launches of degraded components, and in-orbit servicing. In practice, servicing is uncertain given current space infrastructure. For OPV, higher degradation rates imply higher maintenance requirements, though low panel mass reduces replacement costs.
- F_t = required for deployment, orbit correction, and deorbiting. GEO satellites typically need continuous station-keeping to counter gravitational perturbations. Propellant use and resupply contribute non-negligibly to lifecycle costs.
- C_t = lifecycle emissions from launch and manufacturing. Each heavy-lift rocket launch is estimated to emit between 1,100 and 1,400 tCO_2e [12]. These are monetised via carbon pricing scenarios from IEA [6].
- E_t = Energy transmitted to Earth in year t, driven by array efficiency, degradation rate, and system lifetime. For c-Si, degradation is relatively well characterised (~1.2% per year). For OPV, limited long-term space data increases uncertainty (~1.35% per year assumed, based on terrestrial accelerated tests [13, 14]).
- r = discount rate.
- n = system lifetime.

Unlike terrestrial LCOE assessments [6], the LCOSE explicitly incorporates lifecycle emissions costs [12], recognising the environmental footprint of rocket launches and high-embodied-energy manufacturing. Structural components of satellites and ground infrastructure are excluded, isolating the costs of generation.

Limitations of this framework include the exclusion of satellite bus subsystems and ground rectennas, which would add cost if a full system analysis were performed. Another limitation is the reliance on carbon pricing to monetise environmental costs, which varies widely by region and policy scenario.

2.2 Monte Carlo Simulation Approach

Because many input parameters are uncertain or vary across scenarios, a Monte Carlo simulation was adopted. This approach randomly samples values for each parameter from defined probability distributions, repeating the calculation thousands of times to generate a probabilistic range of LCOSE values.

Key parameters and assumptions:

- Conversion efficiency: uniformly distributed between 20–40% for c-Si and 10–30% for OPV [7, 15, 8]. The lower bound reflects current commercially achievable values, while the upper bound

assumes laboratory improvements and future materials.
- Degradation rate: normally distributed around 1.2% per year for c-Si and 1.35% for OPV [13, 14]. These values reflect median expectations, but space radiation may accelerate degradation beyond laboratory predictions.
- Launch costs: triangular distribution centred on current costs (~2,500 USD/kg) with lower and upper bounds reflecting reusable vehicle scenarios (~500 USD/kg) and conservative estimates (>5,000 USD/kg) [4].
- Carbon pricing: scenario-based, ranging from 50 USD/tCO$_2$e to 200 USD/tCO$_2$e over the system lifetime [3].

Two scenarios were run per technology for the power conversion efficiencies for solar cells parked in space:

- Scenario 1: Current power conversion efficiencies - 10% for OPV and 20% for c-Si.
- Scenario 2: Future assumed efficiencies - 30% for OPV and 40% for c-Si.

A target of 2 GW of delivered power to Earth was selected as the reference system size, consistent with prior SBSP studies and large enough to represent a utility-scale baseload plant [4]. System performance was parameterised using an overall end-to-end efficiency factor that combines the sunlight-to-electricity conversion of the panels with all subsequent transmission and reception steps. Two efficiency scenarios were defined for each technology, representing current and future developments: 10% and 30% for OPV, and 20% and 40% for c-Si [7, 16]. These values were multiplied by fixed conversion factors for the DC–RF link, atmospheric transmission, rectification, and grid connection, resulting in total system efficiencies of 3.8–7.6% for OPV and 11.4–15.2% for c-Si.

The required panel area was then calculated from the desired delivered power, the average solar flux in GEO, and the total system efficiency. Mass was obtained by multiplying the area by representative mass-per-area values: 0.5 kg/m² for OPV and 11 kg/m² for c-Si [17, 18, 19]. This approach captures the fundamental trade-off: OPV panels are less efficient but lightweight, while c-Si is more efficient but significantly heavier, leading to much higher launch requirements.

Each simulation consisted of 1,000 iterations. The results provide probability distributions, allowing analysis not only of mean LCOSE values but also of the uncertainty range.

Limitations include the use of simplified distributions rather than detailed probabilistic models for launch economics, and the assumption that efficiency and degradation are independent variables. In reality, material advances could couple the two.

The Monte Carlo simulations were implemented in Python using open-source libraries. All code developed for this study is available at: GitHub - MTNebula/OPV_SBSP: Organic Photovoltaics for Space Based Solar Power [20], allowing reproducibility and further exploration of the modelling framework.

2.3 Data Sources

The model integrates multiple empirical and literature-based datasets:
- PV performance and efficiency: based on international efficiency tables and learning curve data [7, 16]. These provide both current values and future expectations.
- OPV degradation and testing: derived from accelerated lifetime and environmental stress testing [21, 22]. The absence of long-duration spaceflight data for OPV represents a limitation.
- Cost data: derived from NREL and IEA datasets, which track module cost reductions and global LCOE trends [6].
- Launch and deployment: ESA, NASA, and industry reports provide payload mass limits, costs, and emissions per launch [4]. These are particularly important as launch costs were identified as the dominant driver.
- Environmental externalities: quantified using IPCC lifecycle GHG assessments [12], monetized via IEA carbon pricing projections [6].

The reliability of these datasets varies. c-Si data is extensive, covering decades of terrestrial and space use. OPV data is more experimental, leading to higher uncertainty in results. Similarly, launch cost projections depend on the commercial trajectory of providers such as SpaceX and Arianespace, which introduces further uncertainty.

3. Results

The techno-economic analysis of the SBSP systems reveals a wide range in the LCOSE across the different PV and OPV scenarios shown in Figure 3, where the mean cost per MWh is presented with the respective error bars that show the σ per scenario. The mean LCOSE values obtained are as follows

Table 1.Mean LCOSE values obtained.

Technology	**Scenario**	**Mean LCOSE** $(\frac{USD}{MWh})$	**5–95th percentile range** $(\frac{USD}{MWh})$	**Launches required**
c-Si	Current efficiency	2900	2200–3400	>3000
c-Si	Future efficiency	1463	1100–1800	>2000
OPV	Current efficiency	158	110–210	339
OPV	Future efficiency	53	35–70	113

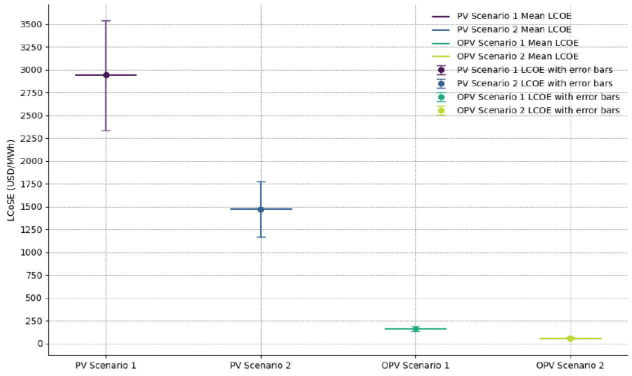

Fig. 2. Levelized Cost of Space Energy (LCOSE) for each scenario analysed. Where Scenario 1 assumes a power conversion efficiency of 10% for the organic photovoltaic (OPV) system and 20% for the crystalline silicon (c-Si) photovoltaic (PV) system. Scenario 2 assumes efficiencies of 30% for OPV and 40% for PV. Despite the significantly lower efficiencies of the OPV systems—up to 50% lower in Scenario 1 compared to PV—the LCOSE values for OPV scenarios are consistently lower than those of the PV scenarios by a substantial margin. The lowest LCOSE for PV is 1463 USD MWh, whereas the lowest LCOSE for OPV is just 53 USD MWh, approximately 4% of the PV cost.

These results suggest that while increases in efficiency do contribute to a linear reduction in costs, the baseline cost of each technology per MWh is far more influential in determining overall cost-effectiveness. Even when considering the slight difference in assumed yearly degradation rates—1.2% for PV versus 1.35% for OPV—and the potential for substantially higher degradation rates in OPV systems (which would require extensive environmental testing under space conditions to accurately determine), the LCOSE for OPV remains so much lower than that of PV that OPV systems could remain cost-competitive even with significantly higher degradation. This competitiveness is primarily due to their intrinsic characteristics, particularly their superior stowability and lower weight.

Launch requirements dominate across all scenarios, as shown in Figure 4. For c-Si, the high mass of rigid modules leads to several thousand launches, keeping LCOSE one to two orders of magnitude higher than terrestrial PV [3]. Even with efficiency improvements, the reduction in array area does not sufficiently offset the mass penalty.

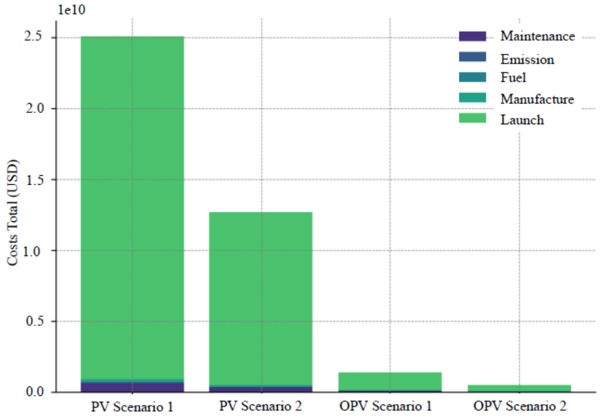

Fig. 3. Total cost of the system per scenario, calculated by summing the costs for the main categories assessed: maintenance, emissions, fuel, manufacture, and launch. In all scenarios, launch costs dominate and far exceed the combined total of all other costs. Prioritising technologies with lower associated launch costs is, therefore, the most effective strategy for reducing the Levelized Cost of Space Energy (LCOSE).

In contrast, OPV delivers significantly lower costs due to its low mass-per-area. Although less efficient and more prone to degradation, its reduced launch requirements result in much lower LCOSE values. In the most optimistic case, OPV achieves an average LCOSE of 53 USD/MWh, placing it within the current terrestrial PV cost range of 20–60 USD/MWh [6].

These findings underscore the trade-off between efficiency and mass as the defining factor in SBSP economics. For c-Si, higher efficiency does reduce the required array area but translates into prohibitive launch mass, which keeps costs uncompetitive. For OPV, lower efficiencies necessitate larger array areas, but the lightweight and flexible nature of the technology more than compensates for this, resulting in significantly fewer launches and much lower costs. The mass-per-area parameter therefore emerges as the most sensitive input in the model, overshadowing even conversion efficiency.

The uncertainty in long-term OPV performance remains a limitation. Degradation rates under space conditions are not yet well characterised, and accelerated laboratory testing can only partially replicate radiation and thermal cycling in GEO. Nonetheless, sensitivity analyses show that even if OPV degradation were substantially higher than the assumed 1.35% per year, the reduction in launch costs compared to c-Si would keep OPV within a competitive range. This suggests that while durability improvements will be essential for operational reliability, OPV already demonstrates compelling economic potential.

Taken together, the results indicate that launch costs are the single greatest barrier to SBSP feasibility. If reductions in launch costs materialise through reusability and economies of scale, OPV-based SBSP could achieve cost parity with terrestrial renewables. Conversely, without significant reductions in launch mass and cost, c-Si remains economically unviable as a candidate technology for large-scale SBSP deployment.

4. Discussion

4.1 Economic Drivers and Constraints

The analysis confirms that launch costs dominate the economics of SBSP, outweighing all other lifecycle components. This aligns with earlier assessments [4] and suggests that SBSP's feasibility is primarily a function of launch technology trajectories rather than panel efficiency gains alone. While incremental efficiency improvements reduce array size, they do not sufficiently offset mass-related penalties for c-Si. By contrast, the intrinsic lightweight and flexible properties of technologies like OPV shift the cost structure by lowering the number of required launches, demonstrating that material choice is as critical as launch economics in determining viability.

A key insight from this study is that mass-per-area is the most sensitive input parameter for LCOSE. This parameter integrates the dual drivers of efficiency and material density, revealing why OPV scenarios consistently outperform c-Si despite lower conversion efficiencies.

4.2 Environmental and Policy Dimensions

Unlike most terrestrial LCOE models, the LCOSE framework explicitly incorporates lifecycle emissions from manufacturing and launch. This ensures alignment with climate policy targets, such as the Paris Agreement [4]. Although these environmental externalities increase headline costs, their inclusion reflects the true societal impact of SBSP. The monetisation of emissions via carbon pricing also highlights a policy lever that could enhance SBSP's competitiveness: higher global carbon prices would increase the relative value of a near-continuous, low-carbon energy source.

Another policy consideration is regulation of orbital environments. Maintenance, debris mitigation, and end-of-life disposal impose operational costs that, while modest compared to launch, must be integrated into a realistic economic model. As SBSP deployment scales, these governance aspects will become increasingly central to the economic calculus.

4.3 Competitiveness with Terrestrial Energy

The lowest-cost OPV scenario achieves LCOSE values of 53 USD/MWh, directly overlapping with the current terrestrial PV range of 20–60 USD/MWh [6]. This result demonstrates that under favourable conditions, SBSP could be cost-competitive with established terrestrial renewables. However, competitiveness in pure cost terms tells only part of the story.

A more compelling aspect of SBSP lies in its ability to deliver continuous, dispatchable renewable energy. Unlike terrestrial PV and wind, which are constrained by diurnal cycles, weather variability, and seasonal patterns, SBSP in GEO receives near-constant solar radiation, with eclipses representing less than 0.1% of the year [4]. This gives SBSP a unique advantage: it can serve as a renewable baseload generation source, directly addressing one of the most critical challenges of the global energy transition: the intermittency of renewables.

This reliability positions SBSP not as a competitor to terrestrial solar or wind, but as a complement that could stabilize electricity systems with high shares of variable renewables. In regions with limited storage infrastructure or weak grid interconnections, SBSP could provide firm capacity that avoids overreliance on fossil fuels for balancing. At a global scale, the capacity to dynamically beam power to different ground stations in response to demand could enable real-time geographic balancing, reducing the need for oversized storage and transmission investments.

From an energy matrix perspective, the integration of SBSP would therefore go beyond lowering marginal costs. It could reshape the overall structure of electricity systems by providing the reliability backbone required for very high shares of renewables. In doing so, SBSP

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could reduce the dependence on nuclear, natural gas, and coal as firming resources, accelerate decarbonisation trajectories, and enhance energy security.

While the focus of this study has been on system-level techno-economics, the broader significance of SBSP lies in its potential to reshape global economic structures. If stowable-low weight-based SBSP proves viable, it could introduce a new class of baseload renewable energy with global reach. This would have implications not only for electricity markets but also for industrial supply chains, financial capital allocation, and the equitable electrification of underserved regions. Section 5 explores these macroeconomic implications in detail, addressing how SBSP could disrupt global energy markets, foster industrial ecosystems, and support climate-resilient economic growth.

5. Macroeconomic Implications of SBSP Deployment

The deployment of SBSP systems at scale has the potential to transform multiple dimensions of the global economy. Beyond technological feasibility and environmental benefits, SBSP can act as a macroeconomic catalyst. This section outlines the key systemic effects.

The International Energy Agency (IEA) projects that global electricity demand will grow at an average annual rate of 3.4% through 2026. In 2023, however, electricity uses in advanced economies declined, limiting overall global growth to 2.2%—a slight drop from the 2.4% increase observed in 2022. While nations like China, India, and several Southeast Asian countries experienced robust demand growth, developed economies faced slower growth due to a weak macroeconomic climate and high inflation, which reduced manufacturing and industrial activity [23].

Between mid-2025 and 2026, approximately 85% of the additional global electricity demand is expected to come from countries outside of advanced economies, with China remaining a key contributor despite undergoing structural economic shifts. In 2023, China's electricity consumption grew by 6.4%, fuelled by expansion in the services and industrial sectors. However, as the country's economic growth moderates and its dependence on heavy industry declines, electricity demand growth is forecast to slow—reaching 5.1% in 2024, 4.9% in 2025, and 4.7% in 2026 [23].

SBSP systems continue to require exceptionally high fixed capital investments, often amounting to billions of dollars per installation. They also depend on complex infrastructure, including launch operations, orbital deployment, microwave or laser transmission technologies, and ground-based receiving stations. Moreover, the growing issue of space debris poses a significant future risk to SBSP operations if no effective and reliable debris mitigation or removal systems are implemented.

5.1 Disruption to Global Energy Markets

SBSP could reshape global trade patterns by reducing dependence on fossil fuels, especially in energy-importing nations. Export-driven economies heavily reliant on oil and gas revenue may need to transition their fiscal models. Simultaneously, energy-importing regions could experience greater resilience, price stability, and sovereignty over energy access.

Through a combination of steady progress and disruptive innovation, organic photovoltaics (OPV) have evolved from a laboratory curiosity in the 1970s to early-stage commercial products, with several hundred megawatts (MWp) of annual production capacity now online. Multiple technological pathways have been explored, and future OPV products are expected to target a range of emerging market applications [24]. However, these systems have yet to be tested in orbit, and if proven effective in space, they could dramatically reshape the future of space-based solar power (SBSP) systems.

Aligning academic research on OPVs with industrial needs requires a targeted focus on real-world manufacturing challenges and material processing techniques that are scalable and commercially relevant. The evolving OPV value chain presents numerous economic opportunities—including intellectual property development, large-scale molecule synthesis, and module production and installation. These stages are realistically achievable through localized efforts worldwide, contributing to both energy security and the creation of skilled jobs at the regional level.

Wireless energy transmission from orbit could provide stable electricity to underserved or remote regions without requiring extensive ground-based grid infrastructure. This could close energy access gaps, accelerate economic development, improve education and healthcare outcomes, and support UN Sustainable Development Goals.

5.4 Creation of a New Industrial Ecosystem

SBSP could stimulate economic growth in emerging sectors such as orbital constructions like commercial space stations, in-space manufacturing activities, wireless power transmission, and advanced materials.

This would create new employment opportunities, drive STEM education, and incentivize both public and private investments in space infrastructure and most importantly cheaper access to electricity.

Achieving stronger alignment between academic OPV research and industry needs will require a targeted focus on addressing real-world challenges faced by the sector, particularly within molecular design and processing methods that are relevant to scalable manufacturing. There is significant economic potential across the emerging value chain—from intellectual property generation and large-scale molecule synthesis to module fabrication and deployment. These activities are not only technically feasible but also viable to implement locally around the world, supporting goals of energy security and local job creation [24].

5.5 Influence on Financial Markets and Capital Allocation

As SBSP matures, new asset classes could emerge, such as space infrastructure bonds or carbon-offset instruments linked to LCOSE metrics. Institutional investors may increasingly reallocate capital toward space-based renewable energy platforms, particularly those that support climate targets.

5.6 Contribution to Climate-Resilient Economies

By offering a continuous, clean energy source unaffected by terrestrial weather or disasters, SBSP contributes to climate resilience and global sustainability. The long-term economic savings from avoided carbon emissions, reduced climate-related disasters, and increased adaptation capacity could be substantial on a global GDP scale.

Early investments in this technology hold not only economic value but also strategic importance. A key issue that is frequently underestimated in current projections is the future scale and consequences of space debris. Within this broader conceptual framework, Space-Based Solar Power (SBSP) should be viewed not merely as a technological advancement, but as a transformative force reshaping competition, accessibility, cost dynamics, and sustainability in global energy markets.

6. Conclusion

This study developed a Levelized Cost of Space Energy (LCOSE) framework to assess the techno-economic viability of space-based solar power (SBSP) systems using crystalline silicon (c-Si) and organic photovoltaics (OPV). Through Monte Carlo simulations across four scenarios combining present-day and future performance assumptions, the results demonstrate that launch costs overwhelmingly dominate the cost structure of SBSP. While c-Si panels remain prohibitively expensive due to their mass and rigidity—resulting in LCOSE values exceeding 1,000 USD/MWh—OPV systems, with their lightweight and compact form, offer a compelling alternative. In favourable scenarios, OPV-based SBSP can reach LCOSE values between 53 and 158 USD/MWh, overlapping with current terrestrial photovoltaic costs.

These results highlight the central trade-off in SBSP design: the tension between power conversion efficiency and mass. Although higher efficiencies reduce the total area of deployed panels, the launch cost penalty of heavy materials often negates this benefit. In contrast, OPV's low mass-per-area and stowability provide a promising pathway to cost-competitive SBSP systems—assuming sufficient durability under space conditions. More than cost, however, SBSP's distinguishing advantage lies in its capacity to provide continuous, dispatchable clean electricity—functioning as a global, high-availability energy backbone and complementing the intermittency of terrestrial renewables.

To realize this potential, future work should focus on three critical areas. First, achieving substantial reductions in launch costs through advances in reusability and heavy-lift capabilities. Second, conducting rigorous in-orbit testing of OPV technologies to evaluate long-term performance under radiation, thermal cycling, and mechanical stress. Third, building holistic models that integrate generation with transmission subsystems, such as rectennas and satellite infrastructure, to present a complete picture of SBSP feasibility. These efforts will be instrumental in transforming SBSP from a theoretical concept into a cornerstone of the future global energy landscape.

Despite current limitations—particularly long investment return periods and reliance on unproven launch technologies—SBSP is no longer just a technological aspiration. This study's generation-centric approach, with explicit inclusion of lifecycle emissions, provides a more holistic lens to evaluate its economic and environmental value. The success of SBSP will likely require multinational collaboration, akin to the International Space Station (ISS) model, to overcome investment hurdles and ensure equitable access to the technology. Moreover, the business case remains fragile and contingent on the reliability and affordability of next-generation launch systems such as SpaceX's Starship. If these conditions are met, early-adopter nations with SBSP manufacturing readiness stand to gain strategically and economically.

Ultimately, SBSP has the potential to support both Earth's sustainability goals and the maturation of the space economy. The spillover effects—ranging from advancements in in-space manufacturing to auxiliary satellite services—mirror the historical trajectory of the satellite industry, which has evolved from single-purpose missions to a globally integrated infrastructure of over 12,000 active satellites. SBSP could follow a similar path, with technologies like OPV enabling scalable, orbitally-deployed energy platforms. However, beyond technical challenges, the successful implementation of SBSP will depend equally on resolving complex legal, political, and governance issues—making it a truly interdisciplinary endeavor.

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