Assess Space-Based Solar Power in European-Scale Power System Decarbonization

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Abstract

Meeting net-zero targets remains formidable as terrestrial renewables grapple with intermittency and regional variability. Here, we integrate space-based solar power (SBSP)—a potential near-constant, orbital solar technology—into a high-resolution, Europe-wide capacity-expansion and dispatch model to quantify its contribution under net-zero constraints. We examine two advanced SBSP designs: (1) a near-baseload, low Technology Readiness Level (TRL) concept (heliostat-based Representative Design RD1) and (2) a partially intermittent, higher-TRL concept (planar-based RD2), both drawing on NASA's 2050 cost and performance projections. Our results show that RD1 can reduce total system costs by 7–15%, displace up to 80% of intermittent wind and solar, and cut battery usage by over 70%, if it meets its forecast cost reductions—though long-duration storage (e.g., hydrogen) remains essential for seasonal balancing. By contrast, RD2 is economically unattractive at its projected 2050 costs. Through extensive sensitivity analyses, we identify cost thresholds at which SBSP shifts from cost-prohibitive to complementary and ultimately to a dominant baseload technology. Specifically, RD1 becomes complementary at roughly 14× and dominant at 9× the 2050 solar PV capital cost, benefiting from its continuous power generation. Meanwhile, RD2 must achieve even lower cost levels (9× to be complementary and 6× to dominate) and would rely on short-duration storage to mitigate its partial intermittency. These findings provide quantified techno-economic benchmarks and reveal alternative net-zero pathways, offering critical guidance for policymakers and industry stakeholders seeking large-scale, centrally coordinated renewable solutions with non- or low-intermittency.

Keywords: space based solar power, decarbonization, energy system modeling, techno-economic analysis

1 Background

By November 2023, nearly 145 countries, accounting for about 90% of global greenhouse gas emissions, have pledged to reach net-zero targets [1]. Meeting these commitments requires shifting from fossil fuels to low-carbon resources such as wind and solar power. Yet, the intermittency and weather-dependence of these terrestrial renewables complicate reliable supply, and the cost-effectiveness of large-scale, long-duration storage remains uncertain, challenging deep decarbonization [2, 3].

In Europe, decarbonization efforts take place within a complex, highly interconnected grid spanning diverse regional resources, demand profiles, and policies. Seasonal imbalances (e.g., higher winter demand met significantly by natural gas) can spur price volatility, emissions, and energy security risks [4]. Whole-system optimization models indicate that achieving high renewable penetration is both technologically and economically feasible [5], but such solutions involve intricate coordination of generation, storage, and extensive transmission upgrades across national borders. As policymakers