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Ecological impact on the environment of laser space solar power plants

Impacto ecológico en el medio ambiente de las plantas de energía solar láser espacial

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ABSTRACT

Climate stabilization and replacement of oil with alternative energy sources are urgent problems in the modern world. Space solar power plants [SSPP] can solve these problems simultaneously. Based on the review of literary sources, we raised one of the primary issues of the SSPP creation related to the need to identify the nature and the extent of its impact on the environment. First, we analyzed the environmental impact of the SSPP and traditional energy sources (thermal power plants, nuclear power plants, and hydroelectric power plants). Second, we considered the environmental impact of various wireless transmission methods of energy from the SSPP: ultrahigh-frequency (microwave) and infrared [IR] laser radiation, and the efficiency of energy transmission from the SSPP. One should emphasize the specific concept of efficiency for these power plants since they have an infinite energy source in the form of the Sun. Thus, the superiority of space solar power plants lies in the absence of nuclear radiation and chemical toxicity, a much higher efficiency, locality of impact (a site with a diameter of 40–50 m on Earth when broadcasting from a geostationary orbit), and a lower cost. For several reasons, mainly due to the terrorist threat, it is advisable to abandon the use of tethered balloons for receiving laser radiation above the clouds to eliminate losses in the atmosphere and carry out a live broadcast and reception of energy on the Earth, creating lasers operating in the windows of atmospheric transparency. One can use local illumination of the atmosphere during the operation of these power plants. The use of laser SSPP is especially relevant for solving the problems of the Arctic and continental shelf development with an extreme climate (taiga and tundra with swamps and permafrost) and for mobile objects and transport.

Keywords: Ecological impact, Space solar power plants, Centrifugal space structures, Laser radiation, Local illumination of the atmosphere, Tethered balloon

RESUMEN

La estabilización del clima y la sustitución del petróleo por fuentes alternativas de energía son problemas urgentes del mundo moderno. Las plantas de energía solar espacial [SSPP] pueden resolver estos problemas simultáneamente. A partir de la revisión de fuentes literarias, planteamos uno de los temas primordiales de la creación del SSPP relacionado con la necesidad de identificar la naturaleza y el alcance de su impacto en el medio ambiente. En primer lugar, analizamos el impacto ambiental del SSPP y las fuentes de energía tradicionales (centrales térmicas, centrales nucleares, centrales hidroeléctricas). En segundo lugar, consideramos el impacto ambiental de varios métodos de transmisión inalámbrica de energía desde el SSPP: radiación láser de ultra alta frecuencia (microondas) e infrarroja (IR), y la eficiencia de la transmisión de energía desde el SSPP. Cabe destacar el concepto específico de eficiencia para estas centrales eléctricas ya que tienen una fuente de energía infinita en forma de Sol. Por lo tanto, la superioridad de las plantas de energía solar espacial radica en la ausencia de radiación nuclear y toxicidad química, una eficiencia mucho mayor, la localidad de impacto (un sitio con un diámetro de 40 a 50 m en la Tierra cuando se transmite desde una órbita geoestacionaria) y un costo más bajo. Por varias razones, principalmente por la amenaza terrorista, es recomendable abandonar el uso de globos cautivos para recibir radiación láser por encima de las nubes con el fin de eliminar pérdidas en la atmósfera y realizar una transmisión y recepción de energía en vivo en la Tierra, creando láseres que operan en las ventanas de transparencia atmosférica. Se puede utilizar la iluminación local de la atmósfera durante el funcionamiento de estas centrales eléctricas. El uso de láser SSPP es especialmente relevante para resolver los problemas del desarrollo del Ártico y la plataforma continental con un clima extremo (taiga y tundra con pantanos y permafrost) y para objetos móviles y transporte.

Palabras clave: Impacto ecológico, Plantas de energía solar espacial, Estructuras centrífugas espaciales, Radiación láser, Iluminación local de la atmósfera, Globos atados.

1. INTRODUCTION

Nowadays, the most significant global problems are stabilizing the climate and replacing oil with new energy sources. One can solve these problems simultaneously by creating space solar power plants [SSPP] transmitting energy to the Earth. (Mankins & Kaya, 2009; Sysoev, Pichkhadze & Verlan, 2013).

During the first two decades of the 21st century, extreme large-scale weather disasters on all continents caused total damage, 10 times higher than the cost of the largest space programs. The reason for these disasters is the excess of the permissible norm of anthropogenic impacts on the environment from human activities, including traditional energy facilities.

2. MATERIALS AND METHODS

The paper aims to identify the nature and extent of the impact of SSPP on the environment, which is one of the critical issues of their creation.

Based on the literature review of various sources on the topics of traditional energy and SSPP (only the sources directly used in the study are indicated in the References section), we formulated the following research tasks:

- Comparative analysis of the impact of SSPP and traditional energy sources on the environment;
- Study of the ecological impact of various wireless energy transmission methods from SSPP: ultrahigh-frequency (microwave) and infrared [IR] laser radiation;
- Examination of the efficiency of energy transmission from SSPP;
- Consideration of the local illumination of the atmosphere and features of the balloon reception of energy from the SSPP.
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3. RESULTS

3.1 Comparative analysis of the ecological impact of SSPP and traditional energy sources

Climate stabilization is closely related to the technogenic impact on the environment of the ground traditional energy systems and the possibility of solving the problem of the energy crisis.

Thermal and NPP make up 80% of today's energy (63% thermal, 17% nuclear) and have a low thermal conversion efficiency of 30%. Thus, 70% of the burned fuel (hydrocarbon and nuclear) energy is dissipated in the environment. Hydroelectric power plants [HPP] account for 18% of energy and have a high conversion efficiency (about 90%).

1) Let us consider the impact of various types of ground energy on the environment (Raikunov, Komkov & Melnikov, 2017). The thermal power plants [TPP] have the negative consequences of using carbon-containing fuel, the combustion of which has a negative impact on the biosphere (CO, CO2, nitrogen oxides, sulfur, lead, arsenic, radioactive elements, and heavy metals enter the atmosphere, a considerable amount of oxygen is taken from the atmosphere during combustion, the environment is warming up, environmentally harmful substances accompanied with burning in the form of soot and ash are carried by the wind for hundreds of kilometers reducing soil fertility, settling on ice and snow and changing their reflectivity, the Earth's albedo changes, contributing to warming);

2) Nuclear power plants [NPP] entail harm from nuclear fuel used in NPP, due to the low thermal efficiency, intensively heating the environment (similar to TPP), contributing to the greenhouse effect, posing problems of nuclear waste disposal and spent reactors, accidents with catastrophic consequences, causing damage several times exceeding the benefits of NPP, as well as uncontrolled production of plutonium as a strategic material for nuclear weapons;

3) Hydroelectric power plants [HPP] flood large areas, cities, and villages, leading to changes in the hydrological regime and climate of adjacent territories, changes in the landscapes of river valleys; hydroelectric dams block the fish spawning sites, but, at the same time, favorably affect fish stocks in the reservoir.

The analysis shows that in order to solve the environmental problem, it is necessary to abandon or reduce the use of hydrocarbons and nuclear fuels, which are the main cause of human-made impacts on the environment. Moreover, one should search for alternative environmental ways of generating energy, including SSPP.

While in orbit, SSPP receives and converts solar energy and transfers it to the consumption areas, excluding the long-distance ground power lines and environmental damage related to their construction (e.g., deforestation, non-use of land). This issue is relevant for the development of the Arctic and continental shelf, where power lines must pass through the taiga and tundra, swamps, and permafrost, as well as for mobile objects, including transport (Raikunov, Komkov & Melnikov, 2017).

3.2 The ecological impact of different ways of wireless energy transmission from SSPP: ultrahigh-frequency and infrared laser radiation

Let us consider the use of ultra-high-frequency (microwave) and infrared [IR] laser radiation for SSPP in the wireless energy transmission to the Earth.

The environmental hazard of the SSPP with a laser in the infrared wavelength range concept of energy transmission is significantly less compared to the microwave method; it is associated with the following circumstances (Melnikov, Bruevich, Parashchuk & Kharlov, 2014):

- Less pronounced biological impact since the microwave beam passes through the biological structure in the same way as a radio signal having a volumetric effect on it, while the IR beam, similar to the light wavelength range, has a surface effect that can be efficiently screened;
- Several orders of magnitude smaller reception area (when broadcasting from a geostationary orbit in the microwave range, a receiving area with a characteristic size of 15–20 km is required, in the laser range 40–50 m);
- Defocusing the laser beam to any required level when it is impossible to target the receiving antenna and other contingency modes;
- Significantly greater technical and operational complexity of microwave systems compared to laser systems, which require a high-voltage power supply of lamps generating microwave, and their cooling in outer space, phase synchronization of the energy supplied to various parts of the radiating antenna.

A laser beam generated in a geostationary orbit on its way to Earth can potentially affect the scientific, commercial, or military equipment of spacecraft in lower orbits and aerial aircraft, as well as birds. The high relative speed of the spacecraft's passage through the laser beam cannot lead to a noticeable overheating of the structure. However, the incapacitation (illumination) of sensitive elements of sensors or other equipment when directly hit by laser light in the IR range is not excluded, which should be considered when designing such devices. Maps of forbidden areas and strict rules for their compliance are crucial for aircrafts. For birds (goose flocks, ducks, gulls), one can take measures similar to fish drainage in water intake structures, based on various physical and biological principles (deterring infrasound effect, glare light effect), which will require particular research and development in the future (Mankins & Kaya, 2009; Melnikov, Bruevich, Parashchuk & Kharlov, 2014; Sysoev, Pichkhadze & Verlan, 2013).

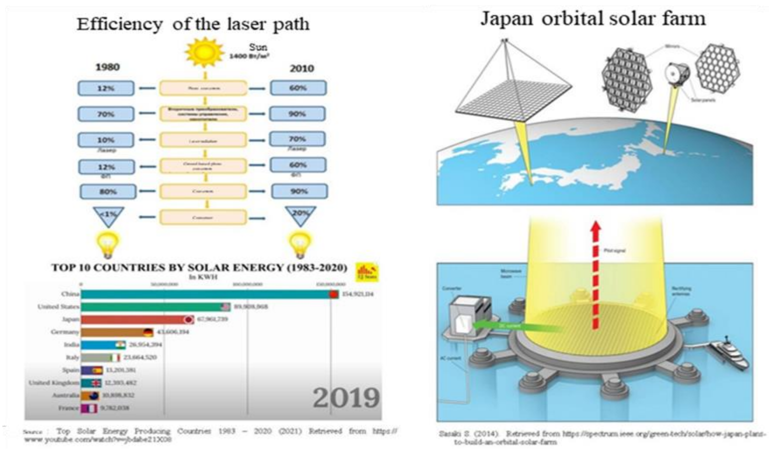
3.3 The efficiency of power transmission from the SSPP

The HPP has the greatest efficiency among the above-mentioned ground power plants, but the SSPP has an infinite energy source (the Sun). Moreover, the concept of efficiency is specific.

According to forecasts, a global increase in solar energy by 150 GW is expected in 2021, and almost 200 GW in 2024 (Sidorovich, 2020). The electricity generation by means of SSPP occupies an insignificant share of modern solar energy, which is a part of renewable energy sources [RES]. Currently, the leading countries of solar energy (China and Japan) are setting plans to implement SSPP by 2023–2024. (Stats, 2020; Sasaki, 2014).

In complex analysis, the efficiency appears as a system parameter similar to other possible parameters. For example, low efficiency can take a back seat for an amorphous silicon solar battery in space conditions, providing radiation resistance, low cost, and low mass characteristics. Due to the solar source infinity, any SSPP power can be provided, even with low efficiency (Raikunov, Komkov & Melnikov, 2020).

Let us consider the most acceptable conversion scheme for a laser SSPP today (Raikunov, Komkov & Melnikov, 2020). Solar panels convert solar energy into electric energy, then the electric energy on solid-state lasers is converted into laser radiation energy, connected to light guides, going through the light guides to the optical system it is transmitted to a ground receiver in the form of solar panels. We will consider this scheme to be basic. As another option, a scheme with the connection of a solid-state laser to a fiber laser and a scheme of balloon reception with different conversion cycles (into laser and microwave radiation, conventional current collector) can be considered (Raikunov, Komkov & Melnikov, 2020; Sasaki, 2014).



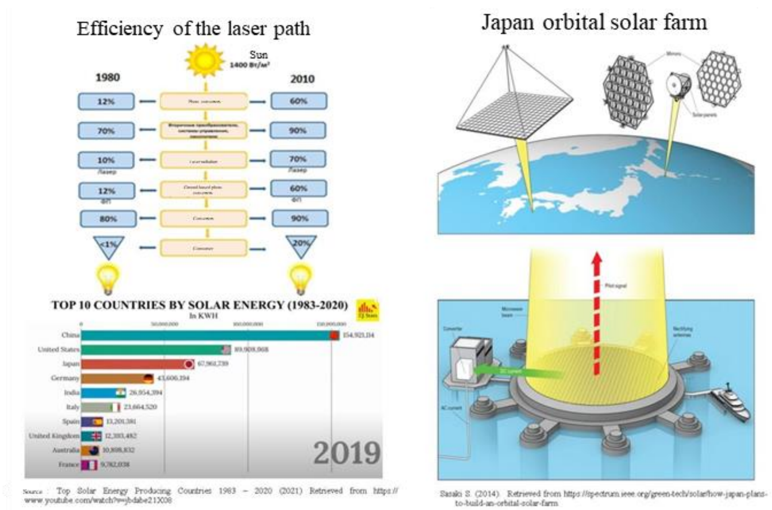


Fig. 1: The efficiency of the laser path of the SSPP by year (where PC are photo converters), and the top 10 leading countries of solar energy, including the Japanese SSPP project.

For the basic scheme, the efficiency of various stages of transformation is shown in Fig. 1 (upper left) (Raikunov, Komkov & Melnikov, 2020; Sysoev, Pichkhadze & Verlan, 2013). The scheme with solar pumping of a fiber laser is of the greatest interest since it does not require solar batteries (Boetti et al., 2018; Melnikov, Bruevich, Parashchuk & Kharlov, 2014). However, to date, such lasers have not been developed sufficiently for use in SSPP. Due to the high efficiency in the future, an analysis of the efficiency of such a scheme is also crucial. The study aims to determine the nature and magnitude of the influence of the laser path on the environment and compare it with the similar impact of nuclear and TPP. One should note that power transmission lines assume losses equal to half of the transmitted power for optimal energy transmission. For SSPP, according to Fig. 1, the first three positions remain in space. These are photo converters of solar panels, secondary converters, and the electricity conversion into laser radiation, the transportation of light energy through optical fibers or a fiber laser, and losses in the optical guidance system to the Earth.

These losses do not affect the earth's balance and the environment; they are influenced by the last two positions: losses in the atmosphere and ground photo-converters that perceive the laser beam. Inverters that convert direct current and voltage from solar panels into the parameters of the consumer power network in frequency, phase, and voltage have an efficiency of more than 90%. Now, we should dwell on the laser beam loss during the atmosphere passage.

One can identify a comparison of the optical transmission spectrum of the atmosphere and the emission lines of high-efficiency fiber lasers with the maxima of the wavelet transform module using the wtmm function, which characterizes the fractality of the signal (see Fig.2). Moreover, in Fig. 2, one can indicate that the two maxima marked with white horizontal lines coincide with the emission lines of high-efficiency fiber lasers (red vertical lines).

However, unlike a microwave laser, one can identify a problem of the influence of the atmosphere (aerosols and turbulence) for a laser energy transmission channel. Losses on the ground receiving solar panels with an efficiency of 40%–60% and losses in the lower layers of the atmosphere in a channel with a diameter of 40–50 m are critical. Fig. 2 shows that when the radiation line of high-efficiency fiber lasers is shifted to the range of 1000–1100 nm and 1300 nm, which is fundamentally possible, it gets into the transparency zone of the atmosphere, indicating a way to increase the efficiency of the laser method of energy transfer (Raikunov, Komkov & Melnikov, 2020).

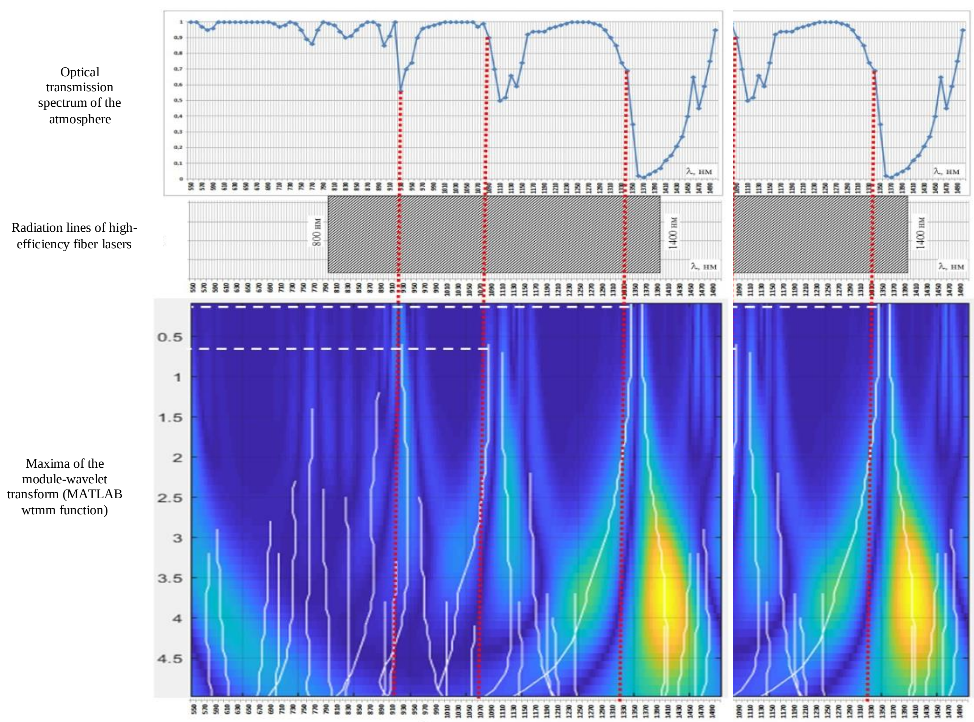


Fig. 2: Comparison of the atmosphere optical transmission spectrum and the emission lines of high-efficiency fiber lasers with the maxima of the wavelet transform module.

The microwave concept assumes a receiving platform with a diameter of 15–20 km for receiving energy from a geostationary orbit, that is, much larger in area than is required for a laser, excluding the possibility of receiving a microwave signal in high-latitude regions when broadcasting from a geostationary orbit since the energy beam, in this case, is close to parallel to the Earth's surface, and the creation of a receiving antenna with a height of 15 km is not feasible.

One should also emphasize that the efficiency of the SSPP elements is continuously being improved as an element base in electronics, and in the future, they will significantly increase today's indicators in industrial production.

In general, the above comparison of traditional energy means, microwave and laser SSPP implies the superiority of laser SSPP due to the significantly higher conversion efficiency, impact locality (when broadcasting from a geostationary orbit on Earth, a platform with a diameter of 40–50 m is required), the low cost of the energy produced (6 times cheaper than its production on Earth according to Japanese estimates) (Sasaki, 2009), and the absence of chemical toxicity and radiation.

4. DISCUSSION

Despite the SSPP advantages, one need to consider two aspects:

1) Local illumination of the atmosphere.

It is possible to use methods of local illumination of the atmosphere in heavy clouds, thunderstorms, and snow. The method of cloud dispersing over Moscow during major holidays by spraying chemicals above the clouds is widely known. However, this method uses aviation, which is relatively expensive and most likely not applicable in the SSPP. For several decades, the United States has accumulated experience in the impact on the atmosphere and ionosphere of electromagnetic radiation from multi-kilometer antenna fields in Antarctica and Alaska (the HAARP system). Other countries, including the Russian Federation, also have a similar experience (Raikunov, Komkov & Melnikov, 2020; Uybo, 2016).

Fig. 3: The system of illumination of the atmosphere in the local area.

Fig. 3 shows the elements of the "Atlant" equipment (Uybo, 2016), which successfully operated at a power of up to 5 kW in several regions of the Russian Federation and on the north-eastern coast of Australia (Australian Rain Technologies, 2021). With its mobility, possibility of covering a small local area, low energy consumption, and efficiency, this method can be used in the annex to the SSPP.

For several reasons, mainly due to the terrorist threat, it is advisable to abandon tethered balloons for receiving laser radiation above clouds to eliminate losses in the atmosphere.

2) Peculiarities of balloon energy intake from the SSPP.

Variants of the reception system using tethered balloons to eliminate losses caused by the opacity of the atmosphere can ensure the reception of a laser beam above the clouds by highly efficient solar panels and its subsequent conversion into laser radiation and transmission to Earth via a light guide or fiber laser with a further conversion cycle to electricity on solar panels (see Fig. 4). The way of electricity transported through an electric cable with an acceptable 2%–5% loss requires additional lifting force from several balloons or kites in the case of a copper conductor. If we use superconducting ceramics, the conductivity of which is at least a hundred times higher than the conductivity of copper, then the situation will change' it can be converted to microwave and broadcast to the Earth, followed by conversion to electric current on microwave converters. In addition to the complexities of the hardware design of such converters, losses in them reduce the overall efficiency of the system. We also identified the following difficulties in using tethered balloons (Raikunov, Komkov & Melnikov, 2020):

- Expensive manufacturing and large-scale space, special equipment, and highly qualified specialists;
- Special hangars and airfields for the storage and operation;
- Problems with departmental affiliation (Ministry of Defense, Aeroflot);
- Lack of operational experience, significant accidents;
- Cable posing a danger to aircrafts, helicopters, and birds;
- Tethered system subjected to horizontal fluctuations (like a flag in the wind complicating the guidance of the laser beam);
- Thunderstorm danger (the cable may be interrupted by an electric discharge from a thundercloud);
- Terrorist threat, a tethered cable, and a balloon destroyed by a drone or a simple missile system (Raikunov, Komkov & Melnikov, 2020).

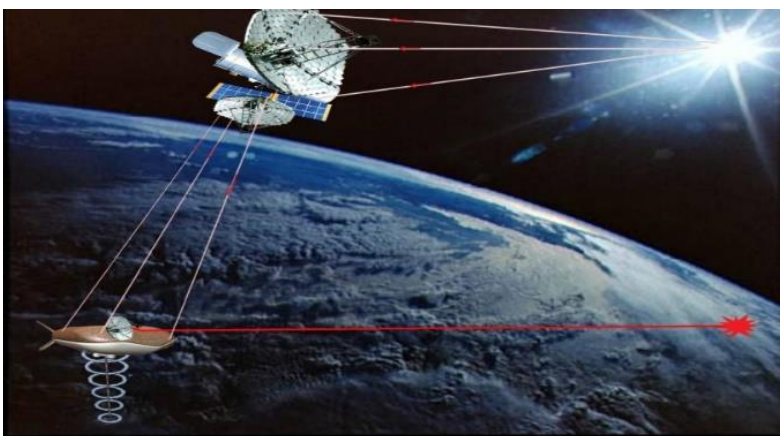


Fig. 4: Receiving a laser beam with a tethered balloon.

The company "Westinghouse" specializing in cellular communications in Europe refused to use balloons as transponders due to the terrorist threat in 2000.

Taking into account the possibilities of local illumination of the atmosphere, we should abandon the use of tethered balloons and carry out live transmission and reception of energy on the Earth, creating lasers operating in the windows of atmospheric transparency. Moreover, one can develop a semiconductor laser in the range of 0.55–0.75 microns or 1.0–1.1 microns of atmospheric transparency windows at the first stage of SSPP creating based on thin-film solar cells and semiconductor lasers powered by them until more efficient solar-pumped fiber lasers are created. In the future, at the second stage of SSPP creation, a solar-pumped fiber laser at the same wavelength can be developed. Large-sized frameless space structures formed by centrifugal forces can be an effective base for SSPP, which has several advantages over traditional frame analogs (Melnikov & Koshelev, 1998).

5. CONCLUSION

Space solar power plants generate electricity in space and transmit it to the required points in any region without the cost of laying power lines. A significant part of the losses of the energy transmission path from laser SSPP remains in space. Besides, SSPP has advantages over nuclear and TPP due to the absence of danger concerning the use of nuclear energy (catastrophic consequences of accidents, problems of waste disposal and NPP, low thermal efficiency [20%–25%], and the associated environmental warming)), as well as the absence of human-made loads in the form of soot, antimony, heavy metals, sulfur, arsenic with consequences accompanying the operation of TPP.

In general, from the above comparison of traditional energy means, microwave and laser SSPP, one can identify the superiority of laser SSPP due to higher efficiency, impact locality (a platform with a diameter of 40–50 m when broadcasting from a geostationary orbit), lower cost, and absence of chemical toxicity and nuclear radiation.

Primarily due to the terrorist threat, it is advisable to abandon tethered balloons for receiving laser radiation above the clouds to eliminate losses in the atmosphere and carry out live transmission and reception of energy on the Earth, creating lasers operating in the windows of atmospheric transparency. Moreover, one can use artificial local illumination of the atmosphere by electromagnetic radiation of relatively low power.

The efficiency of the SSPP elements is continuously being improved as an element base in electronics. In the future, with industrial implementation, these elements will significantly increase today's indicators.

The use of laser SSPP is relevant for the development of the Arctic and continental shelf, which have an extreme climate (taiga and tundra with swamps and permafrost), as well as for mobile objects and transport.

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