Analysis of the environmental factors influence on the efficiency of photovoltaic systems

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Abstract. The development of civilization is associated with the creation of various methods of energy conversion. Humanity has come a long way from the water wheel to modern power plants. Though earlier people did not think about the damage to the environment from the work of a number of power plants, today this cannot be ignored. Renewable energy sources (RES) and their using by modern technologies claim to play a significant role in the world energy sector. Support for the development of RES in Russia is currently based on compensation of costs under contracts for the sale of power in the wholesale electricity and power market. According to the results of the competition of the Trading System Administrator, projects under the contracts for renewable energy power supply selected. Analysis of bids of the Trading System Administrator (TSA) showed that until 2023 will be introduced 1.8 GW of solar power plants, so the actual goal will be the correct operation of them in the weather conditions of Russia. Pollution of various types, which can be on the panels can affect the operation of solar panels (SP) and prevent the ingress of solar radiation on them. The article investigates the influence of various types of pollutants on the power generated by solar panels and promising places for the construction of solar plants in the climatic and geographical conditions of Russia, taking into account possible polluting factors, which can lead to total economic damage of up to 15 million rubles per year.

Keywords: solar panels, renewable energy sources, operation of solar modules, pollution of the solar panel, types of pollution, causes of deterioration of the solar module, the efficiency of the solar battery, the power of solar panels

1. Introduction
The development of civilization is associated with the creation of various methods of energy conversion. Humanity has come a long way from the water wheel to modern power plants. Though earlier people did not think about the damage to the environment from the work of a number of power plants, today this cannot be ignored. Nowadays, it is clear to most people that the generation of energy at thermal power plants leads to pollution of the components of the hydrosphere, atmosphere and lithosphere. Now humanity has to solve issues related not only to the creation of new energy sources, but also to their impact on the environment. For this reason, the key trend in the development of the electric power industry worldwide is the transition to renewable energy sources, which now seems to be the most successful in terms of environmental impact.
1.1. Actual state of renewable sources in the world
RES and their use of modern technologies claim to play a significant role in the global energy sector, as evidenced by the continuous growth of investments in the global energy sector, which in 2017 amounted to 279.8 billion US dollars. The past 2017 was a record year in the growth of renewable energy capacities for the entire period of their development, a similar trend continues in 2018. Since the beginning of 2000, investments in RES show stable growth or a very slight decline, which can not boast of investments in other sectors of the economy, which experienced a significant decline due to the global crisis of 2008. In 2017, investments in green energy increased by 2% compared to 2016, but this is 13% lower than the record high in 2015, which can be explained by a decrease in the specific capital costs of RES equipment. The rapid decline in the cost of equipment led to the fact that with slightly large investments in 2017, the commissioning of power using from RES was 90 GW, and a year earlier only 85 GW.

The leading countries for investment in renewable energy are the United States, Latin America, China, Germany, Italy and India. Moreover, a large share of investments (63%) is accounted for by countries with developing economies, of which 45% are only Chinese investments, which is 10% more than in 2016, the US – 14%, Asia and Oceania (excluding China and India) – 11%, North and South America (excluding Brazil and the US) – 5%, India – 4%, the middle East and Africa – 4%, Brazil – 2% [6, 12-18].

1.2. Development of RES in Russia
In Europe, the development of renewable energy began in the 2000s, in Russia, the first steps for the development of renewable energy were taken by the state in 2009. An order of the Government of the Russian Federation was adopted, in 2013 the state program "energy Efficiency and energy development" [2] was adopted, according to which 6.2 GW of power plants on renewable sources should be introduced in the country by 2020. At the beginning of 2018, the preliminary results of the program implementation were considered, which indicate a low level of budget expenditures, in particular for RES.

Support for the development of RES in Russia is currently based on compensation of costs under contracts for the sale of power in the wholesale electricity and power market. This incentive mechanism has been widely used in various sectors of the Russian economy and was able to be used in the development of pure energy through the adoption of Government Resolution No. 449 on 28 may 2013 [3].

The resolution applies to green energy generating facilities with a power of 5 to 25 MW. At the same time, the volume, structure and price of electricity are determined by the Government, based on the guaranteed return on investment for 15 years. Regulatory levels of capital and operating costs have been introduced, allowing total costs to be controlled and tariff growth to be limited. The selection of projects on RES contracts for the sale of power is carried out on the basis of the competition of the administrator of the trading system (TSA). The planned and actual results of the selection of bids from 2013-2018 (for the year of delivery) are shown in Figure 1-3, the criteria of which take into account the claimed specific capital and operating costs. There is also a diagram (Figure 4) illustrating the share of newly introduced wind farms (WF), solar power plants (SPP) and small hydropower plants (SHP) expected in 2013 by 2020, as a result of the selection of bids until July 2018 [4, 23-24].

It can be stated that by 2020 it was planned to introduce 3.6 GW of wind farms, but only 3.4 GW were selected by the results of the competition; out of the planned 1.5 GW for the share of solar plants, 1.8 GW were selected; while only 0.14 GW of the planned 0.75 GW of small hydropower plants will be introduced by 2023. According to the government decree, by 2020 it was planned to maintain about 6 GW of generated capacities for RES, but in 2018 the total power’s value of the selected applications for the date of commissioning in 2023 in the amount of 5.4 GW, which with some lag corresponds to the government plan, but will not prevent from being implemented in full.
Figure 1. Comparative analysis of planned and commissioned of solar energy power.

Figure 2. Comparative analysis of planned and commissioned of wind energy power.

Figure 3. Comparative analysis of planned and commissioned of SHPP power.
Figure 4. Shares of various types of RES that will be commissioned in Russia by 2023.

From the analysis it can be seen that at the second place in popularity of renewable energy in Russia will be solar photovoltaic installations and their operation in terms of the climate characteristics of Russia will be a great right need.

1.3. Features of the sun as an energy source
Solar radiation, which comes from space is about 7.5 kWh/year. Such power generation theoretically will not give all other renewable sources combined, which indicates the prospects of using the power of the Sun [5].

However, not all radiation that spreads towards the Earth can be used to energy generation. There are a number of factors that change the trajectory of the rays, because of what they do not reach the surface of the solar cells, disperse or absorb them. Factors can be divided into space and earth. The first group includes non-serviceable artificial objects located in near-earth space. So far, this is not a significant reason, which may not even affect the operation of solar photovoltaic installations in space. But with the growing interest in space tourism, it may become more relevant. This category should also include the earth’s atmosphere, which absorbs about 19% of solar radiation. Depending on the wavelength, the atmosphere and clouds can reflect the radiation of the Sun [7, 19-22].

2. Materials and Methods
In addition to the above factors, the operation of solar panels can be affected by various kinds of pollution on the surface of the panels and prevent them from getting solar radiation. Such pollution can include dust, which can be of cosmic origin and come to the planet from different places of the solar system and the Galaxy. Several tons of it daily settles on the Earth [9].

The Earth factors affecting the operation of photovoltaic plants (PP) include soil, deserts, volcanic eruptions, the work of factories and industrial enterprises, extraction of natural resources, construction, agriculture, as they are a source of dust.

The urban environment is a source of different types of pollutants. For example, in winter housing and communal services sprinkle slippery sections of roads with sand and salt, but a strong wind can capture the salt crystals and move to closely spaced solar panels. As a result, in a few days the surface of the PP can be quite heavily contaminated.

Photovoltaic cells feeding traffic lights are most susceptible to pollution, as they are often located in open areas of highways and road junctions. Gas contamination in such areas has an impact on the plant’s power.

If we look at the current picture of the world, in the foreground of which are located hydrocarbon production, ongoing construction and anthropogenic pressure on nature as a whole, it can be conclud-
ed that, following this direction, the amount of dust and other polluting reagents will increase annually [8]. The climate and natural conditions in which solar panels are operated will also have an impact. To study the influence of external factors on the generated power of photovoltaic cells, an experiment was conducted. During the experiment the solar panel "1.5 W Solar Panel 81X137", sodium lamp NAV-T 70W, multimeter BORT BMM-1000N (Figure 5) were used. During the experiment, the RSP-power of the solar panel (W) was found under the conditions of the experiment. The study took into account all the factors of changes in the performance of solar installations: increase and decrease in temperature, intensity and distance from the light source to the solar panel, the angle of incidence.

The panel alternately applied a layer that prevents light (dirt, salt, dust), and then turned on the light source. After that, the panel was cleaned, and the experience was repeated again.

Setting the experiment.

![Figure 5. Laboratory setup scheme.](image)

Each layer of the contaminant was applied with the same thickness and on a clean solar panel to equalize the conditions in all experiments. Periodically, the light source was switched off to avoid overheating of the solar panel, which could lead to a decrease in power and differences in measurements.

3. Results
The power of the solar panel was determined taking into account the pollutant factor. Current and voltage readings were taken from the multimeter connected to the solar panel. The measurement results are present in Table 1.

| Experiment number | Pollutant factor    | Voltage, U (V) | Amperage, I (A) | Power, P (W) |
|-------------------|--------------------|----------------|-----------------|--------------|
| 1                 | No pollutant       | 5,29           | 0,15            | 0,7935       |
| 2                 | Soil, dirt        | 5,2            | 0,1             | 0,52         |
| 3                 | Dust              | 5,1            | 0,09            | 0,459        |
| 4                 | Salt              | 5,25           | 0,11            | 0,5775       |
| 5                 | Dust, dirt, salt  | 5,05           | 0,06            | 0,303        |
The results of the experiments showed that the polluting factor can significantly reduce the productivity of the device. The values of the lost power of the solar panel from the type of pollutant are shown in figure 6.

![Figure 6. Dependence of lost power on the pollutant factor.](image)

Each layer of the contaminant was applied with the same thickness and on a clean solar panel to equalize the conditions in all experiments. Periodically, the light source was switched off to avoid overheating of the solar panel, which could lead to a decrease in power and differences in measurements.

4. Discussion
The influence of all the above factors on the operation of solar panels is obvious, as they either darken the surface of the panel, or deflect the rays from the surface of the panel. Therefore, the study of the dependence of the output power of solar panels on polluting factors is very important, especially for Russia, which has a large extent of territories from East to West and has different climatic conditions. The analysis of bids of the TSA showed that 1.8 GW of solar plants would be introduced by 2023. However, according to the results of our experiment, the total power of the introduced SPP can fall by 0.5-1GW depending on the type of pollutant that can be on their surface, which can lead to a total economic damage of up to 15 million rubles per year.

Similar studies were conducted earlier by the 27 of technology for the Asian region, which included the cities of China, India and Singapore. As well as researchers from the Indian Gandinagar Institute of technology and scientists from Duke University. Scientists at the University of Massachusetts conducted experiments in 16 different locations and found that the power reduction depending on the environmental conditions ranged from 2 to 16% [9, 26].

Duke University scientists have also found that the accumulation of pollution on the SP affects energy production. In their reports, it was stated that the power produced by solar installations does not converge with what the producers indicate, it falls by 17-35% on the territory of the Indian subcontinent [10, 27]. Thus, it was concluded that the profitability of solar panels is much lower in countries with dense smoke and poor environment. Data obtained for China, where 80% of thermal power plants work on coal, and India, where emissions of harmful substances exceeded the world Health organization standards by 30 times. The analysis of data on power loss by solar panels by various scientists is presented in figure 7.
These criteria cannot be applied to Russian conditions in connection with other indicators of these criteria. In our experiment, the polluting factors characteristic were used for natural conditions of our country. Dust and dirt can get on the modules installed near the road, salt on the modules designed to power the lights and traffic lights near the sea and the water that appears on panels during the rain.

5. Conclusion
The territory of the Russian Federation is 17 100 000 km², but not everywhere the installation of SPP will be the most effective. The reason may be not only a small number of Sunny days, but also human activity. Industry has become a powerful source of dust. For this reason, in the territory of enterprises, the produced power of solar panels should be less. In cities such as Azov, Novokuznetsk, Lipetsk, Magnitogorsk, Volgograd, Norilsk, Nizhnekamsk, Chita, developed industrial sectors not only harm the health of inhabitants [10-12], but also destroy the prospects of using Solar energy in these areas. Dust is formed during coal mining. For this reason, the territory of coal mines and mines have solar installations undesirable. These areas include: Kansk- Achinsk coal basin, Kuznetsk coal basin, etc. [11, 24-25].

The most successful will be the construction of SPP in the South of the country, excluding those areas in which industry is developed and construction is underway. Promising areas include the North Caucasus, the Republic of Crimea, and the Vladivostok region. They are also called the most promising areas for the use of solar energy. In addition, the South of Western and Eastern Siberia are promising areas [28-30].

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Figure 7. Dependence of the minimum and maximum levels of power losses.
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