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Abstract. Article systematically considers the main aspects of the cost efficiency field of innovative projects introducing solar radiation as an alternative energy source. The article offers a proprietary methodology of cost efficiency analysis for solar panels installation using the intensity of solar radiation (insolation). The calculations carried out using this method determined the amount of annual economic benefit of installing innovative solar panels.

Introduction

Today, business structures are the main consumers of energy resources. The demand for energy and energy carriers is constantly increasing. One of the main indicators of scientific and technological progress is energy efficiency of labor. During the evolutionary development of production potential up to the end of the 21st century, the main energy source was the combination of human and animal power, as well as burning wood and organic waste. The share of energy consumption in the world was 90% in 1850. This decline trend by 10% was noticeable by 1910. ¾ of energy was obtained in the first quarter of the 20th century due to the burning of hard coal. After the Second World War, oil and gas became dominant in energy consumption. At present, the share of energy consumption is more than 75% of global energy consumption. Currently, the energy of rivers and waterfalls, sea and ocean waves, winds, nuclear energy, solar radiation energy, and geothermal energy is efficiently used while improving the use of modern technologies and innovative materials [6].

Recent achievements and publications analysis, where the solution of this problem has been initiated, the identification of previously unresolved parts of the general problem that this article is devoted to

Energy consumption increase is one of the main features in technological development of human activity in the scientific literature.

Experimental studies of the solar batteries use have shown that the their application effectiveness depends primarily on favorable conditions (temperature, humidity, air mass, the solar daylength, the amount of solar energy input) and the coordinates of the given surface.

The works of Asimov A.M., Aristova G.A., Berman E.Yu., Vershinsky N.V., Kirillin V.A., Konovalova V.K., Kononova Y.D., Konstantinova I.A., Koshkina N.L., Magomedova A.M., Movsumova E.A., Pantskhava E.S., Perova L.A., Petelina N.A., Poppel O.S., Fateeva E.M. [10, 11, 14] consider the feasibility study of solar batteries use.

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The obtained results are fundamental from the point of view of the cost-effectiveness analysis methodology of innovation and investment projects efficiency. At the same time, the scientific researches in the cost efficiency analysis of innovative and investment projects field related to the introduction of alternative energy sources, are quite scarce [1, 2]. The cost efficiency analysis approaches proposed in these works do not fully take into account the introduction and operation specifics of such devices, as well as factors that affect their efficiency. In this regard, the development of methodological recommendations for cost efficiency analysis of the introduction of alternative energy sources is of high scientific and practical importance.

In the solar converters operation that create direct modification of solar energy into electrical energy due to semiconductor photocells, the efficiency coefficient of the photocell, which equals the ratio of the maximum electricity power obtained using a photovoltaic panel to the power entering the open area of the photocell sunbeam [14]. Insolation significantly depends on the area latitude, season and the time of day, the atmosphere transparency, the underlying surface nature and other factors. Experimental studies of solar battery use have shown that its efficiency depends, first of all on favorable conditions (temperature, humidity, air mass, solar day quantity, and the solar day length, the amount of solar energy input) and the given surface coordinates [9].

Objective formulation of and setting work targets

The aim of the study is to develop a methodology for cost efficiency analysis in the field of solar batteries using the solar radiation intensity, i.e. insolation.

In this regard, the following scientific tasks can be formulated:

– analyze geographical location and climatic conditions;
– provide the conditions for the solar battery location and the taken object characteristics;
– provide and analyze the power calculation results of solar radiation and energy generation;
– calculate the economic benefit of solar batteries introduction.

Main research material presentation with full justification of the obtained scientific results, providing recommendations

Enterprise development requires significant investments that are a major part of the strategic importance for economic growth. Despite the fact that capital investments aim to develop and modernize manufacturing, that is, to improve its cost efficiency, the assessment of capital investments efficiency can be done by other methods than economic ones. Thus, for example, capital investments can be directed to increase the environmental friendliness of manufacturing, development of knowledge-intensive industries, creation of social infrastructure. All these capital investments can be expensive today and provide an expected social and economic impact only in a few years, but without them, it is impossible to fully economic development. Investments must return in bigger amount including savings for capital investments to be efficient. From this point of view, capital investment should increasingly meet the society needs and create conditions for the production of a public product with an acceptable consumer price at the lowest cost of public labor.

One of the modernization sources is the use of cheaper energy sources, the use of more efficient technological processes and equipment, forms of labor organization and management in accordance with the achievements of scientific and technological progress. According to experts, up to 30% of the primary energy resources consumed in Russia can be economically justified substituted with the use of non-traditional renewable energy technologies that is about 270 million tons of oil equivalent annually.

The generation amounts of renewable energy sources are constantly increasing. The structure of renewable energy production is as follows (in descending order): wind farms (60 tons of oil equivalent (energy measurement unit) or 19%), small hydroelectric station (65.2 tons of oil equivalent, or 20%), biomass (35 tons of oil equivalent, or 11%), solar power plants (12 tons of oil equivalent, or 4%) (refer with Figure 1) [5].

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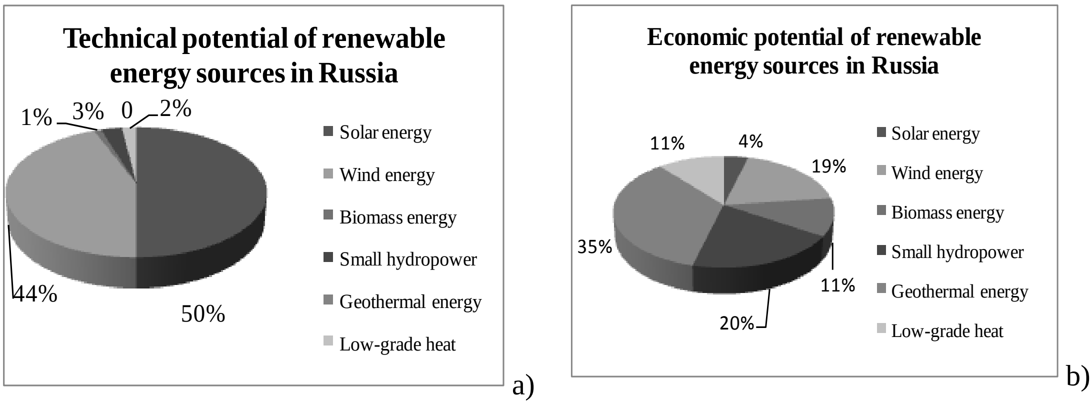

Figure 1. Renewable energy potential in Russia: *a* – technical potential of renewable energy sources in Russia; *b* – economic potential of renewable energy sources in Russia

Energy resources tariffs increase annually. Thus, despite the decline in production, energy consumption is constantly increasing. First of all, it is connected with power equipment losses. At the same time, the constant cost increase of purchased energy raises the question of using cheaper energy resources [3].

Calculations carried out using the method of cost efficiency analysis in the field of solar batteries introduction using the resource of solar radiation intensity, were carried out for Open Joint-stock Company «Klintsovsk bread-baking complex» [6]. The energy consumption dynamics at the enterprise is shown in Table 1.

Table 1. Dynamics of energy consumption at the enterprise [tons, thousand kW*h / year]

Years	Production, [tons]	Energy consumption, Thousand, [kW*h / year]
2015	16205	1190
2016	16193	1452
2017	15108	1336
2018	12495	1440

Investments in the installation of solar batteries will be calculated using the following formula:

$$E_{CI\,SP} = \frac{N{*}Ins.st.r{*}P_{m^2}}{Ins.ф.{*}N_{m^2}} + E_{tr} + E_{in}\text{, where} \tag{1}$$

where *N* is a required power of solar batteries, W;
Ins.ф is an insolation for the studied region, W/m^2;
Ins st.c – insolation for standard conditions, W/m^2;
Nm^2 is a solar batteries power with 1 m^2, W/m^2/year;
Pm^2 is a price of 1 m^2 of solar batteries, rub.;
Etr. is a solar batteries transportation cost, rub.;
Ein is a solar panel batteries cost, rub.

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In this innovative and investment project, capital costs include investments related to the solar batteries purchase, their delivery and installation, i.e. the initial cost.

Total equipment cost excluding installation and delivery is calculated using the following formula:

$$W_{IC\ SP} = \frac{N * Ins.st.r * P_{m^2}}{Ins.ф. * N_{m^2}} \qquad (2)$$

Business project calculation will be done for substituting 30% of traditional energy sources with solar panels. The annual energy enterprise demand with monthly breakdown is presented in Table 2.

Table 2. Enterprise energy consumption by months of the year [kW*h]

Month	Consumption, [kW*h]	Month	Consumption, [kW*h]
January	142.560	July	82.230
February	123.530	August	91.120
March	114.950	September	93.000
April	109.580	October	91.500
May	93.000	November	124.530
June	95.244	December	101.390
Total annual, [kW*h]	1.262.634	30% of the cost of the total amount of energy demand, [kWh*h]	378.790

Table 2 shows that the power of solar batteries should be 378,790 kW*h. The amount of produced energy defines the cost efficiency of the solar batteries installation, which in turn depends on the climatic conditions in a particular region.

The presence of such resource as the intensity of solar radiation, i.e. insolation, is due to the use of solar batteries. Due to the fact that under standard conditions, insolation is defined in the technical data sheet of solar batteries electrical characteristics and is 1,000 W/m^2, however, the value in different regions can significantly differ from standard conditions. Therefore, we need to calculate the actual insolation value for a specific region. Each region of the Russian Federation has web sites with weather and related data archive. We need to find the average annual insolation using the arithmetic mean formula for a period of at least 5 years. Based on the calculation for 5 years, the average annual insolation per day for Bryansk region according to the data of Bryansk regional center for hydrometeorology and environmental monitoring is presented in the table 3.

Table 3. Average monthly insolation value for Bryansk region [kW/m^2/day]

Month	Average insolation on the horizontal surface [kW/m^2/day]	Month	Average insolation on the horizontal surface [kW/m^2/day]
January	0.97	July	5.39
February	1.23	August	4.65
March	3.35	September	3.04
April	4.04	October	1.69
May	5.1	November	0.98
June	5.32	December	0.68
Average annual value, kW/m^2/day 2.585			

Potentially generated energy value in kW per year for Bryansk region will be 2.585 kW/m^2 day * 365 days = 943 kW/m^2/year, i.e. the value of the actual insolation differs from the insolation in standard conditions by 57 kW. The area occupied by solar batteries within the plant depends on the energy-required amount for the plant operation and, consequently, of the batteries size that capture the energy.

The power of solar batteries with 1 m^2 will be calculated based on the technical passport data. 235 W battery will produce about 150 W per hour. In the conditions of Bryansk region, on average (including cloudy days) the specified power solar batteries will produce energy during 5.5 hours per day (i.e. 150 * 5.5 * 365/1000 = 301.125 W/m^2 /year). The price of 1 m^2 of solar batteries will be: 26070/(1,18*1,6) = 13,808.26 thousands rub. The capital costs calculation is presented in table 4.

Table 4. Capital expenditure indicators

Indicator name	Value
Required power SB (30% of 1,263,624), [kW/h/year]	378.790
Insolation for the region under research, [W/m^2/year]	943
Insolation for standard conditions, [W/m^2/year]	1.000
Solar battery power with 1m^2, [Wv^2]	301.125
Price for 1m2 solar panels, [rub]	13.808
Transportation costs, [rub]	6.000
Cost of installation works, [rub]	10.000
$E_{CAP\ SB}$, [rub]	18.108.873

High initial investment costs are a major obstacle to the increased use of solar batteries. This is due to the fact that the energy prices produced by traditional fuel generators currently do not reflect the actual full cost, including the external costs of population living in conditions of environmental degradation caused by traditional fuel use [8, 12]. Another obstacle is that renewable energy technologies, as many other creative technologies, suffer from an initial lack of trust among investors and users [7].

The solar batteries possibilities to generate electricity became known more than a century ago. However, the most serious progress in this area has been observed only in recent decades. New technologies play a key role in the development of solar energy, allowing the production of batteries with an increasing efficiency. STP leads to significant resource savings and reduces the natural materials role in economic development replacing them with synthetic raw materials [4]. Modern equipment and technologies use together led to the creation of flexible production systems, which are widely used in production. We will find the dependence function of the solar batteries efficiency on the year of their introduction (T) in mass production, the efficiency of SB (T) = 107 -20e 0.0243* T, which diagram is shown in Figure 2.

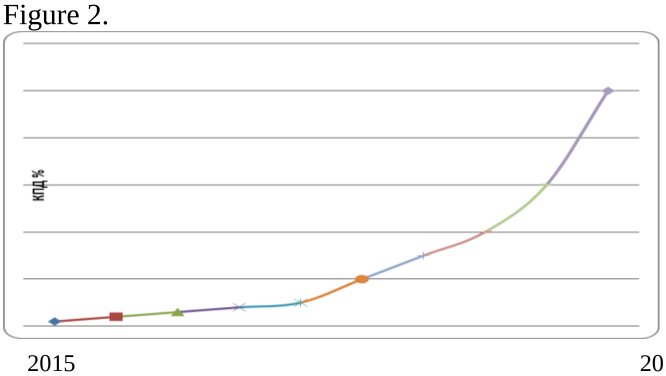

Figure 2. Dependence of solar batteries efficiency on the year of their introduction in mass production

The function can be used to predict the power of innovative solar batteries in the future. To do this, it is necessary to adjust the power of modern innovative solar batteries to the projected value of efficiency gains.

Annual operating costs associated with the introduction of solar batteries will be estimated using the following formula:

$$E_{CE\ SP} = \frac{\frac{N*Ins.st.r.*P_{m^2}+C_{tr}+C_{in}}{Ins.ф.*N_{m^2}}}{T_d} + E_m + H_p + E_{re}, \text{ where} \quad (3)$$

where:

T_a is a depreciation period, years;

E_m are the maintenance costs (snow removal, equipment repair, etc.), rub.;

H_p is a property tax, rub.;

E_{re} are the staff retraining costs, rub.

Table 5. Indicators to calculate the current costs of the solar panel project using solar radiation intensity [rub/year, rub]

Sr.No.	Indicator name	Value
1	Depreciation, [rub/year]	953.099
2	Maintenance costs, [rub/year]	0
3	Property tax, [rub/year]	199.197.6
4	Staff retraining costs, [rub]	20.000
5	$E_{CUR\ SB,\ [}$rub/year]	1.172.296

According to the conducted studies, the given costs for innovative and investment projects of solar panels installation are determined by the formula:

$$E_{\text{FIXED CHARGE SB}} = \left(\frac{N*Ins.st.r.*P_{m^2}}{Ins.ф.*N_{m^2}} + E_{tr} + E_{in}\right) * \frac{r\%}{100\%} + \frac{\frac{N*Ins.st.r.*P_{m^2}}{Ins.ф.*N_{m^2}}+E_{tr}+E_{in}}{T_d} + E_m + H_p + E_{re}, \quad (4)$$

where r — rate of return, %

$E_{\text{FIXED CHARGE SB}}$ = (18,108,872.56 * 0.08) + 117,226.15 = 2 621 006 rub.

To analyze the cost efficiency of the solar batteries installation, we compare the cost of the basic option of power supply and the proposed option. The annual economic impact indicator shall be used for this purpose. According to the conducted studies, the annual economic benefit of the solar batteries introduction is determined by the formula:

$$E_{SP} = E_{\text{FIXED CHARGE SB}} = \left(\frac{N*Ins.st.r.*P_{m^2}}{Ins.ф.*N_{m^2}} + E_{tr} + E_{in}\right) * \frac{r\%}{100\%} + \frac{\frac{N*Ins.st.r.*P_{m^2}}{Ins.ф.*N_{m^2}}+E_{tr}+E_{in}}{T_d} - -E_m - H_p - E_{re} \quad (5)$$

The fixed charge costs for traditional energy sources will be estimated as the cost of the tariff per 1 kW*h, taking into account the maintenance cost and networks depreciation multiplied by the amount of energy required (the tariff for industrial enterprises in Bryansk region per 1 kWh is 3.43 rub/kW*h; other costs 0.74 rub/kW*h). The fixed charge costs for traditional energy sources will be 372,072 * 4.02 = 1,495,729.44 rub./year. According to calculations carried out by the method of cost efficiency analysis, the annual economic benefit of innovative solar batteries installation is: - 1,125.28 thousands rub.

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Summary

Energy consumption increase is one of the main features of modern development in scientific, technical and economic activity of humankind. Currently, various types of energy are used efficiently: energy of rivers, waterfalls, sea and ocean waves, wind, nuclear energy, solar energy, geothermal energy in the process of improving the modern technologies use and innovative materials. The developed methodology allows to solve the problem of cost efficiency analysis of solar panels batteries both in modern conditions and for future periods.

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