ECONOMIC EFFICIENCY OF RUSSIAN RENEWABLE ENERGY PROJECTS IN THE CONTEXT OF STATE SUPPORT OF THE SECTOR

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ABSTRACT
A current global trend in the development of renewable energy (RES) is the phasing out of state support and the transition of this sector to an exclusively competitive market. The question however is, when, among other things, it would be possible for such projects to achieve self-sufficiency. Therefore, the main goal of this work is to study the economic efficiency of Russian RES projects as a prospect for their functioning outside of state support programs. Fifty-two solar, wind, and hydropower projects, which have received support in the form of a capacity-based support scheme in 2018–2020, were selected as the objects of research. The methodological basis of this work is the classical method of investment analysis, supplemented by an industry-specific approach. The efficiency assessment was carried out for the 15-year period of projects' state support, as well as for the entire designed operation period of power plants. The dependence of the projects' economic effect on a combination of factors, including the type of project, the commissioning period, regional affiliation, capital expenditures, etc., were studied. Based on the results of the analysis, the conclusions about the current unpreparedness of the Russian RES sector to operate in a competitive market were substantiated; proposals for the development of programs to support the sector were formulated. A unique factor that has a significant impact on the achievement of a positive economic effect by such projects – the value of specific capital expenditures – was identified. The obtained research results are of practical and methodological significance. They will be used in the development of a methodological approach to assess the effectiveness of the rejection by the Russian RES market of state support tools at certain stages of the projects.
Keywords: capacity-based support scheme, capital expenditures economic efficiency, energy market, hydroelectric power, investment analysis, renewable energy, solar power, state support, wind power.

1 INTRODUCTION

State support for the development of the renewable energy (RES) market in Russia began to be provided in 2013 and will be available till 2024 [1]. The main tool is a program for preferentially priced capacity contracts for the wholesale market (CPS RES) [2]. The program envisages competitive selection of projects for the construction of RES generating facilities and the signing of CPS RES on the selected projects. This program covers solar, wind, and small hydroelectric power plants. Moreover, the law introduces a number of target indicators for the types of projects [1, 3]: the maximum value of specific capital expenditures (per 1 kW of installed capacity), the volume of new capacity put into service, the degree of localization, and the volume of exports.

Currently, it is being decided whether to extend this program for the period 2025–2035. According to preliminary estimates, it will allow the commissioning of RES generation with a total installed capacity of more than 6.7 GW. This decision is due to the success of the initial program, as well as the need to integrate Russian energy into global trends in the development of energy systems, and to increase its environmental friendliness. However, locally this trend does not have the support of all parties involved. On the one hand, experts predict that Russian consumers will have to pay about 1.63 trillion rubles for green energy by 2024 ($21.5 billion at the current exchange rate). In this regard, consumers advocate the abolition

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of state support for such programs [4]. On the other hand, the Ministry of Economy of the Russia proposed to cut the budget of the new program by half from 400 to 200 billion rubles, as well as to tighten sanctions for the failure to meet the requirements for localization and export volumes [5].

There is, therefore, an urgent task to study the possibility of a gradual reduction in the volume of state support for RES within the context of the development of the Russian energy market. This article hypothesizes that such programs can only be scrapped if the sector's projects do not achieve self-sufficiency on a permanent basis. Therefore, the main aim of the work is to assess the economic efficiency of projects, as well as to study factors that have the most significant impact on the economic results achieved. Fifty-two Russian projects were selected as objects; these were received under the program CPS RES in 2018–2020.

This problem and goal determined the following structure of the article. The second section describes a method for assessing the economic efficiency of Russian projects based on classical investment analysis and taking into account the industry specifics of calculating capacity charges in such projects. Further on, in the third section, a brief description of the studied Russian RES projects is given, including their type, affiliation, investment volumes, technical features, etc. A practical assessment of the economic efficiency of the projects was carried out in the fourth section using the indicator of net present value within the time frame of the implementation of CPS RES and full operation of power facilities. The fifth section presents the results of a pairwise regression analysis of factors affecting the economic outcome of these projects. The 'Conclusion' part summarizes the main results of the article; rational conclusions were drawn about the current impossibility of the Russian RES market to refuse state support, and directions for adjusting such programs by project types were proposed.

2 A METHOD FOR ASSESSING THE ECONOMIC EFFICIENCY OF RUSSIAN RES PROJECTS

The basic approach to assess the effectiveness of RES projects is the classical method of assessing economic efficiency, which is the most common in the world industry practice, based on the NV, NPV, and IRR indicators, as well as the additional criteria of PP (PP′) and DPP (DPP′) [6–12], where NV is Net Value, NPV is Net Present Value, IRR is Internal Rate of Return, PP is Payback Period, PP′ is Exact Payback Time, DPP is Discounted Payback Period, and DPP′ is Exact Discounted Payback Time.

This approach is complemented by national guidelines for calculating the share of costs to be reimbursed by payment for the capacity of generating facilities operating on the basis of renewable sources (presented further in section 2.1).

2.1 Calculation of the capacity price

The Decree of the Government of the RF N449 'On the mechanism for stimulating the use of renewable energy sources in the wholesale market of electric energy and capacity' [13] regulates the rules for determining the price for the capacity of generating facilities operating on the basis of RES. In this paper, calculations were carried out according to the methodology adopted for projects selected before 1 January 2021.

Thus, the price for the capacity of a generating facility is defined as the multiplication of the share of costs compensated by the capacity fee and the total costs, including capital expenditures, operational expenditures, and property tax costs.

The planned amount of *capital expenditures* to be compensated is stated in documentation for the competitive selection of projects approved by a competition commission and subsequently adjusted in accordance with the provided coefficients. In particular, the target indicator of the degree of production localization is used, which is equal to

- 1 – if the actual degree of localization exceeds or equals the value of the target indicator.
- 0.35 – for the solar power plant, if the actual degree of localization is below the value of the target indicator.
- 0.45 – for the wind or hydroelectric power plant, if the actual degree of localization is lower than the value of the target indicator.

The second adjustment is made on the basis of the profit coefficient from the wholesale electricity and capacity market (after the payback period and before the end of the service life of the generating facility):

- 0.99 – for the solar power plant.
- 0.9 – for the wind or hydroelectric power plant.

The value of specific *operational expenditures* is set as of 1 January 2012 by type of generating facilities and is indexed for each subsequent period in accordance with the official consumer price index:

- For the solar power plant – 170 thousand rubles/mW per month.
- For the wind power plant – 118 thousand rubles/mW per month.
- For the hydroelectric power plant – 100 thousand rubles/mW per month.

As a result, the calculation of the component of the price for the capacity of facilities that ensures the return of capital and operational expenditures is done using eqn (1):

$$CP_i = \frac{\frac{R_i \cdot RR_{i-1}}{1-IT} + r_i}{12} + EC_i \,, \tag{1}$$

where CP_i is the price of capacity, which ensures the return of capital and operational expenditures in the i-th year; R_i is the amount of invested capital at the beginning of the i-th year; RR_{i-1} is the rate of return on invested capital for the previous i-th year; IT is income tax rate; r_i is the amount of return on invested capital in the i-th year; and EC_i is the multiplication of the value of the operational expenditures of the i-th year and the share of costs compensated by the payment for the capacity of generating facilities.

The rate of return for the i-th year is calculated using eqn (2):

$$RR_i = \frac{(1+RR_b)\cdot(1+LTGO_i)}{1+LTGO_b} - 1 \,, \tag{2}$$

where RR_i is the rate of return on capital invested in the unit for the i-th year; RR_b is the basic level of the rate of annual return on invested capital, equal to 12%; $LTGO_i$ is average profitability of long-term government bonds; and $LTGO_b$ is the basic level of annual profitability of long-term government bonds, equal to 8.5%.

The calculation of the amount of return on invested capital in the *i*-th year is done using eqn (3):

$$r_i = \frac{R_i \cdot RR_{i-1}}{\left(RR_{i-1}+1\right)^{16-i}-1} \tag{3}$$

The amount of invested capital at the beginning of the *i*-th year (for *i* from 2 to 15) is calculated using eqn (4):

$$R_i = R_{i-1} - r_{i-1} + \left(RR_{i-1} - RR_{i-2}\right)\cdot\left(1+RR_{i-1}\right)\cdot R_{i-1} \tag{4}$$

where R_{i-1} is the amount of invested capital at the beginning of the year preceding the *i*-th year and r_{i-1} is the amount of return on invested capital in the year preceding the *i*-th year.

Property tax costs are calculated in accordance with the value of the property and the current tax rate. This amount is adjusted for the preliminary share of costs (PSC), compensated by the payment for the capacity of generating facilities:

- PSC equals 0 if the ratio of the projected profit from the sale of electricity to the total costs of the supplier for the *i*-th year is greater than 1.
- PSC equals 1 if this ratio for the *i*-th year is lower than 0.
- PSC is (1 – the ratio) if this ratio for the *i*-th year is from 0 to 1.

Then this indicator is adjusted in regard of the coefficient of the generating facility load (CGFL), the installed capacity utilization coefficient (ICUC), and the power consumption factor for own/household needs (equal to 1.005 for all types of generation):

- CGFL equals 0 if the growth rate of the ICUC has not exceeded 0.5.
- CGFL equals 0.5 if the growth rate of the ICUC has not exceeded 0.75.
- CGFL equals 1 if the growth rate of the ICUC has exceeded 0.75.

3 BRIEF DESCRIPTION OF THE PROJECTS

For the period 2018–2020, 52 RES projects were competitively selected and approved for implementation [14], including 34 wind energy (wind power plants [WPP]), 11 solar energy (solar power plants [SPP]), and 7 hydropower projects (small hydroelectric power plants [SHPP]). Their brief characteristics are presented in Table 1.

The projects were geographically spread across 16 regions of Russia and initiated by 10 companies. The presented projects belong mainly to the first price zone of the wholesale electricity market (the territories of the European part of Russia and the Urals [15]), with the exception of two SPP projects implemented in the Altai Republic (the second price zone [15]). All projects differ significantly in terms of initial installed capacity, as well as the amount of specific capital expenditures. For SHPP projects, this indicator usually exceeds similar values of WPP and SPP by 100–200%, which is due to the higher capital intensity of hydropower facilities.

4 PRACTICAL ASSESSMENT OF THE ECONOMIC EFFICIENCY OF RES PROJECTS

To carry out an assessment for two time spans, it should be noted that CPS RES state support for all projects is provided for a period of 15 years, the accepted full service life is 25 years for WPP and SPP, and 40 years for SHPP [13].

Table 1: Characteristics of Russian renewable energy projects (competitive selection 2018–2020).

N	Project name	Year of selection	Year of commissioning	Region	Initiator company	Price zone	Installed capacity, MW	Specific capital expenditures, thousand rubles/ kW
1	Experimental WPP-121	2020	2024	Krasnodar region	JSC 'WindSGC-2' (Moscow)	First	20	65
2	Experimental WPP-127		2024	Krasnodar region		First	15	65,05
3	Experimental WPP-130		2024	Krasnodar region		First	40	65
4	Experimental WPP-128		2024	Krasnodar region		First	22.5	65
5	Experimental WPP-125		2024	Krasnodar region		First	20	65
6	Experimental WPP-129		2024	Krasnodar region		First	40	65
7	Experimental WPP-131		2023	Krasnodar region		First	35	65
8	SHPP-1_1		2024	Murmansk region	PJSC 'TGC-1' (Saint-Petersburg)	First	16.5	192
9	Bashennaya SHPP		2024	Chechen Republic	PJSC 'RusHydro' (Moscow)	First	10	193,64
10	SHPP Psygansu		2024	Kabardino-Balkarian Republic		First	19.1	194,639
11	Stavropol WPP-24	2019	2024	Stavropol region	PJSC 'Enel Russia' (Moscow)	First	71.25	64,867

12	SHPP Segozerskaya		2022	Republic of Karelia	LLC 'EuroSibEnergo-Hydrogeneration' (Irkutsk)	First	8.1	175,948
13	SPP-2022-1		2022	Stavropol region	PJSC 'Fortum' (Moscow)	First	5.6	49,788
14	SPP-2018-1	2018	2019	Altai Republic	LLC 'Avelar Solar Technology' (Moscow)	Second	10	122
15	SPP-2018-2		2019	Altai Republic		Second	5	122,001
16	SPP-2018-3		2019	Republic of Kalmykia		First	23.5	122,002
17	Astrakhan SPP		2021	Astrakhan region	PJSC 'Fortum' (Moscow)	First	18	58,984
18	Kalmykia SPP		2021	Republic of Kalmykia		First	15	62,109
19	Saratov SPP		2021	Saratov region		First	15	62,805
20	Orenburg SPP		2021	Orenburg region		First	15	69,453
21	Privolzhskaya SPP		2021	Republic of Bashkortostan		First	15	69,853
22	Privolzhskaya SPP-1		2022	Republic of Bashkortostan		First	17	58,901
23	SPP Kalmykia		2022	Republic of Kalmykia		First	15	59,103
24	SHPP Prosyanskij sbros BSK		2020	Stavropol region	LLC 'EnergoMIN' (Budennovsk)	First	7	174,473
25	Gorko-Balkovskaya SHPP		2020	Stavropol region		First	9	174,473

(*Contiued*)

Table 1: Characteristics of Russian renewable energy projects (competitive selection 2018–2020). (*Cont.*)

N	Project name	Year of selection	Year of commissioning	Region	Initiator company	Price zone	Installed capacity, MW	Specific capital expenditures, thousand rubles/kW
26	Nizhne-Krasnogorskaya SHPP		2023	Karachay-Cherkess Republic	LLC ‘Yuzhenergo-stroy’ (Cherkessk)	First	23.728	174,473
27	WPP WindFarm-35		2019	Republic of Kalmykia	LLC ‘Vetroparki FRV’ (Moscow)	First	19	80,305
28	WPP WindFarm-34		2019	Republic of Kalmykia		First	22.8	81,104
29	WPP WindFarm-36		2019	Republic of Kalmykia		First	19	81,205
30	WPP WindFarm-31		2019	Rostov region		First	19	80,609
31	WPP WindFarm-32		2019	Rostov region		First	19	81,201
32	Experimental WPP-67		2021	Krasnodar region	JSC ‘WindSGC-2’ (Moscow)	First	10	130,926
33	Experimental WPP-52		2021	Krasnodar region		First	20	93,028
34	WPP WindFarm-41		2021	Republic of Kalmykia	LLC ‘Vetroparki FRV’ (Moscow)	First	37.8	59,339
35	WPP WindFarm-42		2021	Republic of Kalmykia		First	37.8	59,339
36	WPP WindFarm-37		2021	Rostov region		First	37.8	59,339
37	WPP WindFarm-38		2021	Rostov region		First	37.8	59,339
38	WPP WindFarm-48		2021	Astrakhan region		First	37.8	59,339

39	WPP WindFarm-49	2021	Astrakhan region	First	37.8	59,339
40	WPP WindFarm-61	2023	Perm region	First	38.7	63,004
41	WPP WindFarm-59	2023	Perm region	First	37.8	68,555
42	WPP WindFarm-60	2023	Perm region	First	37.8	68,555
43	WPP WindFarm-57	2023	Perm region	First	37.8	68,555
44	WPP WindFarm-58	2023	Perm region	First	37.8	68,555
45	WPP WindFarm-52	2023	Orenburg region	First	37.8	62,209
46	WPP WindFarm-51	2023	Orenburg region	First	37.8	62,911
47	WPP WindFarm-71	2023	Republic of Kalmykia	First	38.7	62,406
48	WPP WindFarm-74	2023	Volgograd region	First	38.7	62,41
49	WPP WindFarm-75	2023	Volgograd region	First	38.7	68,555
50	WPP WindFarm-78	2023	Stavropol region	First	38.7	68,555
51	WPP WindFarm-82	2023	Astrakhan region	First	38.7	68,555
52	WPP WindFarm-83	2023	Astrakhan region	First	38.7	70,801

The information and methodological basis for the assessment was drawn from the sources [13, 16–18]. The results of the practical assessment are presented in Table 2.

4.1 Wind energy projects

Among the 34 wind energy projects, only 11 power plants achieved a positive economic effect during the 15-year period of the CPS RES program and 33 facilities achieved a positive economic effect during their planned full operation lifecycle. The only project that has not achieved a positive economic effect is characterized by extremely high specific capital expenditures – 130,926 thousand rubles/kW, with an installed capacity of 10 MW. It is being implemented in the Krasnodar Territory (the first price zone). For comparison, the average amount of specific capital expenditures in 2020 and 2019 was 65 thousand rubles/kW, and in 2018, 71 thousand rubles/kW.

4.2 Solar energy projects

Among the 11 solar energy projects, 7 projects achieved a positive economic effect over a 15-year period and 8 over 25 years. Three projects that did not show a positive economic effect even over the full life of the SPP also have high specific capital expenditures – about 122 thousand rubles/kW for each project. The installed capacity of such projects varies significantly: 5 MW, 10 MW (both are in the Altai Republic, the second price zone), and 23.5 MW (the Republic of Kalmykia, the first price zone). For comparison, the average value of specific capital expenditures in 2019 amounted to 49.8 thousand rubles/kW and in 2018 – 80.7 thousand rubles/kW (in 2020, SPP projects were not selected by competition).

4.3 Small hydropower projects

Among the seven hydropower projects, none has achieved a positive economic effect either during the period of state support or over 40 years of full operation. The selected projects are implemented only in the first price zone, characterized by a high level of specific capital expenditures: an average of 193 thousand rubles/kW in 2020, almost 176 – in 2019 and 174.5 – in 2018. The installed capacity of such projects varies from 7 to 23.7 MW.

Figure 1 presents as a graphical interpretation of the results obtained; and the structure of the projects that have achieved an economic effect by year of selection is shown in Fig. 2.

As a result, out of 52 Russian RES projects, a third – 18 plants, including 11 wind power and 7 solar – have achieved a positive economic effect over the 15 years of the CPS RES program. According to the results of the period of full operation, only 20% were ineffective. Taken together, this indicates that at the current stage, the Russian RES sector is not ready to refuse state support.

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The subsequent study of the degree of influence of individual factors on the achievement of positive economic results by such projects (section 5) will justify the possibility of phasing out state support programs for the sector.

Table 2: Assessment of the economic efficiency of Russian renewable energy projects.

		For a 15-year project support period							For the full period of operation of the plant (25/40 years)						
N	Project name	NV, thousand rubles	PP, period	PP', year	NPV, thousand rubles	DPP, period	DPP', year	IRR, %	NV, thousand rubles	PP, period	PP', year	NPV, thousand rubles	DPP, period	DPP', year	IRR, %
1	Experimental WPP-121	1 145 339.30	9	8.68	142 046.48	13	12.28	1.75	2 763 334.09	9	8.68	522 938.44	13	12.28	4.39
2	Experimental WPP-127	860 566.93	9	8.67	107 087.81	13	12.27	1.76	2 076 672.30	9	8,67	393 371.03	13	12.27	4.40
3	Experimental WPP-130	22 90 678.59	9	8.68	284 092.95	13	12.28	1.75	5 526 668.18	9	8.68	1 045 876.88	13	12.28	4.39
4	Experimental WPP-128	1 288 835.34	9	8.68	159 973.95	13	12.28	1.75	3 109 514.36	9	8.68	588 579.78	13	12.28	4.39
5	Experimental WPP-125	1 145 339.30	9	8.68	142 046.48	13	12.28	1.75	2 763 334.09	9	8.68	522 938.44	13	12.28	4.39
6	Experimental WPP-129	2 290 678.59	9	8.68	284 092.95	13	12.28	1.75	5 526 668.18	9	8.68	1 045 876.88	13	12.28	4.39
7	Experimental WPP-131	22 10 023.52	9	8.07	345 201.94	12	11.64	2.29	5 041 688.36	9	8.07	1 011 803.82	12	11.64	4.65
8	SHPP-1_1	−585 536.98	No	No	−1 325 168.96	No	No	−10.01	2 862 337.62	22	21.47	−941 320.99	No	No	−3.71
9	Bashennaya SHPP	−90 664.85	No	No	−672 595.00	No	No	−7,82	3 022 890.46	16	15.24	−267 216.43	No	No	−1.48
10	SHPP Psygansu	−382 960.40	No	No	−1 398 686.80	No	No	−8.67	4 828 333.47	18	17.16	−751 192.96	No	No	−2.29
11	Stavropol WPP–24	2 739 247.94	11	10.26	−86 903.02	No	No	−0.36	8 010 359.53	11	10.26	1 153 968.73	15	14.60	3.09

(*Contiued*)

Table 2: Assessment of the economic efficiency of Russian renewable energy projects. (*Cont.*)

		For a 15-year project support period							For the full period of operation of the plant (25/40 years)						
N	Project name	NV, thousand rubles	PP, period	PP', year	NPV, thousand rubles	DPP, period	DPP', year	IRR, %	NV, thousand rubles	PP, period	PP', year	NPV, thousand rubles	DPP, period	DPP', year	IRR, %
12	SHPP Segozerskaya	−208 491.55	No	No	−567 852.93	No	No	−9.36	1 460 252.57	20	19.44	−372 028.73	No	No	−3.16
13	SPP-2022-1	384 610.24	8	7.62	107 754.27	10	9.68	6.10	798 885.49	8	7.62	205 278.76	10	9.68	8.11
14	SPP-2018-1	191 406.72	13	12.28	−343 729.90	No	No	−5.21	680 709.41	13	12.28	−228 543.20	No	No	−2.66
15	SPP-2018-2	95 789.10	13	12.28	−171 819.35	No	No	−5.21	340 546.36	13	12.28	−114 201.07	No	No	−2.66
16	SPP-2018-3	755 469.04	12	11.38	−638 654.76	No	No	−4.00	2 290 331.56	12	11.38	−277 332.96	No	No	−1.29
17	Astrakhan SPP	896 204.40	9	8.93	118 302.00	13	12.25	1.94	1 922 339.39	9	8.93	359 864.31	13	12.25	4.25
18	Kalmykia SPP	814 526.15	9	8.83	118 266.45	13	12.04	2.20	1 796 372.30	9	8.83	349 402.73	13	12.04	4.59
19	Saratov SPP	675 222.29	10	9.35	43 276.93	14	13.20	0.82	1 474 969.19	10	9.35	231 545.25	14	13.20	3.20
20	Orenburg SPP	681 644.73	10	9.59	14 412.52	14	13.75	0.25	1 563 566.37	10	9.59	222 025.59	14	13.75	2.78
21	Privolzhskaya SPP	640 764.46	10	9.76	−8 541.13	No	No	−0.15	1 471 409.06	10	9.76	187 000.81	15	14.38	2.37
22	Privolzhskaya SPP-1	730 817.95	10	9.61	60 527.28	14	13.02	1.14	1 670 326.77	10	9.61	281 696.94	14	13.02	3.73
23	SPP Kalmykia	747 180.53	10	9.26	103 212.98	13	12.28	2.13	1 729 026.67	10	9.26	334 349.26	13	12.28	4.76

24	SHPP Prosyanskij sbros BSK	−56 680.56	No	No	−450 768.73	No	No	−7.79	1 727 703.20	16	15.35	−219 078.61	No	No	−1.89
25	Gorko-Balkovskaya SHPP	−72 909.70	No	No	−579 578.43	No	No	−7.79	2 221 181.14	16	15.35	−281 711.45	No	No	−1.89
26	Nizhne-Krasnogorskaya SHPP	−473 242.34	No	No	−1 366 997.22	No	No	−9.07	5 811 304.65	18	17.24	−587 684.04	No	No	−1.77
27	WPP WindFarm-35	783 392.26	10	9.77	−128 632.36	No	No	−1.43	2 024 541.71	10	9.77	163 546.48	18	17.98	1.29
28	WPP WindFarm-34	929 849.85	10	9.83	−166 725.30	No	No	−1.53	2 419 061.04	10	9.83	183 849.73	19	18.33	1.20
29	WPP WindFarm-36	773 930.12	10	9.83	−140 167.44	No	No	−1.55	2 015 079.57	10	9.83	152 011.40	19	18.37	1.19
30	WPP WindFarm-31	680 887.87	11	10.16	−187 477.34	No	No	−2.11	1 803 208.01	11	10.16	76 727.91	21	20.72	0.62
31	WPP WindFarm-32	674 663.88	11	10.20	−195 064.86	No	No	−2.18	1 796 984.03	11	10.20	69 140.39	22	21.03	0.55
32	Experimental WPP-67	187 328.23	13	12.41	−378 672.75	No	No	−5.37	906 523.97	13	12.41	−209 366.96	No	No	−2.12
33	Experimental WPP-52	596 088.61	12	11.24	−293 682.58	No	No	−3.14	2 034 480.09	12	11.24	44 928.99	23	22.46	0.33
34	WPP WindFarm-41	1 631 738.50	10	9.32	115 420.77	14	13.11	0.92	4 100 834.01	10	9.32	696 670.25	14	13.11	3.77
35	WPP WindFarm-42	1 631 738.50	10	9.32	115 420.77	14	13.11	0.92	4 100 834.01	10	9.32	696 670.25	14	13.11	3.77
36	WPP WindFarm-37	1 458 224.31	10	9.61	26 209.90	14	13.79	0.21	3 690 925.65	10	9.61	551 809.86	14	13.79	3.08
37	WPP WindFarm-38	1 458 224.31	10	9.61	26 209.90	14	13.79	0.21	3 690 925.65	10	9.61	551 809.86	14	13.79	3.08
38	WPP WindFarm-48	1 401 195.17	10	9.71	-3 111.15	No	No	−0.03	3 556 200.52	10	9.71	504 198.40	15	14.05	2.84
39	WPP WindFarm-49	1 401 195.17	10	9.71	−3 111.15	No	No	−0.03	3 556 200.52	10	9.71	504 198.40	15	14.05	2.84

(*Contiued*)

Table 2: Assessment of the economic efficiency of Russian renewable energy projects. (*Cont.*)

N	Project name	For a 15-year project support period							For the full period of operation of the plant (25/40 years)						
		NV, thousand rubles	PP, period	PP', year	NPV, thousand rubles	DPP, period	DPP', year	IRR, %	NV, thousand rubles	PP, period	PP', year	NPV, thousand rubles	DPP, period	DPP', year	IRR, %
40	WPP WindFarm-61	842 711.84	12	11.45	−284 221.07	No	No	−2.58	2 860 993.69	12	11.45	190 902.42	20	19.56	1.15
41	WPP WindFarm-59	710 089.50	12	11.85	−390 705.39	No	No	−3.42	2 681 600.07	12	11.85	73 407.68	23	22.17	0.43
42	WPP WindFarm-60	710 089.50	12	11.85	−390 705.39	No	No	−3.42	2 681 600.07	12	11.85	73 407.68	23	22.17	0.43
43	WPP WindFarm-57	710 089.50	12	11.85	−390 705.39	No	No	−3.42	2 681 600.07	12	11.85	73 407.68	23	22.17	0.43
44	WPP WindFarm-58	710 089.50	12	11.85	−390 705.39	No	No	−3.42	2 681 600.07	12	11.85	73 407.68	23	22.17	0.43
45	WPP WindFarm-52	993 114.48	12	11.08	−187 937.47	No	No	−1.72	3 210 937.86	12	11.08	334 160.06	18	17.22	2.01
46	WPP WindFarm-51	978 807.93	12	11.13	−202 246.01	No	No	−1.84	3 196 631.32	12	11.13	319 851.53	18	17.48	1.91
47	WPP WindFarm-71	1 173 039.52	11	10.80	-119 904.86	No	No	−1.05	3 700 709.49	11	10.80	475 133.62	16	15.76	2.68
48	WPP WindFarm-74	1 044 126.31	12	11.03	−181 530.34	No	No	−1.61	3 365 333.32	12	11.03	364 904.72	17	16.95	2.12
49	WPP WindFarm-75	915 911.37	12	11.45	−309 763.17	No	No	−2.58	3 237 118.38	12	11.45	236 671.90	20	19.24	1.29
50	WPP WindFarm-78	1 185 186.67	11	10.97	−181 130.28	No	No	−1.46	3 937 935.12	11	10.97	466 893.90	17	16.47	2.41
51	WPP WindFarm-82	844 104.62	12	11.60	−344 065.27	No	No	−2.89	3 050 233.92	12	11.60	175 279.37	21	20.23	0.97
52	WPP WindFarm-83	797 242.01	12	11.75	−390 934.42	No	No	−3.22	3 003 371.30	12	11.75	128 410.22	22	21.19	0.70

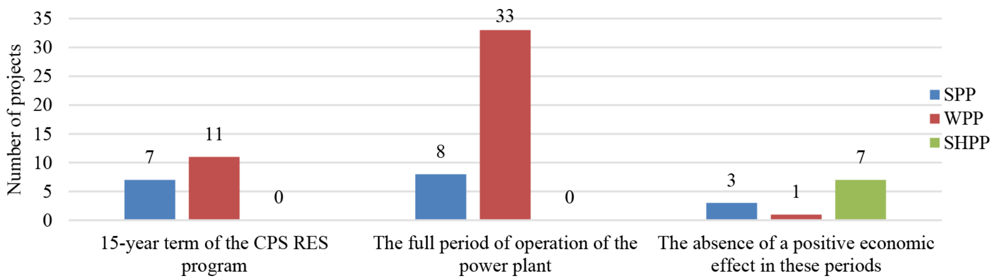

Figure 1: The number of projects that have achieved a positive economic result, by period.

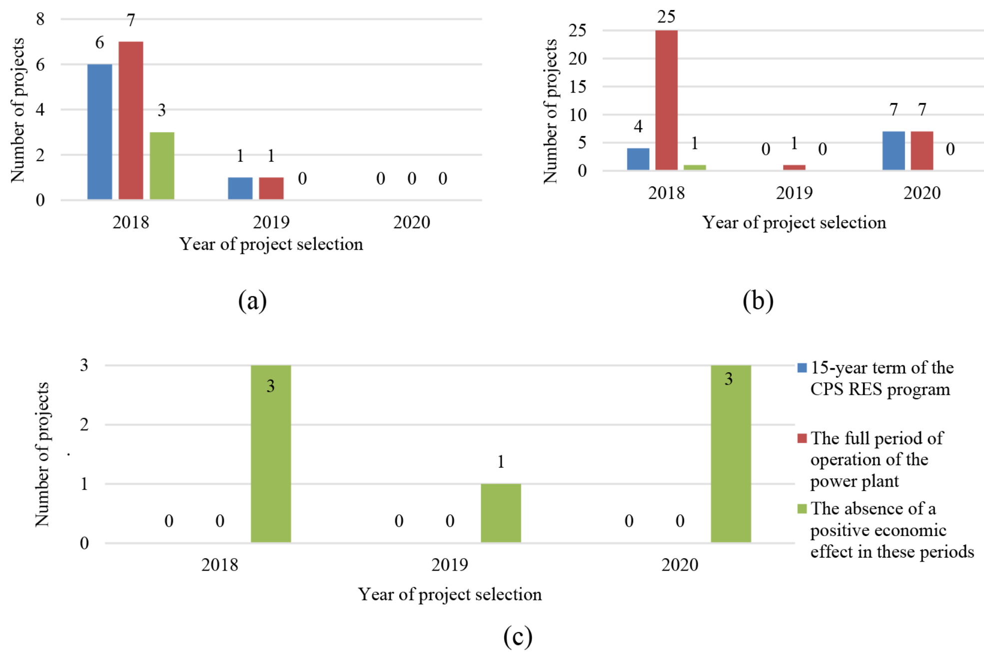

Figure 2: The degree to which the SPP (a), WPP (b), and SHPP (c) projects have achieved a positive economic effect, depending on the year of selection.

5 ANALYSIS OF FACTORS AFFECTING THE ECONOMIC EFFICIENCY OF RES PROJECTS

To identify the factors that have the greatest impact on the economic efficiency of the submitted projects, the following 10 criteria (independent variables) were studied:

- Project type (×1).
- Project selection year (×2).
- Duration of the commissioning period for the plant (×3).
- Year of commissioning (×4).
- Regional affiliation of power facilities (×5).
- Project initiator company (×6).

- Price zone (1 or 2) (×7).
- Installed capacity of the power plant (×8).
- Approved value of specific capital expenditures (×9).
- The volume of investment in the project (×10).

As a dependent variable, the achieved economic effect of the project was selected (NPV indicator). Two types of dependencies have been studied for different project implementation periods: a) for a 15-year period of support through the CPS RES program (y1) and b) during the envisaged full life of the power plant (y2).

Econometric analysis using dummy variables was chosen as the method of the dependency assessment [19, 20]. The results of the pairwise regression analysis are presented in Tables 3 and 4.

Table 3: The impact of 10 variables on the economic effect of renewable energy (RES) projects over 15 years of the CPS RES program (y1).

Independent variable	R^2	Coefficient (Y-intersection)	Coefficient (Independent variable)
×1	0.038288166	0.168967421	0.11374931
×2	0.128226334	0.894551845	–0.214411248
×3	0.325104135	0.904145078	–0.207253886
×4	0.00103289	0.316499782	0.00957771
×5	0.004360781	0.395967378	–0.006038004
×6	0.172805202	0.741489887	–0.057104095
×7	0.021176471	0.72	–0.36
×8	0.007221698	0.425657813	–0.003029659
×9	0.186934893	0.77373052	–0.00493584
×10	0.150333166	0.770430206	–2.12372E-07

Table 4: The impact of 10 variables on the economic effect of renewable energy projects for the full period of operation of plants (y2).

Independent variable	R^2	Coefficient (Y-intersection)	Coefficient (Independent variable)
×1	0.156041976	1.095527333	–0.197128658
×2	0.016004271	0.622144112	0.065026362
×3	0.037529344	0.951208981	–0.06044905
×4	0.007532239	0.85720505	–0.022202873
×5	0.013314401	0.71374124	0.009057006
×6	0.048240111	0.609151455	0.025900345
×7	0.149090909	1.64	–0.82
×8	0.268090222	0.372625433	0.015846274
×9	0.866216408	1.578584314	–0.009120984
×10	0.004297369	0.850040921	–3.08236E-08

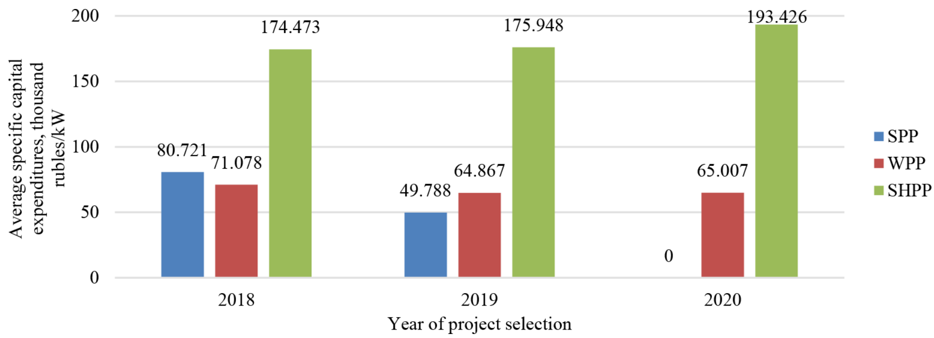

Figure 3: Distribution of the average annual value of specific capital expenditures by type of renewable energy projects*.

*In 2019, one SPP, one WPP, and one SHPP project were selected; in 2020, SPP projects were not selected by competition.

As a result, according to the indicator 'R^2', a very weak influence of these factors on the dependent variable 'y1' was found. Among the factors that have the greatest impact are the duration of the commissioning period for the plant (×3), as well as the amount of specific capital expenditures (×9), the initiator company of the project (×6), and the volume of investments in the project (×10).

When studying the influence on the variable 'y2', other factors come to the fore, such as the installed capacity of the power plant (×8), the type of project (×1), and which price zone it belongs to (×7). However, the maximum impact among all the studied cases on the efficiency of projects was noted to be produced by the factor of specific capital expenditures (×9); the resulting value of 'R^2' exceeds 0.8.

As a result, it is the planned amount of capital expenditures, which is stated in the documentation for the competitive selection of projects and approved by the competition commission, that has the greatest impact on the effectiveness of Russian RES projects. Moreover, the economic efficiency of such projects decreases as the unit capital expenditures increase, and vice versa. The distribution of the average value of this indicator by selection year and project type is shown in Fig. 3.

The presented dynamics of the average annual value of specific capital expenditures as the main factor and the structural analysis of the achievement of a positive economic result by projects (Fig. 2) further justify the ways of phasing out state support programs aiding the Russian RES sector (section 6).

6 CONCLUSIONS

The assessment of RES projects has shown that the Russian sector is currently characterized by a low level of economic effect achieved. Only a third of the 52 announced projects demonstrated a positive result during the 15-year period of the CPS RES program. According to the results of the planned full-service life, 11 power plants did not achieve the required effect. As a result, the refusal of state support for the Russian RES sector is impractical now, provided that it is necessary to ensure its sustainable development.

Based on the results of the pairwise regression analysis, a strict relationship was established between the efficiency of RES projects and the amount of specific capital expenditures for them. The economic efficiency of projects decreases with the growth of this factor and vice versa. The influence of the other nine factors (e.g. type, year of selection/commissioning of projects, regional affiliation, etc.) is estimated as insignificant.

The study of the dependence of the economic efficiency of sector projects solely on the value of specific capital expenditures revealed the following patterns:

- The volume of specific capital in solar energy projects in 2019 is reduced by more than 1.6 times compared to the previous year. As a result, three projects selected in 2018 did not achieve a positive economic effect and one project did so only during its full operational life. The only project selected in 2019 achieved an economic effect in a 15-year period.
- The average specific capital of wind energy facilities is also decreasing by almost 1.1 times compared to 2018 and is set at approximately the same level in 2019 and 2020. This also contributes to more effective implementation of such projects: all of them have achieved a positive economic effect and projects for the selection year 2020 are within the terms of the CPS RES program.
- The exception to the presented dynamics is the SHPP projects. The average volume of specific capital for such facilities is steadily growing (by 1.1 times by 2020), and all projects are economically inefficient even during their full life.

Thus, the gradual reduction of specific capital expenditures by 2020 and the positive dynamics of achieving the economic effect of SPP and WPP projects allow us to talk about the possibility of a subsequent reduction in the terms of providing state support to such energy plants. However, this is possible only if the previous dynamics of specific capital expenditures on them is maintained. A complete rejection of the CPS RES program for SPP and WPP projects is impossible. In the case of the SHPP, support programs should again have longer timeframes and budgets due to the high degree of inefficiency of such projects.

The results obtained will be used in the development and practical testing of the methodological approach to the comprehensive assessment of the effectiveness of Russian sector projects, integrating several types of analysis into a single approach, as well as taking into account the influence of specific uncertainty factors (risks). The purpose of this methodology will be to answer the question about the possibility of implementing Russian projects at the expense of mainly private rather than public investments.

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REFERENCES

[1] Ministry of Energy of Russian Federation, System of state stimulation of electricity storage in Russia [Sistema gosudarstvennogo stimulirovaniya hraneniya elektroenergii v Rossii], 2021. https://minenergo.gov.ru/node/489. Accessed on: 20 December 2021.

[2] Chebotareva, G., Strielkowski, W. & Streimikiene, D., Risk assessment in renewable energy projects: A case of Russia. *Journal of Cleaner Production*, **269**, p. 122110, 2020. https://doi.org/10.1016/j.jclepro.2020.122110

[3] Energy Policy [Energeticheskaya politika], *RES 2.0: A new program for the development of "green" energy in Russia* [VIE 2.0: Novaya programma razvitiya «zelenoj» energetiki v Rossii], 2020. https://energypolicy.ru/a-maksimov-vie-2-0-novaya-programma-razvitiya-zelenoj-energetiki-v-rossii/energetika/2020/17/13/. Accessed on: 10 January 2022.

[4] Kommersant, Green energy is eroding [Zelenaya energetika vyvetrivaetsya], 2017. https://www.kommersant.ru/doc/3342654. Accessed on: 11 January 2022.
[5] Vedomosti, Ministry of Economic Development proposed to cut the renewable energy support program in half [Minekonomrazvitiya predlozhilo urezat' vdvoe programmu podderzhki VIE], 2020. https://www.vedomosti.ru/economics/articles/2020/10/20/843976-minekonomrazvitiya-predlozhilo. Accessed on: 11 January 2022.
[6] Landi, D., Castorani, V. & Germani, M., Interactive energetic, environmental and economic analysis of renewable hybrid energy system. *International Journal on Interactive Design and Manufacturing*, **13(3)**, pp. 885–899, 2019. https://doi.org/10.1007/s12008-019-00554-x
[7] Ghiasi, M., Esmaeilnamazi, S., Ghiasi, R. & Fathi, M., Role of renewable energy sources in evaluating technical and economic efficiency of power quality. *Technology and Economics of Smart Grids and Sustainable Energy*, **5(1)**, p. 1, 2020. https://doi.org/10.1007/s40866-019-0073-1
[8] Diemuodeke, E. O., Addo, A., Oko, C. O. C., Mulugetta, Y. & Ojapah, M. M., Optimal mapping of hybrid renewable energy systems for locations using multi-criteria decision-making algorithm. *Renewable Energy*, **134**, pp. 461–477, 2019. https://doi.org/10.1016/j.renene.2018.11.055
[9] Herbes, C., Roth, U., Wulf, S. & Dahlin, J., Economic assessment of different biogas digestate processing technologies: A scenario-based analysis. *Journal of Cleaner Production*, **255**, p. 120282, 2020. https://doi.org/10.1016/j.jclepro.2020.120282
[10] Trovato, V. & Kantharaj, B., Energy storage behind-the-meter with renewable generators: Techno-economic value of optimal imbalance management. *International Journal of Electrical Power and Energy Systems*, **118**, p. 105813, 2020. https://doi.org/10.1016/j.ijepes.2019.105813
[11] Zhang, Y., Yuan, J., Zhao, C. & Lyu, L., Can dispersed wind power take off in China: A technical & institutional economics analysis. *Journal of Cleaner Production*, **256**, p. 120475, 2020. https://doi.org/10.1016/j.jclepro.2020.120475
[12] Karmaker, A. K., Ahmed, M. R., Hossain, M. A. & Sikder, M. M., Feasibility assessment and design of hybrid renewable energy based electric vehicle charging station in Bangladesh. *Sustainable Cities and Society*, **39**, pp. 189–202, 2018. https://doi.org/10.1016/j.scs.2018.02.035
[13] Decree of the Government of the Russian Federation No. 449, On the Mechanism for Stimulating the Use of Renewable Energy Sources in the Wholesale Electricity and Capacity Market [O mekhanizme stimulirovaniya ispol'zovaniya vozobnovlyaemyh istochnikov energii na optovom rynke elektricheskoj energii i moshchnosti], 2021. https://base.garant.ru/70388616/#block_45. Accessed on: 01 November 2021.
[14] AtsEnergo, Project selection results [Rezul'taty otborov proektov], 2021. https://www.atsenergo.ru/vie/proresults. Assessed on: 01 September 2021.
[15] Association NP "Market Council", Geography of the Russian electricity market [Geografiya rossijskogo elektroenergeticheskogo rynka], 2021. http://ais.np-sr.ru/iasen/information/IASE_0V_R0_OVERALL#0/0/OVERALL. Accessed on: 12 December 2021.
[16] InterRAO, Methodological features of evaluating the effectiveness of projects in the electric power industry [Metodicheskie osobennosti ocenki effektivnosti proektov v elektroenergetike], 2008. https://library-full.nadzor-info.ru/doc/51123. Accessed on: 01 September 2021.

[17] Association NP “Market Council”, Regulations for determining the parameters necessary for calculating the price under contracts for the provision of capacity of qualified generating facilities operating on the basis of the use of renewable energy sources [Reglament opredeleniya parametrov, neobhodimyh dlya rascheta ceny po dogovoram o predostavlenii moshchnosti kvalificirovannyh generiruyushchih ob”ektov, funkcioniruyushchih na osnove ispol’zovaniya vozobnovlyaemyh istochnikov energii], 2016. https://www.np-sr.ru/sites/default/files/sr_regulation/reglaments/SR_0V050259/r19_4_01092016_27092016.pdf. Accessed on: 01 September 2021.

[18] AtsEnergo, Forecasts of free (unregulated) prices for electric energy (capacity) for the subjects of the Russian Federation for 2021 and the initial data for making forecasts [Prognozy svobodnyh (nereguliruemyh) cen na elektricheskuyu energiyu (moshchnost’) po sub”ektam Rossijskoj Federacii na 2021 god i iskhodnye dannye dlya postroeniya prognozov], 2020. http://www.atsenergo.ru/sites/default/files/prognoz/20201229_anpsr_ishodnye_dannye_i_prognoz_na_2021.pdf. Accessed on: 01 September 2021.

[19] Fox, E. B., Dunson, D. B. & Airoldi, E. M., Bayesian nonparametric covariance regression. *Journal of Machine Learning Research*, **16**, pp. 2501–2542, 2015.

[20] Mokhov, V.G., Chebotareva, G.S. & Khomenko, P.M., Modelling of green investments risks. *Bulletin of the South Ural State University, Series: Mathematical Modelling, Programming and Computer Software*, **11(2)**, pp. 154–159, 2018. https://doi.org/10.14529/mmp180213