COULD RUSSIAN HYDROPOWER PROJECTS REACH ECONOMIC EFFICIENCY? JUSTIFICATION OF POSSIBLE SCENARIOS

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ABSTRACT
Classical investment analysis shows that even in conditions of preferential pricing of capacity, Russian hydropower projects are not economically attractive for investors. The purpose of this work is to identify the conditions in the Russian energy market under which capital-intensive and expensive-to-operate hydropower projects are able to achieve economic feasibility. The objects are Russian small hydropower projects selected for the wholesale energy market as part of the first programme of state support for renewable energy. The author's approach to assessing the economic efficiency of these projects based on the calculation of basic investment indicators is proposed. This approach takes into account the industry-specific features of capacity pricing, as well as the author's tools for assessing the cost of risks specific to these energy facilities. As a result, 12 possible scenarios for the implementation of small hydropower projects in the national market taking into account changes in the volume and timing of government support, as well as the degree of influence of political and environmental risks are developed. Based on the results of the scenario assessment of the economic efficiency of these projects, recommendations for the development of a programme of state support for Russian hydropower are proposed.
Keywords: economic efficiency, hydropower projects, renewable energy, scenario assessment, specific risks, state support.

1 INTRODUCTION

The world experience shows that the initial stages of the renewable energy (RE) development require the mandatory application of state support programmes [1], [2]. Subsequently, the effectiveness of the proposed mechanisms depends on the effectiveness of the development of the entire sector [3]. First of all, the main purpose of such support is to attract private and concessional investments for the construction of energy facilities [4]. In practice, there are many different mechanisms for supporting RE projects. In particular, capacity mechanisms [1], [5], subsidies (in the form of feed-in tariffs, 'contracts for difference' and fixed premium) [6]–[9], fiscal incidence [10], government lending [11], energy auctions [12], reliability option scheme [13], renewable energy certificates (including tradable) [14], tendering [15], tax reliefs [16], phasing out capacity support for 'non-green' power plants [17], accounting for demand response [18], system of penalties [3], carbon exchanges [19], 'green' taxes and fees [20], 'green' stocks and bonds [21], [22], etc. As a rule, these support mechanisms are the same for all RE facilities.

Therefore, the research and practical question arises: to what extent these tools are economically justified for individual RE facilities (for example, for solar, wind, bio or hydroelectric power plants). These facilities differ significantly not only in technical, but also in economic characteristics – the required amount of capital investments, operational expenditures, the cost of generated electricity and capacity, etc.

The object of research is the small hydropower projects (SHPP) selected for the Russian wholesale market based on the results of 2018–2020 competition. These competitive selections were carried out within the framework of the state programme to support the sector

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– the contracts for the provision of capacity based on renewable energy sources, well-known as the CSA RES [3].

The main purpose of the work is to provide an economic justification for the proposed scenarios for supporting small hydropower sector, in which these SHPP will be able to achieve economic feasibility during the studied periods. Tasks: (1) to develop a method for evaluating the effectiveness of projects, taking into account the specifics of the industry and the impact of specific risks; (2) to conduct an initial assessment of the effectiveness of selected projects; (3) to propose scenarios for supporting projects in the market; (4) to assess the economic feasibility of these scenarios; and (5) to develop recommendations for improving the existing support programme, taking into account the assessments carried out.

The article has the following structure. In the second section, the author's approach to assessing the economic efficiency of projects is proposed. It takes into account the industry specifics of pricing capacity, the impact of specific risks through their cost indicators and the life cycle of projects. The third section provides a brief description of the projects and an initial assessment of their effectiveness. In the fourth section, the calculations are carried out, the scenarios that individualise the approach to supporting the SHPP are developed and justified. These scenarios take into account the national rating, the price of greenhouse gas emissions, the amount and period of government support. In conclusion, the main results of the work are summarised, alternative scenarios for project support are proposed.

2 METHODS

This section presents two methods used by the author for a step-by-step assessment of the economic efficiency of the SHPPs. These methods are based on the calculation of classical investment indicators: net present value (NPV) and internal rate of return (IRR) [19]. They take into account the industry-specific features of the formation of the price for the SHPP capacity [23].

These indicators are calculated for two periods: (1) at the end of the period of state support (15 years;) and (2) at the end of the planned period of operation of the power facility (40 years) – according to the equations presented below.

However, the first method is based solely on the principles of classical investment analysis (Section 2.1). The second method takes into account the impact of specific risks on the effectiveness of such projects (Section 2.2).

2.1 The classical method

The NPV indicator for the SHPP is estimated according to eqn (1):

$$NPV_{hydro} = \sum_{i=0}^{i1\ or\ i2} \frac{CF_i^{i1\ or\ i2}}{(1+d)^i}, \tag{1}$$

where i is the year of project implementation; $i1$ is the period of state support, $i1$ = 15 years; $i2$ is the planned period of operation of the SHPP, $i2$ = 40 years; CF_i is the amount of cash flows for period i, totally generated for periods $i1$ or $i2$; d is the discount rate, taking into account the projected inflation rate.

The cash flow of such projects takes into account all expenditures associated with the construction and operation of SHPP, as well as income from the sale of the achieved capacity and electricity produced for the wholesale energy market. The price of capacity during the period of state support is preferential according to eqn (2):

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$$CP_i = \frac{\frac{R_i \cdot RR_{i-1}}{1-IT} + r_i}{12} + EC_i, \tag{2}$$

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; 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.

Methods for calculating individual elements of the capacity price are presented in detail in Chebotareva [24]. Prices for electricity for the entire period of operation of the power facility and for capacity after the end of the support programme are formed on the market in the appropriate price zone.

The calculation of the IRR is carried out according to eqn (3):

$$\sum_{i=1}^{i1\ or\ i2} \frac{CF_i^{i1\ or\ i2}}{(1+IRR)^{i1\ or\ i2}} = CF_0. \tag{3}$$

2.2 Proposed method

In the new methodology, the author proposed to take into account the value of specific risks of the SHPP in the amount of cash flows. These risks include political, environmental and economic risks. Then the specified amount of cash flow is estimated using eqn (4):

$$CF_{i,upd}^{i1\ or\ i2} = CF_i^{i1\ or\ i2} - PR_i^{i1} - ER_i^{i1\ or\ i2} - CaR_i^{i1\ or\ i2}, \tag{4}$$

where PR_i is the cost of political risk for the period i; ER_i is the cost of environmental risk for the period i; CaR_i is the cost of economic risk for the period i.

Political risk includes the risks of a sudden change in the strategy for the development of RE and schemes for support, financial aspects of investors' dependence on state programmes, imperfection of legislation that may arise depending on the current state (rating) of the country. This indicator is calculated over a 15-year period of support based on the rating approach according to eqn (5):

$$PR_i = PD_i \cdot RC_i, \tag{5}$$

where PD_i is the probability of default of the country, estimated on the basis of the assigned national rating; RC_i is the amount of the preferential capacity fee; $i = 0, \ldots, 15$.

Environmental risk assesses the damage caused to the environment in the form of greenhouse gas emissions at the stages of production, utilisation of energy equipment and electricity generation. This risk is assessed during the entire duration of the project according to eqn (6):

$$ER_i = Em_{CO2i} \cdot Pr_{CO2}, \tag{6}$$

where Em_{CO2i} is the amount of greenhouse gas emissions in equivalent of CO_2; Pr_{CO2} is the price of emissions; $i = 0, \ldots, 40$.

Economic risk takes into account the impact of a set of intra-industry economic processes on the project and is calculated over the entire implementation period as additional capital necessary to cover losses from emerging risks (risk capital) of the project, according to eqn (7):

$$CaR_i = EAD \cdot LGD \cdot (N \cdot \left(\frac{N^{-1}(PD_i)+\sqrt{R}*N^{-1}(\alpha_i)}{\sqrt{1-R}}\right) - PD_i) \cdot M_i \qquad (7)$$

where EAD is the full value of the project, $EAD = CF_0$; LGD is the industry average indicator of the expected relative losses of the project in case of default; R is the coefficient of correlation of project indicators with the general state of the industry; α_i is the level of reliability of the project; M_i is penalty for exceeding the 1-year (risk-free) project period; $N(\ldots)$ and $N^{-1}(\ldots)$ are functions of the standard normal distribution and its inverse value, respectively.

3 INITIAL ASSESSMENT OF HYDROPOWER PROJECTS

This section describes the objects of research (Section 3.1), as well as presents the results of the initial assessment of projects in accordance with the classical (Section 3.2) and proposed (Section 3.3) methods.

3.1 Brief description of the projects

The characteristics of the projects are given in Table 1. All projects belong to the first price zone of the wholesale electricity and capacity market in Russia [25]. In this price zone, the sale of electric energy and capacity is carried out at free (unregulated) prices. Prices are formed based on the results of competitive bidding in the European part of Russia and the Urals.

Table 1: Key indicators of hydropower projects.

Title of SHPP	Select.	Comm.	Region	Initiator company	Capacity	CAPEX	Investment
SHPP-1_1	2020	2024	Murmansk region	PJSC ‘TGC-1’	16.5	192	3,168,000
Bashennaya	2020	2024	Chechen Republic	PJSC ‘RusHydro’	10	193.6	1,936,400
Psygansu	2020	2024	Kabardino-Balkarian Republic	PJSC ‘RusHydro’	19.1	194.6	3,717,605
Segozerskaya	2019	2022	Republic of Karelia	LLC ‘EuroSibEnergo Hydro-generation’	8.1	176	1,425,179
Prosyanskij sbros BSK	2018	2020	Stavropol region	LLC ‘EnergoMIN’	7	174.5	1,221,311
Gorko-Balkovskaya	2018	2020	Stavropol region	LLC ‘EnergoMIN’	9	174.5	1,570,257
Nizhne-Krasnogorskaya	2018	2023	Karachay-Cherkess Republic	LLC ‘Yuzhenergostroy’	23.73	174.5	4,139,895

Explanations for some indicators: Selection (Select.) is the year of competitive selection; Commissioning (Comm.) is the year of commissioning; Capacity is installed capacity, MW; CAPEX is the specific capital expenditures, thousand rubles/kW; Investments are total investment, thousand rubles.

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A distinctive feature of these projects is the active participation of regional (non-capital) energy companies in competitive selections. Thus, by the end of 2018, projects are implemented exclusively by companies representing the region of SHPP construction. In 2019, a Siberian company (Irkutsk-city), which implemented a project in Karelia, was selected. However, by the end of 2020, the projects are being implemented by companies from Saint Petersburg and Moscow. For comparison, solar and wind energy in the Russian market is dominated exclusively by companies operating in Moscow and implementing projects in other regions [3], [26].

3.2 Economic efficiency of projects (without the cost of risks)

The results of the evaluation of the economic efficiency of the studied projects for two specified periods are presented in Table 2.

Table 2: Projects' economic efficiency indicators.

Title of SHPP	**15 years after**		**40 years after**		**Growth rate (%)**	
	NPV (thousand rubles)	**IRR (%)**	**NPV (thousand rubles)**	**IRR (%)**	**ΔNPV**	**ΔIRR**
SHPP-1_1	−1,325,169	−10.01	−941,321	−3.71	71.03	37.06
Bashennaya	−672,595	−7.82	−267,216	−1.48	39.73	18.93
Psygansu	−1,398,687	−8.67	−751,193	−2.29	53.71	26.41
Segozerskaya	−567,853	−9.36	−372,029	−3.16	65.52	33.76
Prosyanskij sbros BSK	−450,769	−7.79	−219,079	−1.89	48.60	24.26
Gorko-Balkovskaya	−579,578	−7.79	−281,712	−1.89	48.61	24.26
Nizhne-Krasnogorskaya	−1,366,997	−9.07	−587,684	−1.77	42.99	19.52

As a result, the evaluation of projects using the classical method showed that even preferential pricing of capacity does not allow capital-intensive hydropower projects to achieve a positive economic effect. Moreover, this effect is achieved not only based on the results of the of state support, but also during the planned 40-year operational period.

3.3 Economic efficiency of projects (including the cost of risks)

The results of a similar assessment of the economic efficiency of projects, but taking into account the cost of specific risks, are presented in Table 3.

Naturally, when taking into account the additional cost of risks, the indicators of economic efficiency of projects decrease. Moreover, the decrease in NPV and IRR within a 15-year period averaged 26%–28%, and over a 40-year period – already 55%–60%. Due to the absence of the influence of political risk, after the end of the state programme, the growth rate of performance indicators estimated using the second method accelerates.

Therefore, in the case of small hydropower, it is impossible to talk about the reducing state support programmes compared to projects in the solar and wind sectors. On the contrary, it requires the development and study of support conditions under which SHPPs will be attractive to private investors.

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Table 3: Projects' economic efficiency indicators (with cost of risks).

Title of SHPP	**15 years after**		**40 years after**		**Growth rate (%)**	
	NPV (thousand rubles)	**IRR (%)**	**NPV (thousand rubles)**	**IRR (%)**	**ΔNPV**	**ΔIRR**
SHPP-1_1	−1,635,812	−12.58	−1,302,559	−4.93	79.63	39.19
Bashennaya	−862,405	−10.13	−487,951	−2.58	56.58	25.47
Psygansu	−1,763,018	−11.07	−1,174,892	−3.42	66.64	30.89
Segozerskaya	−708,127	−11.86	−535,074	−4.36	75.56	36.76
Prosyanskij sbros BSK	−570,687	−10.03	−358,511	−2.98	62.82	29.71
Gorko-Balkovskaya	−733,759	−10.03	−460,982	−2.98	62.82	29.71
Nizhne-Krasnogorskaya	−1,772,724	−11.76	−1,059,560	−3.00	59.77	25.51

4 SCENARIO ASSESSMENT OF HYDROPOWER PROJECTS

This section presents the developed scenarios for supporting projects that can allow them to achieve economic feasibility (Sections 4.1 and 4.3). In addition, the calculated justification of each of the scenarios was carried out according to the proposed methodology (Sections 4.2 and 4.4).

4.1 Initial scenarios

Taking into account the results of the initial assessment, the development of scenarios should be associated with a phased increase in the volume and/or period of state support for projects, as well as take into account the degree of impact of identified risks. The purpose of developing these initial scenarios is to study the 'behaviour' of the economic efficiency of projects under given basic conditions for changing the rating, the cost of emissions, as well as the volume and period of support.

As a result, eight scenarios were initially proposed. Their brief description is given in Table 4, and comments on the scenario indicators are below:

- The variation of the national rating from 'A' to 'BB' relative to the zero scenario reflects not only a change in the ability of the state's economy to provide financial support for projects, but also the development of its own industrial base or new logistics to provide energy facilities with equipment and components.
- In some scenarios, the price of greenhouse gas emissions in accordance with world practice [27], [28] is updated at the current exchange rate [29]. In other scenarios, a zero cost has been adopted, since in fact, a fee for emissions in Russia is planned to be introduced no earlier than 2028 [30].
- The variation of the indicators of the volume and period of state support up to 200% and 40 years is the author's hypothesis aimed at finding threshold under which SHPPs are able to achieve economic feasibility.

Table 4: Initial project support scenarios.

Scenario's indicators	Number of scenario								
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
The level of national rating	*BBB*	A	BB	A	BB	A	BB	A	BB
The price of greenhouse gas emissions, rubles	*438*	600	600	0	0	600	600	0	0
The amount of state support, %	*100*	200	200	200	200	100	100	100	100
The period of state support, years	*15*	15	15	15	15	40	40	40	40

Explanations for some indicators: The zero scenario reflects the conditions of the initial assessment of the effectiveness and is used as an informative one, here the volume and period of support are indicated in accordance with the Resolution [23]; The value of the national rating is taken into account in the cost of political and economic risks as the probability of default; The cost of emissions is indicated per 1 ton of CO_2.

4.2 The economic feasibility of projects under the initial scenarios

A summary of the number of projects capable of achieving a positive economic result, depending on the studied periods and the impact of identified risks, is presented in Table 5. The economic indicators actually achieved by the projects are given in [31].

Table 5: Number of economic efficiency projects.

Number of scenario	The period of assessment and risks' impact			
	15 years (without risks)	**40 years (without risks)**	**15 years (with risks)**	**40 years (with risks)**
1	5	7	0	6
2	5	7	0	5
3	5	7	0	6
4	5	7	0	5
5	0	2	0	0
6	0	2	0	0
7	0	2	0	0
8	0	2	0	0

The calculations showed that taking into account the cost of emissions does not significantly affect the possibility of achieving economic efficiency for projects. In scenarios 3 and 4, 7 and 8, where the cost of emissions is zero, the number of effective projects has not changed compared to scenarios 1 and 2, as well as scenarios 5 and 6, respectively.

The probability of a possible default has demonstrated a weak impact on the achievement of efficiency by projects. Thus, if the amount of state support is set at 200% for 15 years and the rating is lowered to 'BB', fewer projects achieve a positive effect within 40 years (taking into account the impact of risks) compared with the 'A' rating (1–4 scenarios). When providing support at the level of 100% for 40 years (5–8 scenarios), there is no fundamental impact of the rating.

As a result, only scenario conditions have the greatest impact in terms of the volume and period of state support. A twofold increase in the volume of support over 15 years (scenarios 1–4) will ensure that a large number of projects achieve an economic effect compared to the extension of initial financing throughout the planned project period (scenarios 5–8).

Consequently, based on the results, assumptions are made for the subsequent development of updated scenarios:

- The price of greenhouse gas emissions is assumed to be 600 rubles.
- Scenarios should take into account the originally set national ratings ‘A’ and ‘BB’.
- In order for projects to achieve a positive effect within 15 years, the amount of support should be increased compared to the originally 200%.
- In order to reduce the burden on consumers during the first 15 years, it is important to explore the possibility of extending the duration of the support programme while maintaining the initially 200%.

4.3 Updated scenarios

Four updated scenarios for supporting small hydropower projects have been proposed (Table 6).

Table 6: Updated project support scenarios.

Scenario’s indicators	**Number of scenario**			
	9	**10**	**11**	**12**
The level of national rating	A	BB	A	BB
The price of greenhouse gas emissions, rubles	600	600	600	600
The amount of state support, %	250	250	200+100	200+100
The period of state support, years	15	15	15+5	15+5

4.4 The economic feasibility of projects under the updated scenarios

A summary of the number of projects capable of achieving a positive economic result under the updated scenarios is presented in Table 7. The economic indicators actually achieved by the projects are given in [31].

Table 7: Number of economic efficiency projects.

Number of scenario	**The period of assessment and risks’ impact**			
	15 years (without risks)	**40 years (without risks)**	**15 years (with risks)**	**40 years (with risks)**
9	7	7	7	7
10	7	7	6	7
11	5	7	0	7
12	5	7	0	6

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As a result, an increase in the amount of financial support by 2.5 times compared to the initial programme (scenarios 9 and 10) allows projects to achieve a positive effect not only during the planned period of operation, but also over a 15-year period, even taking into account the cost of specific risks. The only exception is a project with a downgraded national rating. Calculations show that in this project, an additional 10% support will be required to overcome losses.

Undoubtedly, such economic conditions are favourable for the implementation of projects. However, this is an additional financial burden for energy consumers – industrial enterprises and the population, who are the main payers under this state programme. Therefore, in conditions where 100% support even for 40 years is not able to provide the required economic result, the author suggests scenarios in which 200% financing for 15 years is supplemented by 5 years of 100% support (scenarios 11 and 12).

With such financing, many projects pay off before a 40-year period, as well as a 15-year period (without risks' impact). For other projects with higher capital expenditures, an increase in the period of additional support to 10 years is required.

5 CONCLUSIONS

Small hydropower projects are among the most capital-intensive in the Russian RE market. It is not only about the absolute value of the required investments, but also about the specific capital expenditures per unit of installed capacity. For comparison, if wind and solar projects are characterised by a gradual reduction in capital expenditures, then the reverse dynamics is characteristic for hydropower. During the period studied in the work, this indicator increased by an average of 10%. In addition, the research in Chebotareva et al. [3], Chebotareva [24] and Rausser et al. [26] show that wind projects can achieve an economic effect within the 15-year period of support programmes, while solar energy projects strive for this result. In turn, hydropower projects at the current level of support are not economically feasible even within a 40-year period. This means that an individual approach to the development of financial support programmes is required for this sector of national RE market.

Determining the possible quantitative conditions of the programme for the hydropower sector has become the main goal of this work. To solve it, the author has developed twelve scenarios for the development of the sector support programme. These scenarios are based on four criteria – the potential level of default, the price of greenhouse gas emissions, as well as varying volumes and periods of state support. Moreover, eight initial scenarios were aimed at studying the 'behaviour' of the economic efficiency of projects under the given basic conditions. This made it possible to determine the threshold (minimum) values of the required volumes and periods of support, as well as to assess the significance of other conditions. Based on the results of preliminary calculations, four updated scenarios were developed, which made it possible to accurately assess the economic efficiency of hydropower projects within the framework of the proposed support programmes.

The methodical basis of the research was the approaches proposed by the author to assess the economic efficiency of investment projects specified for the hydropower sector. In particular, these approaches take into account the specifics of the formation of a preferential price for capacity, two evaluation periods – within the framework of the support programme and the full operational life, the degree of influence of specific risks (political, environmental and economic) through the calculation of their cost.

As a result, it was determined that in order to ensure economic payback at the current level of specific capital expenditures, hydropower projects need to increase the amount of financing by 2.5 times over a given 15-year period. With an increase in capital expenditures, the required volume of concessional financing may increase by another 10%. This will ensure the payback of projects over a 15-year period, even taking into account the negative impact of risks. However, in practice, this means that the burden on the actual payers under the state programme – business and the population – will also grow by 2.5–2.6 times. It is impractical given the current state of the Russian economy.

Therefore, the author proposed an alternative programme scenario. Here, financial support increases only twice over a 15-year period, and then it is supplemented by 100% support for 5 years. Under such conditions, most projects achieve payback within 15 years (without the cost of risks). For projects with higher capital expenditure, additional support will be required for a 10-year period.

To sum up, in this paper it is proved that the technical and economic features of the small hydropower projects, in particular the high level of capital expenditures, installed capacity, planned operation periods, etc., require an individual approach to the formation of state support programmes. Based on the results of the study, conditions under which these capital-intensive projects are able to achieve economic efficiency, both within the 15-year support period and throughout the entire life cycle are proposed. In practice, these results will be recommended for improving the new programme of support for Russian RE projects. The continuation of scientific research is associated with a similar assessment of projects under the existing second support programme, as well as taking into account the impact of the cost of various 'green' sources of financing in the formation of economic results for similar projects.

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