REDUCING INVESTMENT RISKS IN THE DEVELOPMENT OF RUSSIA'S ENERGY INFRASTRUCTURE THROUGH DISTRIBUTED GENERATION OF SMALL HYDROPOWER PLANTS

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Abstract

This study examines ways to reduce investment risks in developing Russia's energy infrastructure by using distributed generation from small hydropower plants (SHPPs). This research is relevant because large-scale energy projects, particularly in remote and hard-to-reach regions, have high capital intensity and prolonged payback periods. The paper proposes diversifying energy investments by developing SHPP networks to reduce dependence on centralised generation facilities and distribute risks across a range of local projects. This includes forming autonomous energy systems that are disconnected from Russia's Unified Energy System (UES). The analysis focuses on the economic aspects of small-scale hydropower, emphasising the long operational lifespan of SHPPs and their low operating and maintenance costs. These factors contribute to reliable and stable capital returns. The paper also reviews policy instruments and mechanisms for attracting private investment to support the growth of distributed generation. The paper substantiates the strategic role that SHPPs can play in the sustainable development of Russia's energy sector, ranging from substituting conventional fossil fuel-based systems in isolated areas, to stimulating local economies and strengthening regional energy security.

Keywords: investment risks, energy infrastructure, distributed generation, small hydropower plants, sustainable development, investment attraction, regional specifics

I. Introduction

Russia's energy infrastructure traditionally relies on large generating facilities and extensive networks, which is accompanied by significant investment risks and capital maintenance costs. The capital intensity and long construction time of large power plants (for example, hydroelectric power plants or nuclear power plants) make it difficult to attract private sector investment. Investors face payback uncertainty and external risks, from fluctuations in demand to regulatory changes. In recent years, there has been a trend towards the creation of decentralized energy systems: distributed generation is seen as a tool to increase sustainability and reduce the risks of infrastructure projects. More than half of the entire territory of Russia is located in a decentralized zone and occupying the world's largest territory in terms of area, taking into account a variety of regional conditions and features, the transition to distributed generation is becoming especially relevant. Electricity and heat supply in remote regions is provided by diesel generators, coal and petroleum products, meanwhile, a huge number of rivers with a total length of more than 6.5 million km flow through Russia. And this resource seems promising for the development of the electric power industry in the concept of a distributed energy network. Small hydroelectric power plants (small HPPs) located near consumers can become one of the key elements of such a distributed system, providing local electricity generation and reducing the load on the backbone networks [5].

II. Distributed Generation and Small Hydropower in Russia

Distributed generation involves the placement of small generating capacities near the places of consumption, which reduces losses during energy transmission and increases the reliability of the power system. In the context of Russia, small hydroelectric power plants (with an installed capacity of about several megawatts) represent a promising type of distributed generation, given the abundance of rivers and the need for energy supply in remote areas. Expanding the use of renewable sources, including wind, solar, and small rivers, could increase the share of renewable energy in Russia's energy mix to 25-30%, creating a more sustainable and diversified system. SHPPs could significantly contribute to this goal, particularly in regions endowed with substantial hydropower potential. However, current utilization levels of this potential—especially that of small rivers—remain low, despite Russia having one of the world's largest hydropower resources. The total technical potential is estimated at approximately 850 billion kWh per year, of which 300–350 billion kWh is considered economically viable; yet, less than 20% of this capacity has been harnessed to date. The main constraints include high upfront investment requirements for large-scale facilities and the lack of effective incentive mechanisms. [1-3]

From an economic standpoint, SHPP projects offer a number of advantages that make them attractive for distributed generation. First, they require significantly lower one-time capital investments compared to large-scale power plants, thereby reducing the financial burden on individual investors. Second, SHPPs have shorter construction timelines and utilize well-established technologies, which mitigates the risk of cost overruns and delays. Finally, they exhibit long operational lifespans and low operating expenses: modern small hydro installations can function for over 70 years, with annual operating and maintenance (O&M) costs amounting to just 3–4% of the initial capital expenditure (Table 1.)

Table 1: *Economic characteristics of small hydropower projects in Russia*

Parameter	Grid-connected Small Hydropower systems	Off-grid Small Hydropower systems
Levelized cost of energy (RUB/kWh)	0.4–0.6	1.1–2.3
Payback period (years)	7–8	7–10
Service life (years)	≥ 70	≥ 70
Annual O&M cost (% of CAPEX)	3,5–4,5%	3–4%

The levelized cost of electricity (LCOE) for small hydropower plants connected to the centralized grid is estimated at approximately 0.4–0.6 RUB/kWh, whereas in off-grid systems—serving isolated areas—it ranges from 1.1 to 2.3 RUB/kWh. Nevertheless, even in remote regions, small-scale hydropower remains cost-competitive with diesel-based power generation. The typical payback period for SHPP projects is estimated at 7–10 years, which is slightly longer than for some other renewable energy technologies but is justified by the extended operational lifespan. The durability of SHPP installations—often exceeding 70 years—ensures decades of stable operation, while low operating and maintenance costs minimize financial risks once the plant reaches the break-even point. These characteristics make SHPPs economically resilient generation assets, whose cumulative integration into distributed energy networks can significantly enhance the reliability and stability of the overall power system [2].

III. Investment Risks and Risk Mitigation Mechanisms

A key barrier to the development of new energy infrastructure in Russia lies in the investment risks associated with uncertain project returns. Under the traditional centralized energy model, large-scale projects—such as high-capacity hydro or thermal power plants (several GW)—are exposed to systemic risks: delays or project failures can result in substantial financial losses and power deficits. In contrast, distributed generation spreads total investment across a large number of smaller projects, thereby reducing aggregate risk—failure of an individual SHPP has minimal impact on the system, while the majority of assets continue to operate. This portfolio diversification effect enhances the resilience of the energy infrastructure. Moreover, SHPPs offer greater flexibility in staged implementation, allowing assets to be commissioned sequentially with the ability to adjust plans in response to evolving demand or macroeconomic conditions—something largely unfeasible in megaprojects..

The principal categories of risk in energy infrastructure projects include construction risks (budget overruns, timeline delays), technological risks (equipment failure, underperformance), market risks (fluctuations in electricity prices and demand), and regulatory risks (changes in tariff regimes, legislation, and compliance frameworks). Distributed generation based on SHPPs helps mitigate many of these risks. Construction risks are reduced due to the maturity of SHPP technology and the possibility of engaging local contractors familiar with site-specific conditions. Technological risks are inherently low for hydropower, as it is a mature and reliable sector with predictable performance indicators—the water-to-electricity energy conversion efficiency in Russia can reach up to 90%. Market risks are also diminished: small units can be adapted to local demand, and their commissioning is more agile, reducing the risk of excess generation capacity. [4]

Regulatory and financial risks are significantly mitigated through dedicated investment support mechanisms. Since 2013, Russia has implemented a renewable energy incentive scheme based on capacity supply agreements (CSA) through competitive project selection on the wholesale market. Under this mechanism, the state commits to compensating capital expenditures for renewable projects (solar, wind, SHPPs) by providing increased capacity payments, subject to timely commissioning. This effectively ensures investment return, thereby substantially lowering financial risks for project developers. According to estimates, a total of 5.5 GW of solar, wind, and small hydropower plants were commissioned under this scheme by 2024. [7]

Although this model shifts part of the risk to end consumers through tariff adjustments, it has nevertheless provided the initial impetus for sectoral development. In addition to capacity payment contracts, there are other instruments for risk mitigation and investment attraction—such as preferential "green" tariffs for distributed generation, capital subsidies, tax incentives, and the involvement of international financial institutions [4].

IV. Regional Specifics and Sustainable Development

Russia possesses a uniquely diversified energy geography: in addition to the Unified Energy System (UES)—which was originally designed and deployed during the Soviet era—there exists a wide array of isolated energy nodes across Siberia, the Russian Far East, and the Arctic and sub-Arctic regions of the Far North [8]. For many remote settlements and industrial facilities, thermal power plants operating on imported fossil fuels have remained the only source of energy for decades. This reliance results in extremely high electricity costs and significant environmental externalities, including greenhouse gas emissions and risks of fuel spills. Transitioning such isolated zones to locally available renewable energy sources—including small hydropower where hydrological resources permit—has the potential to drastically reduce energy expenditures and improve the quality and reliability of power supply. For instance, in mountainous villages of the North Caucasus or the Altai region, small run-of-river hydropower plants could fully meet local residential and agricultural electricity needs, displacing expensive imported fuels [4]. In the Chechen Republic, a recent assessment demonstrated strong investment returns for a cascade of SHPPs designed to power rural areas, with such systems showing long-term operational stability and minimal investor risk.

Moreover, in regions of Russia characterized by low population density and significant remoteness from centralized grid infrastructure, the selection of optimal generation technologies must be guided by a combination of factors: capital investment requirements, operational efficiency, payback periods, and overall investment risk. These parameters form the basis for sound energy planning and support the rationale for prioritizing SHPP deployment as a cornerstone of regional distributed energy strategies (Table 2).

Table 2: *Economic characteristics of distributed energy technologies in Russia*

<table>
<tr><th rowspan="2">Parameter</th><th rowspan="2">Solar PV (rooftop and small ground)</th><th rowspan="2">Small Wind Turbines</th><th rowspan="2">Small Bioenergy Units (CHP or biomass)</th><th colspan="2">Small Hydropower systems</th></tr>
<tr><th>Grid-connected SHPPs</th><th>Off-grid SHPPs</th></tr>
<tr><td>Levelized cost of energy (RUB/kWh)</td><td>2.8–4.5</td><td>2.2–3.5</td><td>1.5–2.5</td><td>0.4–0.6</td><td>1.1–2.3</td></tr>
<tr><td>Payback period (average, years)</td><td>6–9</td><td>7–11</td><td>5–8</td><td colspan="2">7-8</td></tr>
<tr><td>Service life (years)</td><td>20–25</td><td>15–20</td><td>20–30</td><td colspan="2">≥ 70</td></tr>
<tr><td>Annual O&M cost (% of CAPEX)</td><td>1.5–2.5%</td><td>2–3%</td><td>3–4%</td><td colspan="2">3–4%</td></tr>
<tr><td>CAPEX (mln RUB per MW)</td><td>60–90</td><td>75–110</td><td>85–120</td><td colspan="2">90–110</td></tr>
<tr><td>Typical installed capacity (MW)</td><td>0.01–0.5</td><td>0.01–0.3</td><td>0.1–1</td><td colspan="2">1–5</td></tr>
<tr><td>Annual generation (mln kWh)</td><td>0.01–0.65</td><td>0.01–0.45</td><td>0.15–1.5</td><td colspan="2">5–25</td></tr>
<tr><td>Revenue (RUB/kWh sold)</td><td>5.5</td><td>5.5</td><td>5.5</td><td colspan="2">4.0</td></tr>
<tr><td>Annual O&M cost (mln RUB)</td><td>0.9–2.2</td><td>1.0–2.5</td><td>2.5–4.8</td><td colspan="2">1.8–3.3</td></tr>
<tr><td>Net annual income (mln RUB)</td><td>0–1.38</td><td>-0.5–1.1</td><td>1.2–6.3</td><td colspan="2">18.2–96.7</td></tr>
<tr><td>IRR (%)</td><td>8–11</td><td>6–9</td><td>10–13</td><td colspan="2">13–16</td></tr>
<tr><td>Investment Risk Level (qualitative)</td><td>Medium</td><td>High</td><td>Low–Medium</td><td colspan="2">Low</td></tr>
</table>

Table 2 presents a systematized comparison of four key areas of small-scale distributed energy in Russia: solar photovoltaic (PV) systems, small wind turbines, bioenergy units, and small hydropower plants (SHPPs). For each technology, average benchmark indicators are provided to assess investment attractiveness, including the levelized cost of energy (LCOE), capital expenditure (CAPEX), payback period, annual generation, net income, internal rate of return (IRR), and a qualitative evaluation of investment risk. The analysis demonstrates that SHPPs show the most favorable performance across the majority of these parameters.

Regional specificity is particularly evident in the distribution of untapped hydropower potential: most of the available small-scale resources are concentrated in mountainous and remote areas, such as the North Caucasus, Southern Siberia, and the Russian Far East [3]. In contrast, the European part of Russia offers fewer opportunities due to its relatively flat terrain and the high degree of development of major rivers. Accordingly, support measures should be targeted at regions with isolated energy systems and high tariffs for imported fuels, where the impact of distributed generation is likely to be most significant. Furthermore, in remote areas, SHPP projects should be viewed not only through the lens of energy provision but also as drivers of regional development. Reliable electricity supply facilitates the emergence of new industrial activity, supports small business growth, and improves quality of life through enhanced access to lighting and essential infrastructure. Thus, investments in small-scale hydropower serve a dual purpose: advancing sustainable energy and delivering tangible socio-economic benefits to local communities [6].

Hydropower, as a renewable and virtually carbon-free energy source, contributes to the achievement of Russia's climate objectives. Moreover, combining SHPPs with other renewable technologies—such as wind-diesel hybrid systems in Arctic zones or solar-hydro energy complexes in southern regions—can ensure secure and resilient power supply through diversification and enhanced energy security across Russian territories. In the long term, the development of distributed generation will be supported not only by the state but also by private consumer initiatives and businesses seeking independence through localized energy solutions. With predictable output and extended operational lifespans, SHPPs are well-positioned to become a core component of the emerging decentralized energy architecture alongside other distributed resources [7-27].

V. Conclusion

Small hydropower systems represent an economically viable and investment-resilient solution for the development of distributed energy systems in Russia. Their key advantages include a low levelized cost of electricity, extended service life, moderate capital expenditures, and minimal operating and maintenance costs. Locating SHPPs in close proximity to end-users helps reduce the load on trunk transmission infrastructure and enhances the reliability of local energy supply. These projects are particularly relevant for remote and isolated areas, where SHPPs can effectively replace costly diesel-based power generation. In addition to their economic benefits, SHPPs generate positive social and environmental impacts by promoting regional development and reducing greenhouse gas emissions. Government support measures and investment incentives in this sector have proven effective but require long-term institutionalization and adaptation to regional conditions. In the long term, SHPPs are poised to occupy a central role in Russia's energy strategy as a key component of a sustainable, decentralized, and low-carbon power system.

CONFLICT OF INTEREST.
Authors declare that they do not have any conflict of interest.

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