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Strategy for Implementing Hybrid Power Supply Systems in Large-Scale Construction Projects

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Abstract

The organization of power supply at construction sites in Russia, particularly in remote and climatically challenging regions, is characterized by a high dependence on diesel generators for temporary power supply. Fuel delivery is associated with increasing costs, price volatility, and a significant environmental footprint. This article examines the use of hybrid power supply systems (wind turbines, solar photovoltaic panels, and battery storage) as an alternative to conventional diesel-based power supply schemes. Hybrid energy solutions combining diesel generators with renewable energy sources can improve the reliability and economic efficiency of power supply. Rising fuel prices, environmental concerns, and the growing availability of renewable energy technologies are stimulating the adoption of hybrid power supply systems at large construction sites. The methodological framework of this study includes calculations of the Levelized Cost of Electricity (LCOE), Internal Rate of Return (IRR), and Net Present Value (NPV), as well as sensitivity analysis with respect to fuel price fluctuations and wind conditions. The article also presents a comparative analysis of Russian and international practices, demonstrating the increasing role of hybrid power supply systems in the construction sector. The results indicate the high investment attractiveness of hybrid technologies and their potential for scaling up within national programs for economic and construction sector development.

Keywords: construction site power supply, hybrid power supply systems, wind turbine, solar photovoltaic system , LCOE, IRR, NPV, economic efficiency

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大型建设项目混合供电系统实施战略

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摘要

俄罗斯建筑工地能源供应的组织特点，尤其是在偏远地区和气候条件复杂地区，面临的一个突出问题是临时供电对柴油发电机的高度依赖。燃料运输不仅会推高成本，还会带来价格波动和更大的生态环境负担。本文探讨了采用混合能源供应系统（风力发电装置、太阳能电池板和蓄电池）替代传统柴油供电方案的可行性。在这种背景下，将柴油发电机与可再生能源相结合的混合能源解决方案正发挥越来越重要的作用。燃料价格上涨、生态环境问题以及可再生能源技术的日益普及，正在推动混合能源系统在大型建筑项目中的应用。研究的方法论基础包括平准化度电成本（LCOE）、内部收益率（IRR）和净现值（NPV）的测算，以及对燃料价格变化和风力条件变化的敏感性分析。文章还对俄罗斯及国外相关实践进行了比较分析，展示了混合能源系统在建筑领域日益重要的作用。研究结果表明，混合能源技术具有较高的投资吸引力，并具备在国家经济和建筑业发展规划框架下实现规模化推广的潜力。

关键词： 建筑工地能源供应，混合能源系统，风力发电装置，太阳能发电站，平准化度电成本（LCOE），内部收益率（IRR），净现值（NPV），经济效益。

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Introduction

Global energy consumption continues to increase due to population growth, economic development, and improvements in living standards and life expectancy. As a result, the demand for new and more efficient technologies in the energy sector is steadily growing. One of the most prominent trends in the development of modern power systems is the adoption of energy-efficient technologies, which enable reductions in energy costs while mitigating the environmental impact of industrial activity. Key drivers of this trend include the relatively low cost of fossil fuel extraction, geopolitical instability, and the increasing volatility of national economies worldwide [Ageev, 2018].

Improving energy efficiency and promoting resource conservation have therefore become critical challenges for most countries. In response, new energy policies have been developed over recent decades that emphasize the deployment of hybrid power supply systems integrating renewable energy sources (RES). In such systems, conventional power generation technologies are combined with renewable energy sources, including solar photovoltaic (PV) systems, wind turbines, and other RES-based technologies.

According to the Energy Strategy of Russia through 2030[1], the strategic objectives associated with the development of RES and the use of locally available fuels include reducing anthropogenic environmental impacts, improving the efficiency of fossil fuel utilization, decreasing fossil fuel consumption, protecting public health and quality of life, lowering energy transmission and distribution costs, expanding the national fuel and energy resource base, and strengthening energy security through the decentralization of power supply systems.

The Ministry of Energy of the Russian Federation supports the development of hybrid power supply systems based on RES as part of national policy aimed at diversifying the country's energy mix, improving its environmental performance, and strengthening national energy security. Hybrid systems combining RES with conventional generation technologies or battery storage represent a promising technological pathway for the sustainable development of national energy infrastructure.

The Russian power system has traditionally been dominated by thermal power plants (TPPs), hydropower plants (HPPs), and nuclear power plants (NPPs). However, over the past decades the share of RES has been gradually increasing, creating favorable conditions for the deployment of hybrid power supply solutions, particularly in remote and isolated areas as well as at large construction sites.

Comprehensive statistical data on hybrid energy systems are currently unavailable both globally and in Russia. Nevertheless, their development is closely linked to the increasing share of RES in national energy balances. Available statistics therefore reflect this trend indirectly, primarily through indicators describing the expansion of renewable power generation capacity. As of 1 August 2025, the total installed capacity of RES-based power plants in Russia amounted to 6.64 GW (Figure 1). The structure of installed RES capacity is dominated by wind and solar power plants, accounting for 2.57 GW and 2.55 GW, respectively, while small hydropower plants with capacities of up to 50 MW contribute 1.31 GW. In addition, the country operates power plants based on biomass, biogas, landfill gas, municipal solid waste, and geothermal energy, with a combined installed capacity exceeding 200 MW[2]. Although the share of RES in Russia is increasing gradually, renewable energy already accounts for approximately 29% of global electricity generation worldwide.

Thus, countries around the world, including Russia, are gradually entering the fourth energy transition and aim to achieve carbon neutrality by 2050, increasing the share of RES-based power generation [Mokshin et al., 2025].

1. Research Background

Hybrid power supply systems (hereinafter referred to as HPSS) are based on a unified technological principle that makes it possible not only to reduce fuel consumption but also to improve the quality of electricity supply, thereby increasing the operational reliability of power systems and reducing environmental impacts.

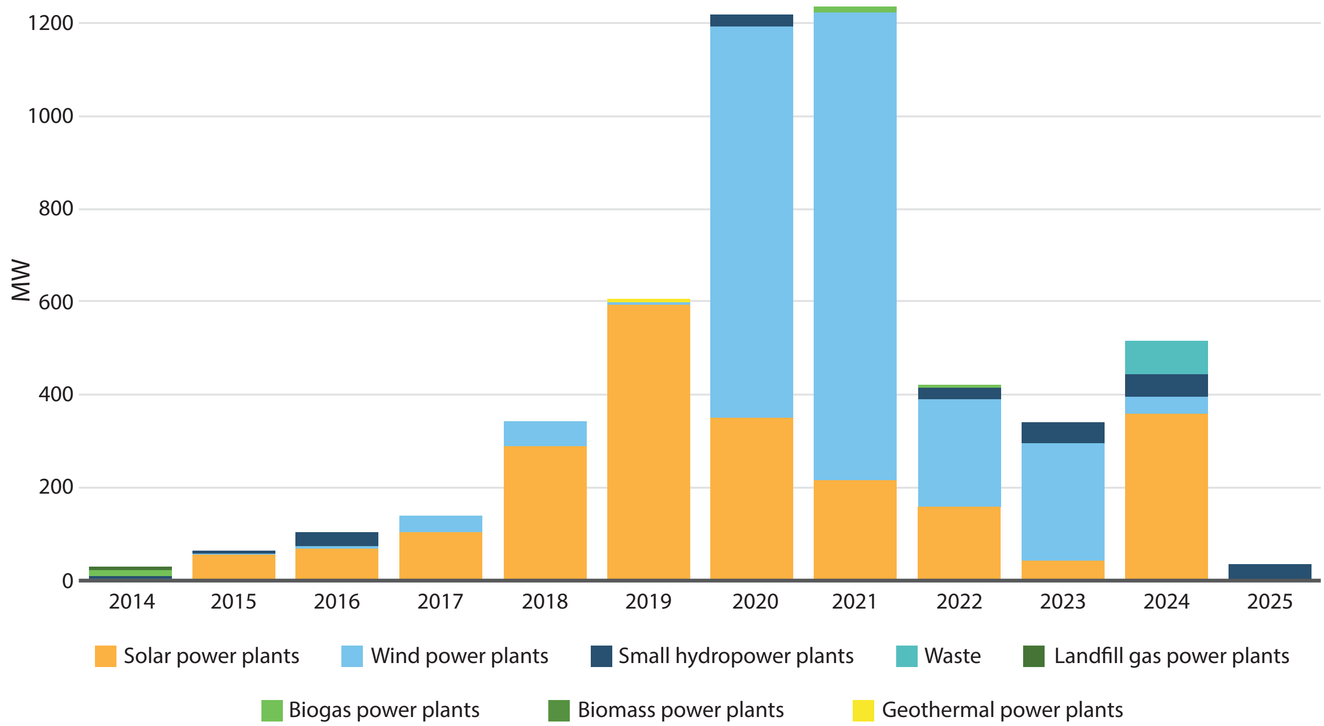
One proposed solution is the deployment of HPSS, which can significantly reduce power supply costs and improve the stability of power supply. An example of a successful pilot project is provided by the village of Menza in Zabaykalsky Krai of the Russian Federation, where HPSS provide local residents with uninterrupted electricity supply [Sharkova et al., 2025].

However, the widespread deployment of such systems in Russia is constrained by technological, economic, and infrastructure barriers, including the low level of localization of critical components such as lithium-ion

and insufficient adaptation of equipment to severe climatic conditions [Kapustina et al., 2025]. Russia is characterized by a clear division of the year into cold and warm seasons and by significant temperature fluctuations within each season. Climatic conditions in Russia affect the operation of virtually all types of power plants. The operating conditions of power plants are closely linked to natural factors that determine fuel and water supply, emission dispersion, the efficiency of cooling systems, as well as the number of sunny days per year and wind potential in different regions.

The Unified Energy System of Russia includes seven interconnected regional power systems—Eastern, Siberian, Ural, Middle Volga, Southern, Central, and North-Western—which are linked to regional power systems within the

[1] https://normativ.kontur.ru/document?moduleId=1&documentId=145742#h1708.
[2] https://rreda.ru/industry/statistics/.



Источник: https://rreda.ru/industry/statistics/.

Fig. 1. Commissioning Dynamics of Renewable Energy Power Plants in Russia

constituent entities of the Russian Federation and operate as an integrated complex providing electricity generation, transmission, and distribution across the country. However, about 700,000 people living in remote regions of the Russian Federation do not have access to power grids and rely on diesel generators for electricity generation. Diesel fuel is delivered to remote areas slowly and with considerable logistical difficulty, while electricity generated from diesel fuel is expensive.

The cost of electricity supplied from the Unified Energy System of Russia to industrial consumers is comparable to the cost of power supply from their own generating facilities, including the capital costs of their construction. Against the background of rising electricity and heat tariffs, this stimulates the development of distributed generation and encourages some consumers to move away from centralized power supply. As a result, an increasing number of consumers are considering the establishment of their own electricity generation facilities.

Thus, the key technical and economic characteristics and challenges of energy-isolated territories of the Russian Federation include:

- the predominant use of low-capacity diesel generators (up to 1 MW);
- high electricity production costs caused by the relatively low efficiency of diesel generators;
- a significant share of household expenditures on utilities, which, according to [Kapustina et al., 2025], may reach 70%;
- high costs associated with the maintenance of power transmission lines [Kapustina et al., 2025].

Given these factors, the development and operation of hybrid power supply systems in remote regions of the country represent a particularly relevant research topic.

Although the Government of the Russian Federation has approved the General Scheme for the Placement of Electric Power Facilities up to 2035[3], the transition to the deployment of hybrid power supply systems is not explicitly addressed in this document.

The application of hybrid power supply systems integrating RES has both advantages and disadvantages, which will be discussed in this article.

The objective of this study is to investigate the application of hybrid energy-efficient technologies in power supply systems at remote industrial sites, such as construction projects, and to identify ways to improve their efficiency.

The power supply of temporary construction sites is one of the key challenges facing the construction industry. In remote regions such as the Arctic, the Far East, and the Far North, up to 80–90% of temporary power demand is supplied by diesel generators. Fuel costs, transportation ex-

[3] https://www.garant.ru/products/ipo/prime/doc/71599734/.

penses, and high maintenance costs significantly increase overall construction costs.

The issue of construction site power supply is closely linked to the development of construction technologies, infrastructure, and the broader economy. In the early stages of construction development, electricity was supplied through temporary generators and low-voltage temporary networks, which were unsafe and inefficient. Later, large industrial construction projects introduced more reliable solutions, including temporary transformer substations, mobile diesel generator units, and improved cable systems, ensuring safe and stable electricity supply at construction sites.

The use of hybrid power supply systems at construction sites has been studied in international practice for more than two decades. In Russian scientific literature, however, research has focused primarily on general energy systems and renewable energy sources, while the specific features of power supply for construction projects have received considerably less attention. This article seeks to partially fill this research gap by examining the application of hybrid power supply systems in the context of power supply for remote industrial and construction sites.

Within the framework of this study, a comprehensive approach was applied to evaluate the effectiveness of domestic autonomous hybrid power generation units (AHPGU) designed to provide power supply for isolated and hard-to-reach territories of Russia. To determine the level of localization of production of system components, an expert assessment method was employed, based on an analysis of production chains and technological processes of domestic enterprises. The information base of the study included official statistical data from the Ministry of Energy of the Russian Federation on the state of power supply in isolated and remote territories, industry reports from ROSNANO and the International Renewable Energy Agency (IRENA), thematic reviews by professional associations, and scientific publications in the fields of distributed generation and hybrid power supply systems.

2. Overview of Industrial Hybrid Power Supply Systems

A promising area of application of hybrid systems based on RES with a fuel substitution level of at least 50% and small installed capacity in Russia is the power supply of approximately 100,000 facilities and small isolated settlements across the country, including regions of the Far North and the Far East. These facilities include cellular communication infrastructure, meteorological stations, lighthouses, autonomous technical and navigation posts, pipeline route consumers along oil and gas pipelines, electrochemical protection stations for pipelines, valve control nodes, farms, hunting and fishing facilities, border posts, and other special-purpose installations [Vasilevsky et al., 2017].

Within the framework of this article, a hybrid system is understood as an autonomous power supply system with several sources of electrical energy (generators) using at least two different power generation technologies.

Compared with traditional power supply systems for isolated consumers based on diesel generator units, hybrid systems provide several advantages. These include not only a reduction in fuel consumption and the cost per kilowatt-hour but also a significant reduction in service and maintenance requirements. This is particularly important for the deployment of autonomous power supply systems for various purposes in remote territories characterized by difficult terrain and severe climatic conditions.

In international practice, several types of hybrid power supply systems have been developed and are currently operating in different countries, including the Russian Federation:

1. 1. Solar-hydropower plants use solar energy to pump water from a lower reservoir to an upper reservoir, creating potential energy that is subsequently converted into electricity when the water is released.

A notable technological solution is the world's only floating solar platform located in Portugal at the Alto Rabagão dam. Projects involving the installation of solar modules on the downstream slopes of dams are also known in Japan, including installations at the Kotani (5 MW) and Gongen (1.76 MW) dams. The largest solar-hydropower plant in the world (850 MW) is located in China and represents a striking example of hybrid hydro-solar generation integrated with the nearby Longyangxia hydropower plant (1280 MW) and coordinated with its operation[4]. In Russia, the possibility of using dam structures and adjacent areas of hydropower plants for the installation of solar modules has not yet been considered.

2. A hybrid wind-hydropower plant combines wind turbines with a pumped-storage hydropower facility to ensure stable electricity generation.

In 2022, the Swedish energy company Vattenfall commissioned the first hybrid power plant "Haringvliet" in the Netherlands, which integrates solar photovoltaic generation, wind generation, and an energy storage system. The facility consists of a solar PV plant with a capacity of 38 MW and a wind power plant with a capacity of 22 MW (six turbines), complemented by 288 lithium-ion batteries installed in 12 maritime containers[5].

3. 3. A floating hybrid solar-wind power plant represents a new and technologically complex solution developed by SolarDuck (Netherlands) in cooperation with Italian partners. The Corigliano project with a capacity of 540 MW is planned to be constructed off the southern coast of Italy in the Ionian Sea and commissioned in 2028.

4. Battery energy storage systems continue to be widely used and successfully developed. When operating

[4] https://econet.kz/articles/178271-gibridnaya-energetika.
[5] https://www.in-power.ru/news/alternativnayaenergetika/44487-vvedena-v-stroi-gibridnaja-vetro-solnechnaja-elektrostancija-s-nakopi.html.

in hybrid mode with a diesel generator, they provide a high level of efficiency and help reduce operational costs. When used as standalone equipment, battery energy storage systems also represent an environmentally sustainable solution, as they allow energy generated from renewable sources such as solar PV panels and wind turbines to be stored and supplied when required[6].

5. A unique hybrid energy concept involving energy generation from marine algae is planned in Germany[7]. A building designed for the International Building Exhibition in Hamburg in 2014 features a façade covered with bio-adaptive louver panels containing marine algae. Each panel functions as a flat bioreactor containing algae. In addition to providing a suitable environment for algae growth, these panels create shading for interior spaces. The bioreactor also captures thermal energy released by the algae, which is subsequently collected and used to meet the building's energy needs.

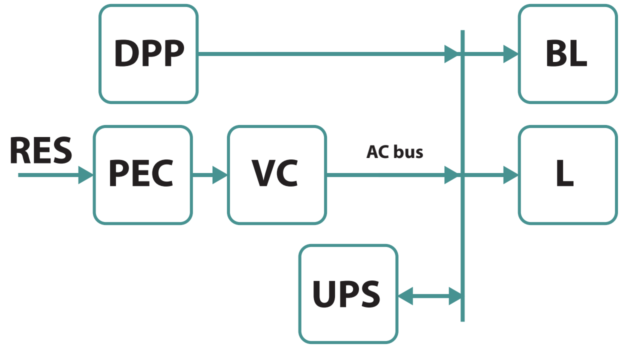
Within the context of hybrid systems, it is also important to consider the demand of the construction industry for a reliable energy source, particularly during the construction of large industrial facilities in remote locations. This demand can be met only through the deployment of autonomous hybrid power supply systems located near the construction site.

Currently, temporary power supply for construction sites in Russia is typically provided through two main solutions depending on the required capacity[8]:

1) connection via a temporary transformer substation;
2) deployment of on-site power transformers.

In recent years, generators have played a key role in providing electricity at all stages of construction, serving as the primary, backup, or emergency power source in locations remote from centralized power supply systems. The choice of generator type depends on the characteristics of the construction project, its power demand, fuel availability, and environmental requirements. In most cases, diesel power plants and diesel generator units are considered universal and reliable options during the design of construction site electrification projects. However, the use of generators as the sole source of power for electricity supply, lighting, and dewatering at construction sites is not always justified under current conditions due to high fuel costs, noise generation, harmful atmospheric emissions, the need for preventive maintenance, and voltage fluctuations that may damage equipment. Additional challenges include the limited capacity of generators and the decline in operational and economic efficiency associated with high fuel consumption, the need for regular maintenance, and the risk of downtime.

Within the framework of this study, a hybrid power supply system for a large construction project is defined as a system designed to fully or partially replace electricity supplied from the urban power grid while simultaneously functioning as an uninterruptible power supply source (Figure 2).



Note. DPP — diesel power plant, RES — renewable energy sources, PEC — primary energy converter, VC — voltage converter, UPS — uninterruptible power supply, L — load, BL — ballast load.
Source: [Trofimova, Zatsepina, 2023].

Fig. 2. Hybrid Power Supply System with a Backup Diesel Power Plant

Hybrid power supply systems involve the use of multiple energy sources. Electrical energy is generated using solar photovoltaic panels, wind turbines, or other conversion technologies. Thermal energy for heating systems, domestic hot water supply, and industrial processes can be generated using solar thermal collectors (flat-plate and evacuated tube), geothermal systems, and other thermal energy conversion technologies. The integration of different RES technologies and the use of a unified control system to ensure their coordinated and efficient operation constitute the basis of a stable hybrid power supply system [Meirbekova, Myrzabek, 2022].

Among the key advantages of hybrid power supply systems for large construction projects are the following [Kamanina et al., 2023]:

- diversity of energy sources (solar, wind, hydropower, thermal energy, biomass, diesel fuel, etc.), allowing the system to optimally utilize available resources depending on specific conditions and operational requirements;
- enhanced reliability, since the use of multiple sources reduces the risk of outages or operational failures and ensures that electricity demand can always be met;
- significant cost reduction when more than one energy source is used, provided that careful system design is undertaken to select the most suitable energy generation technologies for the given conditions;
- reduced environmental impact, as hybrid systems incorporating RES make electricity generation more environmentally sustainable;

[6] https://www.atlascopco.com/ru-kz/construction-equipment/resources/generators-guide/why-battery-based-hybrid-energy-storage-solutions-represent-the-future.
[7] https://www.vzavtra.net/eko-zdaniya/pervoe-v-mire-zdanie-s-energoobespecheniem-ot-morskix-vodoroslej-budet-postroeno-v-germanii.html.
[8] https://энерготрест.рф.

- flexibility and adaptability, since hybrid power supply systems can be adjusted to different climatic conditions and customer requirements through integrated battery energy storage systems (BESS);
- reduction of electricity losses, as BESS integrated into hybrid systems enable surplus electricity generated during periods of low demand to be stored and subsequently supplied to the network;
- independence from centralized power supply, since hybrid systems can be deployed in remote and hard-to-access locations where connection to the power grid is not feasible.

Practical experience shows that when battery energy storage systems are used in autonomous hybrid power supply systems, several specific factors must be taken into account. In particular, the service life of battery energy storage systems in autonomous RES-based energy systems may be shorter due to uneven power generation caused by weather variability and seasonal fluctuations. For this reason, when designing hybrid power plants based on RES technologies, it is necessary to consider the climatic conditions of the region and to select energy storage technologies that meet the requirements for durability, reliability, and economic efficiency. According to a group of Russian researchers led by Professor V.A. Zubakin, the classification of hybrid energy systems depends on the operational objectives defined by the customer [Zubakin et al., 2024]. At modern construction sites, hybrid power supply systems are increasingly used as an optimal solution for the electrification of remote rural areas [Ogunlana, 2017] and isolated construction sites where expansion of the centralized power grid is technically difficult and economically inefficient. Depending on the characteristics of the facility and the required power parameters, several sources can be combined to provide electricity for modern construction sites, including grid connection, generators, solar photovoltaic panels, and wind turbines[9].

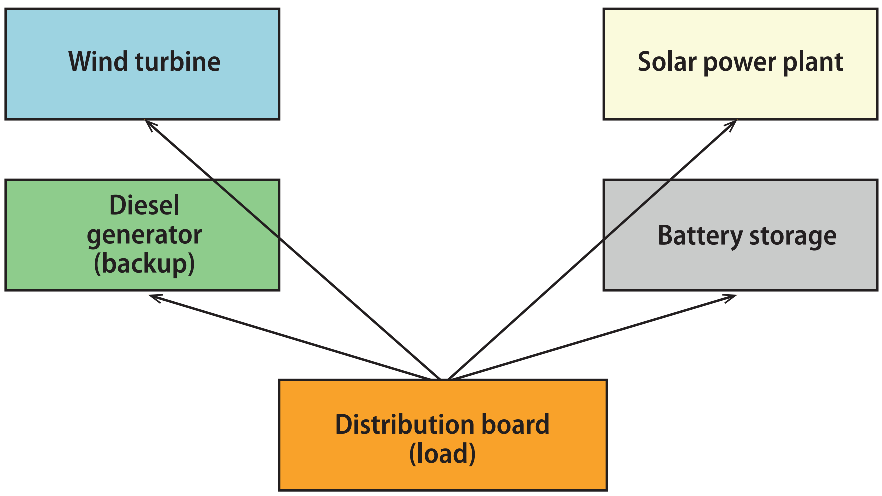
Each of these energy sources has specific characteristics and limitations that must be considered when designing a construction site power supply system. For example, low temperatures typical of many regions of the Russian Federation pose a serious challenge for electrical equipment. Battery capacity decreases rapidly, cables become brittle, and generators may fail. Addressing these challenges requires the use of modern materials and technologies that are resistant to subzero temperatures.

The ability of electrical substations to operate autonomously is a critical factor when construction sites are located far from existing power grids. In such conditions, the role of backup power sources—such as diesel generators and battery energy storage systems—becomes particularly important and must be carefully considered and integrated into the overall power supply design.

In recent years, the decarbonization of the construction industry and the transition to sustainable technologies have received increasing attention. The Low-Carbon Development Strategy of the Russian Federation up to 2050[10] explicitly emphasizes the need to reduce the carbon footprint of the construction sector. This highlights the importance of identifying alternatives to diesel-based generation for temporary construction site power supply.

3. Research Methodology

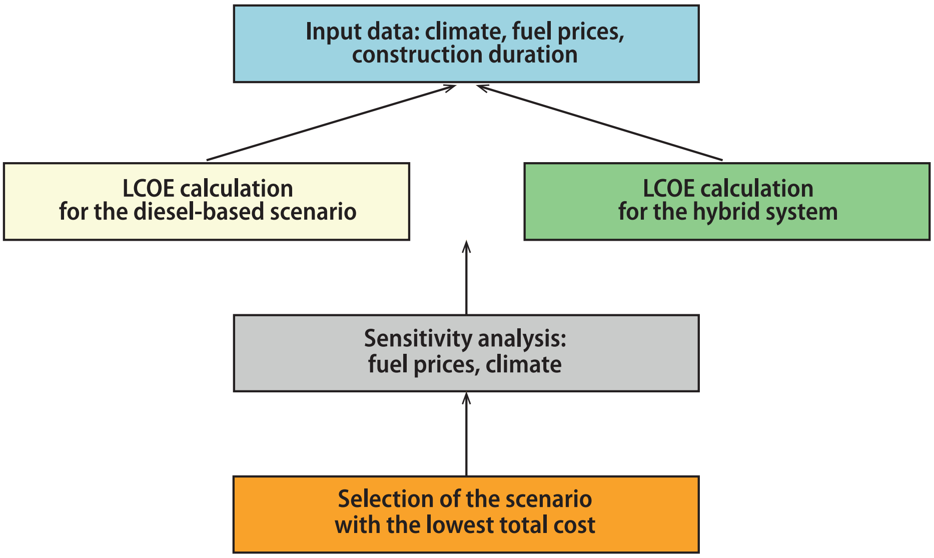
The object of the study is the power supply of large construction projects located in remote areas.



Source: compiled by the authors.

Fig. 3. Hybrid Power Supply System Architecture for a Construction Site

[9] https://energy-systems.ru/main-articles/proektirovanie-elektriki/effektivnoe-proektirovanie-elektrosnabzheniya-stroitelnoy-ploschadki-klyuchevye-aspekty-i-luchshie-praktiki.
[10] http://government.ru/docs/43708/.



Source: compiled by the authors.

Fig. 4. Algorithm for Selecting the Optimal Power Supply Scenario for a Construction Site

The subject of the study is automated hybrid power supply systems for large construction sites implemented in different countries worldwide.

All construction equipment—cranes, hoists, drilling rigs, most types of concrete mixers, air heaters, and lighting systems—operates on electricity. Interruptions in electricity supply or a complete shutdown of power supply lead to construction delays and negatively affect construction quality, ultimately resulting in financial losses.

Power supply for remote construction projects has a specific characteristic: the need for the rapid deployment of electricity supply of standard quality to mobile electrical loads, together with the ability to regulate electrical loads to ensure the mobility of construction machinery and equipment [Orlov, 2016]:

Within the framework of this study, two power supply scenarios for large construction projects are compared. The first scenario represents the conventional diesel-based approach, relying on diesel generators and fuel delivery logistics (Figure 3). The second scenario involves a hybrid power supply configuration consisting of a Condor Air 10 wind turbine, AXITEC AC-375MH/144V solar photovoltaic modules, Delta GX 12-200 battery energy storage units, and a Growatt inverter (Figure 4).

3.1. Methods of Analysis

The evaluation of the economic performance of industrial energy systems is widely addressed in the scientific literature. Particular attention is given to economic indicators such as LCOE, IRR, NPV, profitability, and payback period [Mokshin, 2024].

In Russian practice, the evaluation of energy projects most commonly relies on indicators such as the capacity utilization factor and the payback period. At the same time, the Levelized Cost of Energy (LCOE) is also applied in analytical assessments, including those used by the industry regulator—the NP Market Council Association, which represents participants in the wholesale electricity market.

It is therefore recommended to incorporate the LCOE metric into Russian evaluation practice, taking into account CO_2 emission costs and sustainability considerations. This approach is consistent with the methodology proposed in [Zubakin, Zhukov, 2024]:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{CAPEX_t + OPEX_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}, \quad (1)$$

where $CAPEX_t$ — capital expenditures in period t, $OPEX_t$ —operating expenditures in period t, F_t —fuel costs in period t, E_t —electricity generated in period t, r —discount rate, t —period index, n —number of periods.

A sensitivity analysis was conducted with respect to the following parameters:

– changes in diesel fuel prices (±30%);
– variations in wind speed (±20%);
– construction project duration (6–24 months).

Figure 3 illustrates the architecture of a hybrid power supply system for a construction project. It also reflects the logic used to compare two alternative power supply scenarios (diesel-based and hybrid) and to select the option with the lowest total cost.

3.2. Results

The economic efficiency assessment of the power supply systems is presented in Table.

Table
Economic Efficiency of Power Supply Systems

Indicator	Diesel-Based Scenario	Hybrid System
Annual costs (mln RUB)	16.4	6.25
Cost savings (mln RUB)	–	10.15
NPV(mln RUB)	–	> 10
IRR (% per year)	–	170
Payback period (years)	–	< 1

Source: compiled by the authors.

The environmental performance of the power supply systems was also assessed:

– diesel-based scenario: >150 t CO_2 per year;
– hybrid system: <20 t CO_2 per year;
– emission reduction: more than sevenfold.

A sensitivity analysis of the power supply systems was conducted:

– if diesel fuel prices increase by 30%, cost savings increase to 12 mln RUB;
– if wind speed decreases by 20%, the economic effect remains positive (cost savings of 7.5 mln RUB);
– if the construction site operates for 24 months, the IRR remains at 145–150%.

3.3. Validation and Discussion of Results

The comparative analysis shows that hybrid power supply systems provide clear advantages and make it possible to:

– reduce the cost of temporary power supply by 40–60%;
– increase the investment attractiveness of construction projects;
– reduce the environmental footprint.

Similar effects have been reported in the application of hybrid systems for power supply at large industrial facilities in several countries:

– Germany—cost savings of 35–50% when hybrid systems are used [Jacobson et al., 2022];
– China—cost reductions of up to 60% at construction sites in north-western regions [Zhao et al., 2023];
– United Arab Emirates—carbon emission reductions of up to 70% [Kumar et al., 2022].

The main risks associated with the operation of hybrid systems include the high cost of battery storage and their dependence on climatic conditions. However, when solar and wind generation are properly combined and supported by modern energy management systems, these risks can be significantly reduced.

Figure 3 presents a schematic representation of a hybrid power supply system for a construction site, illustrating the integration of renewable energy sources (wind turbines and solar power plants), battery storage, and a backup power source within the overall power supply architecture of the facility. The flow diagram shows the sequence of analysis: from initial input data to the calculation of LCOE for the diesel-based and hybrid scenarios, followed by sensitivity analysis and the selection of the power supply configuration with the lowest total cost.

Conclusion

The analysis of domestic practice shows that combining renewable energy sources with backup generation units to form hybrid power supply systems can ensure more cost-effective, environmentally sustainable, and reliable electricity supply under varying demand conditions compared with the use of single-source energy systems.

One of the key issues in designing a hybrid system for temporary construction site power supply is determining the optimal composition and capacity of its components in order to meet the required load while minimizing capital and operating costs. The implementation of hybrid power supply systems for temporary construction sites can significantly reduce costs and improve the environmental sustainability of construction activities. Within the framework of the authors' "Wind Map"[11] project, a model scenario was developed for a construction site with an estimated load of 100 kW and an analysis horizon of 12 months. The results indicate that annual cost savings exceed 10 million RUB, the internal rate of return exceeds 170%, and CO_2 emissions are reduced by more than sevenfold compared with the diesel-based scenario.

Most countries and companies have set the goal of achieving carbon neutrality by 2050 through the integration of green technologies into national energy systems. The global transition from traditional energy generation methods to alternative energy sources is expected to lead to significant structural changes in the global economy. In the long term, these changes may result in the loss of a substantial number of jobs, social unrest, and subsequent economic crises.

[11] "Wind Map" is a digital tool designed to optimize the costs of temporary power supply at construction sites, developed on the basis of the authors' analytical calculations. A project presentation is available upon request.

References

Ageev A.I. (2018). Is It Possible to Plan in an Era of Turbulence? *Strategic Planning in the Energy Sector*, 3: 3-8. (In Russ.)

Vasilevsky N.S., Kuvaldin A.E., Zhornova O.N., Filippovsky N.F. (2017). Prospects for the Use of Hybrid Power Installations in Russia. In: *Energy and Resource Saving. Energy Supply. Non-Traditional and Renewable Energy Sources*: Proceedings of the International Scientific and Practical Conference of Students, Postgraduates and Young Scientists, Yekaterinburg, December 11–15, 2017. Yekaterinburg, Ural Federal University: 119-123. https://elar.urfu.ru/handle/10995/57788. (In Russ.)

Zubakin V.A., Zhukov P.A. (2024). Economic Efficiency of Power Plants Based on Renewable Energy Sources Using the LCOE Indicator as an Example. *Plumbing. Heating. Air Conditioning*, 10: 72-75. https://www.c-o-k.ru/articles/ekonomicheskaya-effektivnost-elektrostanciy-na-vozobnovlyaemyh-istochnikah-energii-na-primere-pokazatelya-lcoe. (In Russ.)

Zubakin V.A., Yusupov K.N., Shchaulov V.V., Minaev I.S. (2024). Hybrid Renewable Energy Complexes for Power Supply of Remote Industrial Facilities. *Plumbing. Heating. Air Conditioning*, 8: 62-67. https://www.c-o-k.ru/articles/gibridnye-kompleksy-vie-dlya-energosnabzheniya-udalennyh-promyshlennyh-obektov. (In Russ.)

Kamanina M.A., Demidova A.M., Okhlopkov D.O. (2023). Features of a Hybrid Energy System with Renewable Energy Sources and an Energy Storage System. *Bulletin of Science*, 7(64): 321-324. http/osobennosti-gibridnoy-energeticheskoy-sistemy-s-vie-i-sne.pdf. (In Russ.)

Kapustina M.D., Sharkova A.V., Romanov A.S. (2025). Assessment of the Competitiveness of Domestic Autonomous Hybrid Power Installations. *Journal of Eurasian Science*, 17(s1). https://esj.today/PDF/98FAVN125.pdf. (In Russ.)

Meirbekova O.D., Myrzabek B.O. (2022). On the Development of Hybrid Energy Systems. *Young Scientist*, 47(442): 48-53. https://moluch.ru/archive/442/96732/. (In Russ.)

Mokshin M.Yu. (2024). Application of IRR and LCOE for the Evaluation of Renewable Energy Projects. *Financial Economics*, 5: 67-75. (In Russ.)

Mokshin M.Yu., Zhabitsky M.G., Rimskaya O.N. (2025). The State of the Russian Fuel and Energy Sector and Development Paths under the Fourth Energy Transition. *Strategic Decisions and Risk Management*, 16(1): 55-68. https://doi.org/10.17747/2618-947X-2025-1-55-68. (In Russ.)

Ogunlana A.O. (2017). *Prospects for the Application of Hybrid Installations (Based on Renewable Energy Sources) in Small-Scale Power Engineering in Russia*: Master's Thesis. Tomsk, National Research Tomsk Polytechnic University. https://earchive.tpu.ru/bitstream/11683/39843/1/TPU395254.pdf. (In Russ.)

Orlov P.S. (2016). Engineering Measures to Improve the Reliability of Power Supply at Construction Facilities. *Journal of Mining Institute*, 222: 845-851. (In Russ.)

Trofimova E.R., Zatsepina V.I. (2023). Energy-Saving Technologies in Energy Systems Based on Renewable Energy Sources. In: *VI International Youth Scientific and Practical Conference "Energostart"*, November 17-23, 2023. Kemerovo, Kuzbass State Technical University. https://science.kuzstu.ru/wp-content/Events/Conference/energos/2023/energstart/pages/Articles/413.pdf. (In Russ.)

Sharkova A.V., Kapustina M.D., Romanov A.S. (2025). Experience in the Development of Hybrid Energy Systems in Distributed Generation in Russia. *Economics, Labour, Management in Agriculture*, 4: 87-94. DOI: 10.33938/254-87. (In Russ.)

Jacobson M.Z., Delucchi M.A., Cameron M.A. (2022). Accelerating the Transition to 100% Clean Energy. Energy Policy, 169: 113-125.

Zhao X., Zhang S., Tang K. (2023). Techno-Economic Evaluation of Hybrid Renewable Systems for Remote Construction Sites. *Journal of Cleaner Production*, 382: 135-148.

Kumar A., Singh J., Sharma R. (2022). Economic and Environmental Performance of Renewable Microgrids in Construction Projects. *Sustainable Energy Technologies*, 52: 102-118.

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