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Directions for increasing the effective use of regional hydropower sector on the basis of the construction of small hydroelectric stations (on the example of the East Kazakhstan region)

The article considered theoretical aspects of the substantiation of the hydroelectric stations construction in the East Kazakhstan region. The important role of hydro-energetics in the economic and social sphere of any country, which is one of the basic branches of the economy, is shown. It was noted that as a result of violation of financial obligations of the population and enterprises, there were massive disconnections of them from centralized power supply (in small settlements and farms located in the foothill zone, power transmission lines of which were disconnected or even destroyed, which led to a sharp increase in the combustion of solid carbon fuel, chaotic deforestation of forest plantations). The world experience of the maximum deployment of the hydro-potential of a number of countries was studied, even in the presence of alternative energy resources. The hydro-potential of the Republic of Kazakhstan has been identified. The specific features of a particular region have been studied from the point of view of providing it with electricity. A sociological study was conducted of the need to build a small hydroelectric station on the territory of the East Kazakhstan region to solve the problems linked with supplying electricity of the hard-to-reach territories in the region, including providing it to rural consumers and facilities of distant-pasture cattle rearing, mining and exploration facilities, tourist complexes and other facilities. A choice of an alternative hydraulic structure was selected using the hierarchical analysis method to justify the construction of a small hydroelectric station on the Yazovayriver and calculate its installed capacity. The economic substantiation of the innovation project is given, the main types of risks associated with its implementation are identified.

Keywords: energy security, hydro-energetics, small hydroelectric stations, innovative project, efficiency, risk.

In the Message of the President of the Republic of Kazakhstan to the people of Kazakhstan «Strategy «Kazakhstan-2050»: a new political course of the State» Nursultan Nazarbayev outlined ten global challenges of the 21st century, including acute water shortage and global energy security [1].Today, all developed countries increase investments in alternative and «green» energy technologies. And by 2050, their use will generate up to 50 % of all energy consumed. It is clearly that the era of the hydrocarbon economy is gradually approaching its end and a new era is beginning in which human life activity will be based not so much on oil and gas as on renewable energy sources.

Traditionally, Kazakhstan's energy sector is represented by two main sectors: thermal power engineering - 91 % and hydropower - 9 %. The potential of hydropower in Kazakhstan according to the assessment of the European company Pure Nature Energy GmbH is 4 million kW. This is equivalent to the installed electric capacity of EkibastuzSDPP 1 [2].

At present, a stable economic situation in Kazakhstan allows and requires a clear definition of priorities in the development of hydropower. The deficit of maneuverable generating capacity to cover peak loads, associated with a low proportion of hydroelectric power plants in the structure of the generating capacity of the unified energy system (UES) of Kazakhstan, leads to the dependence of the country's energy sector on neighboring countries. This is already becoming a matter of energy security.

Hydropower, being one of the basic branches, plays an important role in the economic and social sphere of any state. Therefore, the electric power complex is defined as one of the priority sectors of the economy of the Republic of Kazakhstan and is viewed as a dynamically balanced system «energy - economy - nature - society» with sustainable development of the electric power industry based on new highly efficient technologies and constant reduction of the energy intensity of the country's gross domestic product.

The legal basis for the modern development of hydropower in Kazakhstan are the current laws of the Republic of Kazakhstan «On Electricity» [3], «On Electricity Supply and Energy Efficiency Improvement» [4], and the Concept for the Development of the Fuel and Energy Complex of the Republic of Kazakhstan until 2030 [5].

World experience shows us the global tendency of maximum development of hydro potential, even if there are alternative energy resources. A striking example is Norway, which has large reserves of natural gas,

whose energy is 100 % based on hydroelectric power stations (HPPs). At present, the hydro potential is mastered: in Germany - by 95 %; in the UK - 90 %; in Japan - 84 %; in the United States - 82 %; in Russia it is 20 %. According to the estimates of the Kazakhstan Government, the hydro potential of the republic is about 170 billion kWh per year, while 62 billion kWh are technologically possible for use, 27 billion kWh are economically economical, of which over 8.8 billion kWh per year (14 % of the technically possible). The potential resources of all rivers of Eastern Kazakhstan, the most promising for the construction of hydroelectric power stations, are 42.7 billion kWh, of which technically possible - 20 billion kWh, and economically feasible for practical use - 17 billion kWh, of which only about 5.0 billion kWh.

The using of energy from small watercourses with the help of small hydroelectric power plants is one of the most effective areas for the future development of alternative energy that will reduce the shortages of electricity and capacity, improve the reliability of energy supply to consumers of the unified energy system of Kazakhstan for a certain category of people in remote areas.

Such hydropower plants usually produce less than 100 kW of energy, for comparison, a large house or small farm usually consumes about 10 kW. This is much cheaper and more profitable than the construction of power lines or the operation of diesel installations.

The following domestic and foreign scientists and practitioners were engaged in analysis of the current state and prospects for the development of small hydropower in Kazakhstan and CIS countries, nontraditional renewable energy sources, methods and means of energy and resource saving: A.V.Belosliudov [6, 7], T.T.Sarsembekov [8], L.M.Cetoshnikova [9], V.V.Stafievskaya [10], A.M.Velenteenko [10], G.Zh.Kasymbekov [11] et al.These authors have studied various aspects of the further development of hydropower. However, in our opinion, our regional problems of the energy consumption have not been adequately studied taking into account the needs of the population and the water resources of specific regions that have hydro potential.

Nevertheless, the further development of hydropower in the republic is associated, mainly, with the construction of small hydropower plants in the South Kazakhstan and East Kazakhstan regions (EKO), where problems remain unavoidable due to the unavoidability of using the richest hydro and energy potential of rivers. We have also a need to attract investments in the modernization of the exploited and the construction of new small HPPs, taking into account the interests of the Unified Energy System of Kazakhstan.

At present, we have only three small hydropower stations operate in the East Kazakhstan region with a total installed capacity of 13.78 thousand kW and one micro hydro power plant at the Malo-Ulba Reservoir. On the territory of the East Kazakhstan region on the first stage of the development of hydropower resources of small rivers, there is the possibility of broad construction of new small HPPs and the addition of small HPPs to existing reservoirs with a total capacity of about 350,000 kW and generating clean electricity in the amount of 1 billion 750 million kWh. in year.In addition, it is possible to install a large number of micro hydro power plants in the EKO with a capacity of 10 to 100 kW with a total installed capacity of 1 thousand 100 kW and produce more than 9 million kWh. ina year. In this way, the small hydropower industry will be an integral part of the developing energy system of the EK region and will prove to be non-alternative.

The hydropower potential of small rivers in the East Kazakhstan area was studied in 1935, 1940, 1952, 1962, and also in the early 90s. However, due to the powerful development of heat power engineering, the construction of large hydroelectric power stations and widespread electricity supply from the power system of «Altaienergo», the interest in small hydro power plants was lost.But already at the beginning of the 90s, on the instructions of JSC «Altaienergo», the «Almaty hydroproject» institute fulfilled the «Scheme for placing small hydropower stations on the rivers of the East Kazakhstan region». After the transfer of energy objects into private ownership, energy monopolies emerged, dictating tariffs for electricity and heat.

As a result of violation of financial obligations of the population and enterprises, massive disconnections of them from centralized power supply occurred. This led to a sharp increase in the combustion of solid carbon fuels and chaotic felling of forest plantations.

This situation was especially acute in small settlements and farms located in the foothill zone, the power transmission lines of which are switched off or even destroyed. In the conditions of revival of the village and support of the processing industry of agricultural producers, a stable power supply is required.

In this regard, the return to the use of small rivers is quite timely and right. Small hydropower plants are the closest to the consumer, require small-scale distribution networks and, accordingly, with small losses in networks.

Hydraulic engineering structures of small hydropower plants are created by the simplified schemes with minimal alienation of land. The cost of 1 kW of installed capacity of small hydropower plants is in the range

of 2-7,5 thousand US dollars, and in each case it is formed individually. For instance, in the case of the addition of a small hydro power station to existing reservoirs, its cost will be minimal.

As a pilot variant, an innovative project «Design and construction of the Yazovskaya small hydropower plant on the river. Yazovaya» was proposed. At present, the diesel and petrol-electric units are mainly used for power supply of small dispersed consumers in the village, which have significant short comings - pollution of the environment by exhaust gases and fuel, the difficulty of delivering fuel over long distances, the need for constant maintenance, and high noise.

To determine the necessity and feasibility of building hydroelectric power stations on the territory of the East Kazakhstan area, the Katon-Karagai district, the village of Yazovoye, the Yazovaya River (length 22 km), which flows from Lake Karakol (Yazevoye) height 1685 meters above sea level, a sociological study was conducted, the sample of which amounted to 98 people. The results of the questionnaire survey of local residents to identify the need for electricity are as follows:

1. The question «Do you know about the existence of a small hydropower plant»: 35 % of the respondents answered «Yes», and «No» - 65 % (Fig. 1).

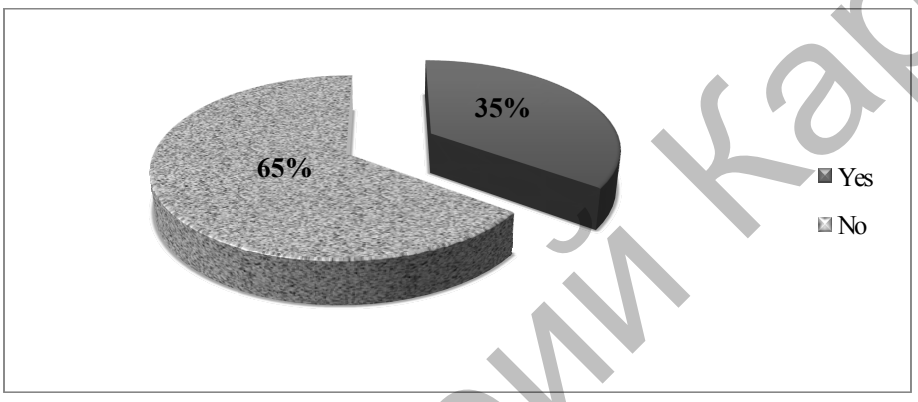

Figure 1. View Poll Results – the question «Do you know about the existence of a small hydropower plant?»

2. The question «What kind of power units did you use?» The following results of the answers presented in Figure 2 were obtained.

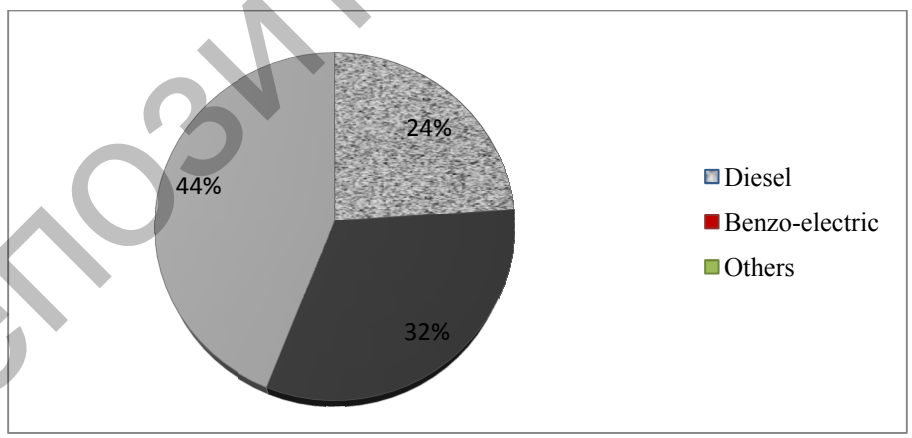

Figure 2. View Poll Results – the question «What kind of power units did you use?»

3. The main disadvantages in using these aggregates, established in order of importance, are shown in Figure 3.

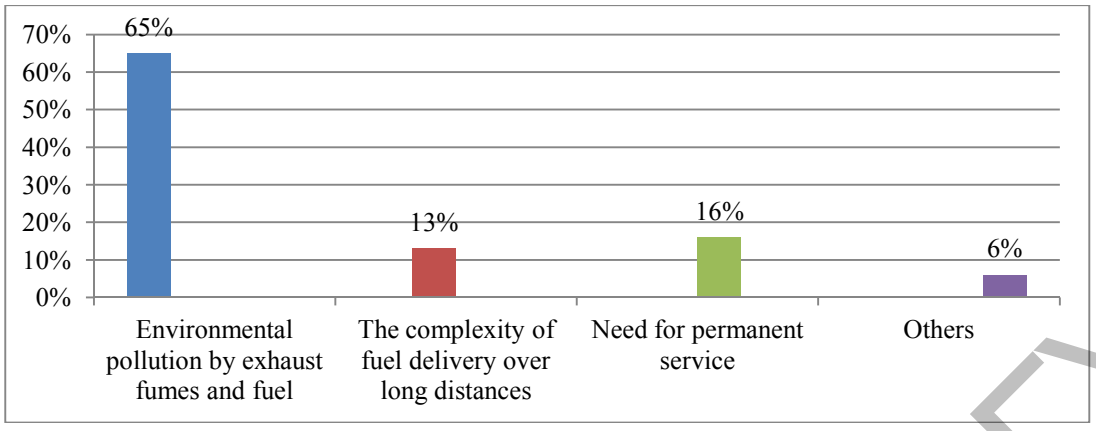

Figure 3. View Poll Results – the question «What major drawbacks do you see inusing process of these aggregates?»

4. Of the total number of respondents, 54 % consider the construction of a small HPP is useful, and only 13 % answered «No», while a significant number of respondents (almost a 1/3) answered that they did not know-33 %.

5. On the question of whether they need this kind of construction, 65 % of the respondents answered «yes», «no» - 10 % and «I do not know» - 25 % (Fig. 4).

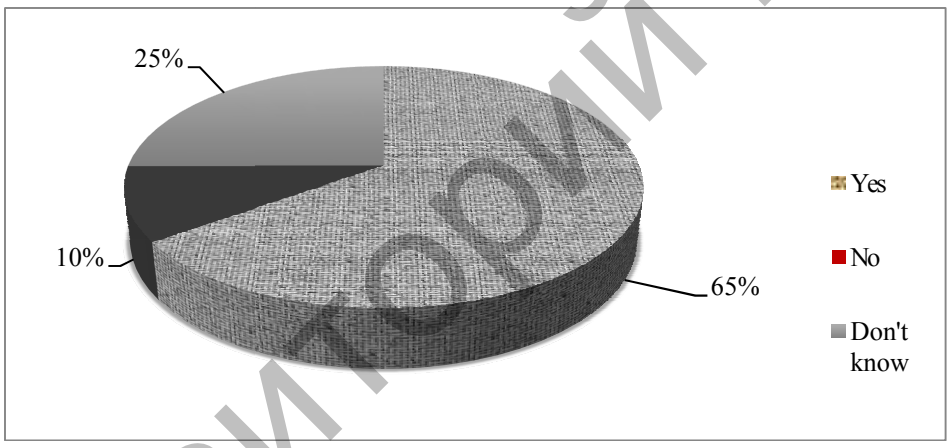

Figure 4. View Poll Results – the question «Do you need a construction of this type?»

Thus, as a result of the survey as a whole, the bulk of respondents noted positively the need for the construction of small hydropower stations on the territory of the East Kazakhstan area. Therefore, further, we proceed to justify the construction of these hydraulic structures in the region.

Before proceeding to the justification of the construction of a small hydropower station in the EK region, it is necessary to submit their classification. So, the small hydropower stations are divided into the following types: low-pressure H <20 m; medium-pressure H = (20-100) m; high-pressure H> 100 m.

In this work, the authors used the hierarchy analysis method (HAM) proposed by T.Saati [12] to select the construction type of a small HPP on the Yazovaya River, which is a systematic procedure for the hierarchical representation of the elements that determine the essence of the problem.

Table 1 shows the matrix of pairwise comparison of the choice of the small HPP type by head.

From the analysis of the calculation results presented in Table 1, it can be clearly seen that low-pressure small HPPs (43.3 %) are on the first place, the second one is high-pressure hydropower stations (41.5 %), in the third place - medium-pressure hydropower stations (15.2 %). Consequently, a small HPP type was successfully chosen - low pressure.

HPPs of small hydropower, depending on the method of use of water energy, are divided into: dam, derivational, dam-derivational and free flow.

Table 1

Matrix of pairwise comparison of the small HPP type'schoice

Type of small HPP	Low-pressure	Medium-pressure	High-pressure	The generalized vector	The normalized vector	Priority
Low-pressure	1	5	1/4	2,083	0,433	1
Medium-pressure	1/5	1	1	0,733	0,152	3
High-pressure	4	1	1	2,000	0,415	2
Total				4,816		

It should be noted that each species has certain features:

– dam HPP: high cost of hydraulic structures, flooding and removal of large areas of economic activity, significant environmental damage;

– derivation hydropower plants take their share of the river's expenditure, by derivation;

– free-flow HPPs are located directly in the river in submerged position and they use the kinetic energy of the water flow. These facilities are environment ally friendly sources of electricity.

Table 2 shows the choice of the type of small HPP, depending on the way water is used.From the analysis of the results of the calculation, it was found that the choice is preferred for the derivational small HPP (35.6 %), in second place - dam-derivational (25.9 %), the third - free-flow (20.1 %) and in fourth place - dams (18.4 %). In this way, it is proposed to build a derivational small HPP on the Yazovaya River.

Table 2

The choice of the small HPP type, depending on the way water it used

Type of small HPP, depending on the way water it used	Dam	Derivational	Dam-derivational	Free-flow	The generalized vector	The normalized vector	Priority
The dam	1	3	1/6	1	1,290	0,184	4
Free-flow	1/3	1	4	1/3	1,415	0,201	3
Dam-derivational	6	1/4	1	1/5	1,823	0,259	2
Derivational	1	3	5	1	2,500	0,356	1
Total					7,028		

Thus, if the head is H = 16 m with an average water flow Q = 2.2 m^3 s, then the power (P) of the Yazovskaya small HPP can be calculated as follows:

$$P = 9{,}81 \cdot Q \cdot H \cdot \eta = 9{,}81 \cdot 2{,}2 \cdot 16 \cdot 0{,}80 = 276 \text{ kW}. \quad (1)$$

The average annual output may be about 1.84 million kWh in a year.

To implement this innovative project, the following costs are required:

1. The investment construction cost of a small HPP on the Yazovaya River, including construction costs - 118.6 million KZT.

2. Annual costs for operation and maintenance of small hydro power plants (fixed and variable) - 11.43 million KZT.

The construction period - 8 months, and the economic life is 25 years.

The technical and economic indicators of the efficiency of the Yazovskaya small HPP are presented in Table 3.

Table 3

Technical and economic performance indicators of Yazovskaya SHPP

№	Name of indicators	Consumption	
		Measure	Q=2,2
1	Power generation	mlns of kW*h	1,84
2	Investmentsin SHPP	mlns of KZT	118,6
3	Annual costs (5 % of capital investments)	mlns of KZT	5,93
4	Tariff of the first level for 1 kW*h. electricity (including VAT - 12 %)	price/kW*h	11,45
5	Revenues from electricitysales	mlns of KZT	21,068
6	Income	mlns of KZT	9,47
7	Payback period	years	5,6

If this innovative project is implemented, risks of a different nature may occur (Table 4). Assessment of the probability of occurrence was given by the expert son the 5 point system (1 – the small estprobability, 5 – the highest probability). Analysis of the data presented in Table 4 shows that the most dangerous types of risks are:

– lack or inadequacy of funding (2,9);
– the fragility of HPP (2,5);
– possible increase in prices for purchased equipment (2,1).

In this way, as a result of the construction of this small hydroelectric power station, it is possible to supply electricity to such settlements as: Yazevoye village, Yazovaya complex, the national park, Berel village, where the open-air museum «Valley of the Kings» is planned.

Despite the fact that this region is already provided with electricity, taking into account the fact that its population is increasing, new facilities are being built, the introduction of new sources of electricity is relevant at the moment.

Table 4

Types of risks and the main measures for their neutralization during the construction process of a small HPP

№	Type of risk	Factors/Causes	Effects/Aftermath	Probability	Risk reduction activities
1	2	3	4	5	6
1	Rise in prices for purchased equipment	Inflation, changing political and economic situation	In creasingin project cost	2,1	1. To assess vendor reliability 2. To set fixed prices in supply contracts
2	Absence / Insufficientfinancing	Prolonged financing. Shortage or lack of funds	The beginning of the project is postponed	2,9	Timely and qualitative expenditure planning
3	Disruption of the delivery time of prefabricated buildings and equipment	The irregularity of the work of manufacturing plants, equipment, materials and transport infrastructure	Delay in the commissioning of the facility	1,6	1. To assess the reliability of the contractor. 2. To provide all penalties for the failure of delivery dates in contracts
4	The problem of attracting specialists	Limited number of specialists	Slow down in project development	1,5	1. Justification for the discovery of a new specialty. 2. Industrial practice for young professionals.

Continuation of Table 4

1	2	3	4	5	6
5	Decreased solvency of the population	Growth of tariffs on the wholesale electricity market, lack of control and errors in billing customers using special tariffs	Theft of electricity, not only in the municipal, but also in the industrial sector	1	Development, creation and wide application of the automated systems of the control and the account of the electric power (ASCAE)
6	Thefragilityof HPP	Dilapidated buildings	The destruction of hydroelectric power stations	2,5	1. Modeling of hydrological processes using real-time models and regimes. 2. Automation of the process of monitoring the state of dams, dams, etc.

During the implementation process of the pilot project, the following results are expected to be achieved:

1. Creation of the special infrastructure for the development of small hydropower in the East Kazakhstan region.

2. In addition to increasing the regulating power of commissioning a new HPP on the territory of the EK region, it also would allow the region to receive cheaper electricity than received through interconnection links from the Pavlodar region, developed at thermal power plants.

3. The low-cost electric power of the hydropower plant contributes to the development of existing and deployment of new energy-intensive industries.

4. High maneuverability of the HPP allows us to assign to them not only the work at the peak of the schedule, but also maintaining frequency, carrying out an emergency reserve.

5. Reducing environmental pollution by reducing the consumption of carbon fuels, greenhouse gas emissions.

6. Formation process of institutional and organizational conditions for the development of small hydropower.

7. Creating a favorable climate for more investment in the development of small hydropower in the region.

8. Development of infrastructure in the areas of development of hydroelectric resources of small rivers, creation of favorable conditions for the processing industry in the countryside, creation of additional jobs.

9. Improving the quality of life, expressed in the life-saving function of the HPP (generating 1 billion of kW of electric power at HPPs instead of TPPs leads to a reduction in the death rate of the population by 100 to 226 people per year).

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Шағын ГЭС құрылысына негізделген аймақтың гидроэнергетика саласын тиімді пайдалануды арттыру жолдары (Шығыс Қазақстан облысы мысалында)

Мақалада Шығыс Қазақстан облысының аумағындағы шағын ГЭС құрылысын негіздеудің теориялық қырлары қарастырылған. Экономиканың негізгі бір саласы болып табылатын, кез келген мемлекеттің әлеуметтік және экономикалық саласындағы гидроэнергетика саласының маңызды рөлі көрсетілген. Атап өтілгендей, халықтың және кәсіпорындардың қаржылық міндеттемелерінің бұзылу нәтижесінде оларды жаппай орталықтандырылған электрмен жабдықтау ажыратылды (тау бөктері аймағында орналасқан шағын ауылдарда және фермерлік шаруашылықтарда, электр беру желілері ажыратылған немесе мүлдем тұралап қалғандықтан, ол, өз кезегінде, қатты көміртек отынды жағудың тез өсуіне, орман екпелерінің бейберекет кесілуіне әкелді). Баламалы энергия ресурстарының болуын ескерумен, бірқатар елдердің гидроәлеуетін максималды игерудегі тәжірибелері қарастырылған. Қазақстан Республикасының гидроәлеуеті анықталған. Нақты аймақты электр энергиясымен қамтамасыз ету тұрғысынан аймақтың ерекшеліктері зерттелген. Аймақтың шалғай аудандарын электр энергиясымен жабдықтаумен байланысты мәселелерді, сонымен қатар жергілікті ауыл тұрғандарын және шалғайдағы мал шаруашылығын, тау-кен және геологиялық барлау объектілерін, туристік кешендерін электр энергиясымен қамтамасыз ету мәселелерін шешу үшін Шығыс Қазақстан облысы аумағында шағын су электрстанциясын салу қажеттілігіне әлеуметтік зерттеу жүргізілген. Язов өзенінде шағын ГЭС салу үшін иерархиялық талдау әдісін қолдана отырып, баламалы гидротехникалық үймеретке таңдау жасалған және ГЭС-тың қуаты есептелген. Инновациялық жобаның экономикалық негіздемесі көрсетілген және жобаны жүзеге асырудағы негізгі тәуекелдері анықталған.

Кілт сөздер: энергетикалық қауіпсіздік, гидроэнергетика, шағын гидроэлектрстанциялары, инновациялық жоба, тиімділік, тәуекел.

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Направления повышения эффективного использования регионального гидроэнергетического сектора на основе строительства малых ГЭС (на примере Восточно-Казахстанской области)

В статье рассмотрены теоретические аспекты обоснования строительства малой ГЭС на территории Восточно-Казахстанской области. Показана важная роль гидроэнергетики в экономической и социальной сфере любого государства, которая является одной из базовых отраслей экономики. Отмечено, что в результате нарушения финансовых обязательств населения и предприятий произошли массовые отключения их от централизованного электроснабжения (в малых посёлках и фермерских хозяйствах, расположенных в предгорной зоне, линии электропередач которых отключены или вообще разрушены), что привело к резкому увеличению сжигания твердого углеродного топлива, хаотической вырубке лесных насаждений. Изучен мировой опыт максимального освоения гидропотенциала ряда стран, даже при наличии альтернативных энергоресурсов. Выявлен гидропотенциал Республики

Казахстан. Исследованы особенности конкретного региона с точки зрения обеспечения его электроэнергией. Для решения проблем, связанных со снабжением электроэнергией труднодоступных территорий в регионе, в том числе с обеспечением сельских потребителей и объектов отгонного животноводства, горнодобывающих и геологоразведочных объектов, туристских комплексов и других объектов, проведено социологическое исследование необходимости строительства малой гидроэлектростанции на территории Восточно-Казахстанской области. Сделан выбор альтернативного гидротехнического сооружения с применением метода анализа иерархий с целью обоснования строительства малой ГЭС на реке Язовая и рассчитана ее установленная мощность. Дано экономическое обоснование инновационного проекта, выявлены основные виды рисков, связанные с его реализацией.

Ключевые слова: энергетическая безопасность, гидроэнергетика, малые гидроэлектростанции, инновационный проект, эффективность, риск.

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