Utilization of Renewable Energy Sources in the Eastern Regions of Russia: Problems and Prospects

SANEEV, Boris G.
Deputy Director, Melentiev Energy Systems Institute, Siberian Branch of Russian Academy of Sciences (SB RAS)
IVANOVA, Irina Yu.
Senior Researcher, Melentiev Energy Systems Institute, SB RAS
TUGUZOVA,Tatiana F.
Senior Researcher, Melentiev Energy Systems Institute, SB RAS

(1) State-of-the-art

Recently utilization of renewable energy sources has become a priority direction in the energy strategy of many world countries. The share of renewable energy sources (RESs) makes up 18% in the structure of the world electricity production. Above 95% of it is produced by hydro power plants (HPPs). The share of wind, solar and geothermal power plants continuously increases. Wind energy is developing at particularly rapid paces: the total installed capacity of wind power plants (WPPs) in the world reached 94 thousand MW, Germany being the undoubted leader in this direction [1]. Solar power plants are used mainly in heat supply systems. At present the area of solar collectors is above 140 million m^2, including more than half of it in China [2].

Renewable energy sources are involved in the energy balance intensively enough primarily because of environmentally clean energy produced by them. The national governments specify a set of measures contributing to utilization of such plants. The measures aim not only at preferential investments and allocation of state subsidies, but preferences in operation, all stimulating energy production by renewable energy sources.

In Russia the RESs share is 19% of the total electricity generation. However, the main part of these sources falls on large hydro power plants accounting for some 98% (Fig. 1). Small (SHPPs) and micro-HPPs, wind and geothermal power plants with the capacity below 30 MW make up 1.9% in electricity production structure. They are not widely used so far, with the exception of small HPPs with the total capacity 700 MW in the Northwestern, Southern, Urals and Central Federal Okrugs, which equals 88% in the structure of small-scale RESs (Fig. 2).The wind and solar energy in Russia is characterized by the lowest indices: the total installed capacity of wind power plants in Russia is 13 MW. The total area of solar collectors amounts to 15 thousand m^2.

The hydro energy is the most developed resource of renewable energy resources in the eastern regions of Russia. The total installed capacity of large HPPs here is above 28 thousand MW, which amounts to 62% of their capacity in Russia.

Fig. 1 - Structure of electricity production in Russia (Current state)

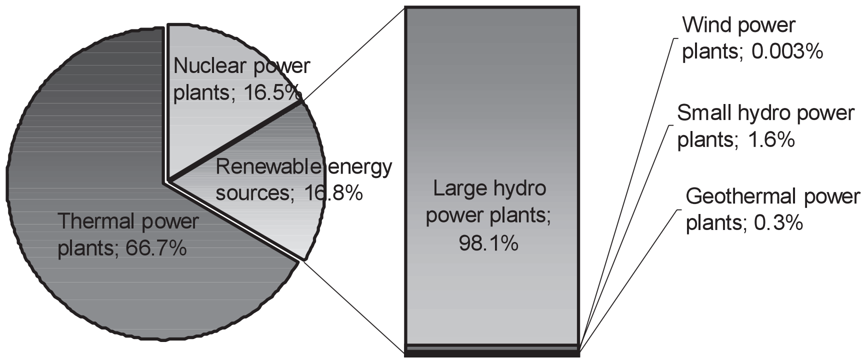


Fig. 2 - Structure of capacities of small-scale renewable energy sources in Russia (Current state)

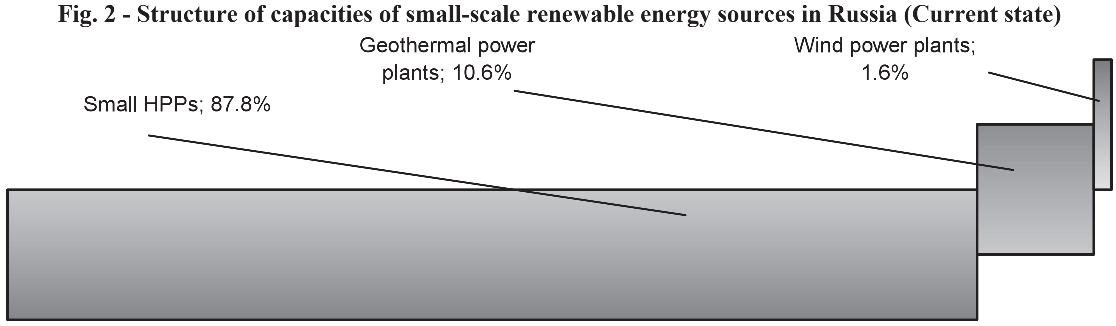


Fig. 3 - Location of renewable energy sources in the eastern regions (Current state)

In addition, a geothermal potential is used extensively enough. All the Russian geothermal power plants are located in the East. The total capacity of the Pauzhetkskaya, Verkhne-Mutnovskaya, Mutnovskaya GeoPPs in Kamchatka Krai, the Mendeleevskaya and Okeanskaya GeoPPs in Sakhalin Oblast reaches 83.7 MW. Geothermal power plants generate 480-490 million kWh/yr.

The rest of renewable energy sources in the eastern regions are utilized insignificantly. Only five SHPPs of the total capacity 29 MW and three WPPs of the capacity 3.25 MW are in operation here (Fig. 3).

At the same time renewable energy sources have a good potential for utilization in the eastern regions for energy supply. Primarily it concerns consumers in the zone of decentralized energy supply that covers more than 80% of the territory.

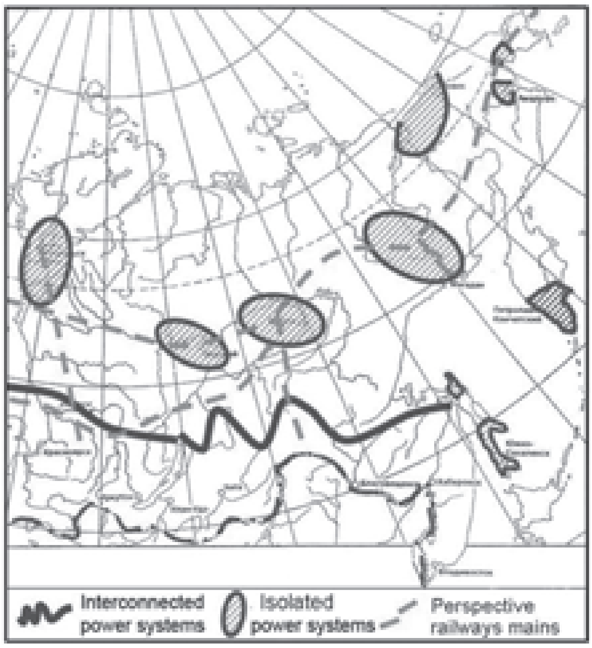
In the East of Russia only the southern areas are supplied with electricity in a centralized way. In the North only a minor part of the territory is supplied from isolated power systems. A great number of consumers in the remaining part are supplied from autonomous energy sources, basically from diesel power plants (DPPs) (Fig. 4). Such isolated consumers are also available in the southern habitable areas, however the share of diesel power plants in electricity production in these areas does not exceed 1%. And in the northern areas of the Far East this index equals 12-15%.

The main problem in energy supply of such consumers is their dispersion over the territory, poor development of transport infrastructure, complex scheme and seasonal character of fuel delivery. These factors cause high prices of diesel fuel (25-30 rub/t and hence, high cost of electricity production by DPPs that reaches 10-15 rub/kWh.

Utilization of renewable energy sources will make it possible to:

- decrease fossil fuel consumption and hence alleviate dependence on its supplies;
- reduce the cost of energy production;
- decrease the negative energy impact on the environment;
- mprove conveniences, style and quality of population life.

Fig. 4 - Zoning of the territory of the eastern regions by the degree of electricity supply centralization



Potential of virtually all renewable natural energy resources in the eastern regions is huge. They concentrate above 80% of the potential of geothermal energy, about 60% of wind and solar energy and almost 70% of the potential of small watercourses in Russia (Table 1) [3].

Table 1 - Gross potential of renewable natural energy resources, million tce

Country, region	Wind energy	Solar energy	Small watercourses	Geothermal energy*
Russian Federation, total	$320 \cdot 10^3$	$2205 \cdot 10^3$	145	$2287 \cdot 10^6$
of which: Eastern regions	$180 \cdot 10^3$	$1342 \cdot 10^3$	99	$1930 \cdot 10^6$

Note. * for hot water supply with the temperature range 70° /20℃

Fig. 5 - Zoning of Russia's territory in terms of the index of mean annual wind speeds

Besides, there are sizeable potential tidal resources on the sea coasts of the Pacific.

The main factors influencing the efficiency of using renewable energy sources are the following:

- intensity, duration and volatility of renewable natural energy resources;
- cost of renewable energy source;
- price and share of displaced fossil fuel.

(2) Utilization efficiency

Wind energy

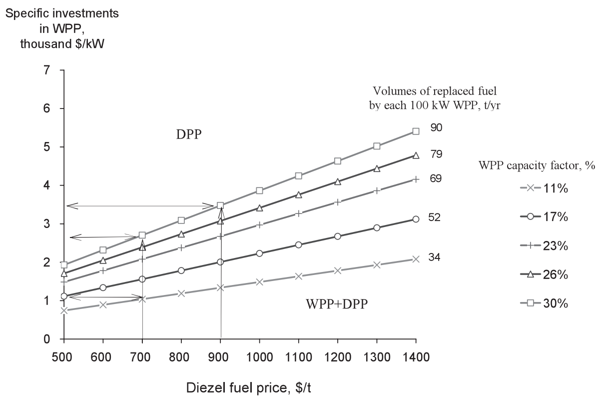
The basic part of the eastern regions lies in the zone with the wind speeds of about 3 m/s (Fig. 5). The mean annual speeds above 5 m/s are observed on the coasts of the northern and eastern seas and also in such local zones as Lake Baikal [4, 5].

Because of irregularity in wind speed over time the autonomous RES-based systems can not completely replace conventional schemes of electricity supply to consumers. They can only supplement them rationally, replacing thus part of fossil fuel.

The projects on WPP construction for decentralized consumers are not commercially attractive, since the average cost of electricity generation by the combination of DPP and WPP will remain higher than the established tariff for population. The project payback is provided by the decreasing fuel costs due to its partial displacement.

The studies by using the technique devised by the authors allowed the maximum values of specific investments in WPP construction projects to be calculated. At these values WPPs are equally economic to the existing

Fig. 6 - Conditions for economic expediency of WPPs utilization



electricity supply scheme (Fig. 6) [6]. The capacity factor that directly depends on the value of wind potential indices has the greatest effect on the efficiency of WPP construction projects.

At the current level of diesel fuel prices 700-900 $/t WPP construction will be economically sound at the specific investments no higher than 1.1-3.5 thousand $/kW for different values of the WPP capacity factor. The lower value of specific investments corresponds to the capacity factor 11-17%, the upper one - to the capacity factor 30%. In this case each 100 kW of WPP capacity displaces 34-90 t of fuel at the diesel power plant.

Small-scale hydro energy

Large HPPs that are extensively used in the East of Russia adversely affect the environment: flood of

Table 2 - Hydro power potential of small watercourses, billion kWh

Country, region	Gross potential	Technological potential	Electricity production at operating SHPPs
Russian Federation, total	1180	372	2.5
of which: Eastern regions	803	256	0.06

Fig. 7 - Zoning of Russia's territory in terms of provision with hydro power resources

fertile lands and mineral deposits, underflooding of urban territories, change of the climate, landscape, terrestrial and aquatic flora and fauna. All these disadvantages are eliminated by using the potential of small rivers with low-capacity HPPs constructed with and without dams.

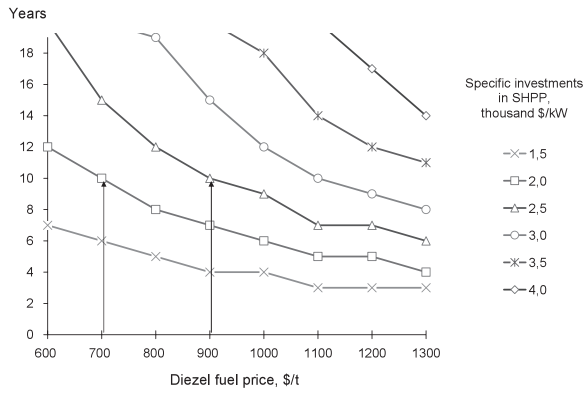
The technological hydro power potential of small watercourses in the eastern regions is estimated to be 256 billion kWh, however only one hundredth percent is used (Table 2) [3].

Small rivers are characterized by the high flow unevenness in seasons, which is a serious barrier for their effective utilization. The largest flow is typical of the spring-summer period during snow melting and raining. The flow volume at this period ranges from 70 to 95% of the annual value. At the winter period the flow decreases: from December to March its total volume is no larger than 10-13% of the annual one. Besides, in winter some rivers freeze to the bottom.

Fig.7 presents zones of possible use of the energy potential of small rivers that run basically in the southern and medium latitudes of the considered regions.

Small rivers can be classified by the bed slope that depends on specific features of local relief. Watercourses of the mountainous areas have a bed slope above 1% and much higher velocity of flow than the rivers of flat land. They are less exposed to freezing to the bottom in winters and more preferable for use, since their flow has higher energy potential. These factors allow utilization of different diversion schemes of small HPPs, when only part of the river flow directed to the canal or arm is used for energy purposes.

Fig. 8 - Conditions for financial-economic attractiveness of projects on SHPP construction



The bed slope of the rivers running along the flat land is, as a rule, less than 1%. The run-of-river SHPPs, both floating and submersible, can be constructed on these rivers.

Conditions for financial-economic attractiveness of the projects on construction of small HPPs that were determined on the aggregate production and financial model show their rather high efficiency. The acceptable terms for SHPP payback at the diesel fuel price 700-900 $/t and the average value of hydro power potential for the eastern regions are reached at the specific investments no higher than 2-2.5 thousand $/kW (Fig. 8).

With the small hydropower plants used seasonally the maximum specific investments shrink to 1.3 thousand \$/kW, while their all year round utilization increases the investments to 3 thousand \$/kW [6,7].

Solar energy

The amount of solar radiation striking the horizontal surface varies greatly throughout the territory of Russia: the total solar radiation and duration of radiance naturally increase with latitude, from north to south. In the east of Russia the highest solar potential is observed in the southern areas where the major economic activities are concentrated (Fig.9) [5].

During a year the largest amount of solar energy is received in summer which affects negatively the efficiency of its use because the maximum energy consumption occurs in winter. Therefore solar power plants can not completely replace energy sources on fossil fuel and should operate complementing them.

With a current price of diesel fuel for consumers in the southern part of the eastern regions that lies in the range of 600-800 \$/t the acceptable payback period for the projects on construction of photovoltaic cells (PC) in addition to autonomous diesel power plant can be reached if the investments in them do not exceed 300-400 \$/m^2 (Fig.10). This proves their non-competitiveness since the current level of PC costs is 1000-1500 \$/m^2.

The solar heat supply systems (SHSS) at a current coal price of 30-50 \$/tce can be economically attractive in the southern part of the eastern regions only if the investments to be held are no higher than 100 \$/m^2 (Fig.10) [8]. Should the cost indices be above 200 \$/m^2, which corresponds to the prices of the Russian and world's producers, the payback period of the projects will exceed 20 years.

At the same time the solar heat supply systems can be competitive in comparison with the boiler plants which use crude oil whose price is 150-180 \$/tce. This type of boiler plants is widely used in the oil production areas in the east

Fig. 9 - Zoning of Russia's territory in terms of solar potential

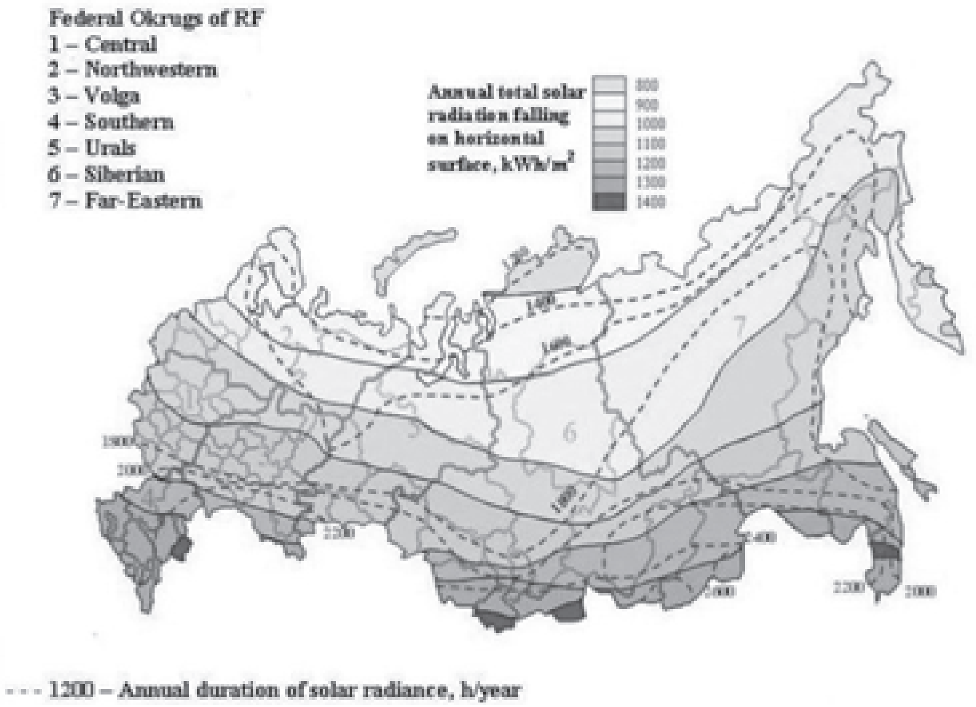
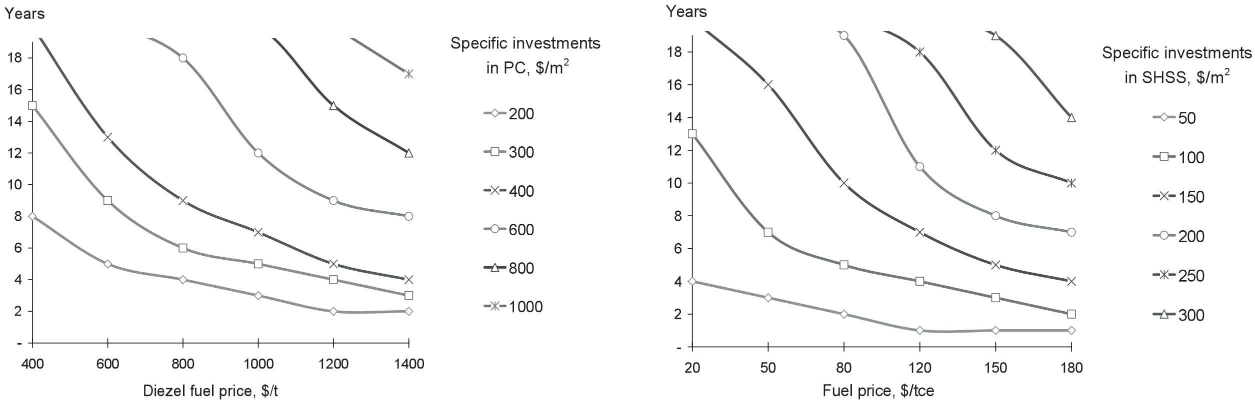


Fig. 10 - Relationship between payback periods of solar power plant construction projects and fuel cost, and specific investments



of Russia.

The efficiency of solar energy utilization depends very much on the environmental factor since small-capacity coal-fired boiler plants make a considerable contribution to the environmental pollution. Currently the boiler plants pay for pollution. This payment is insignificant and represents some form of compensation for economic damage caused by the emissions and discharges of pollutants.

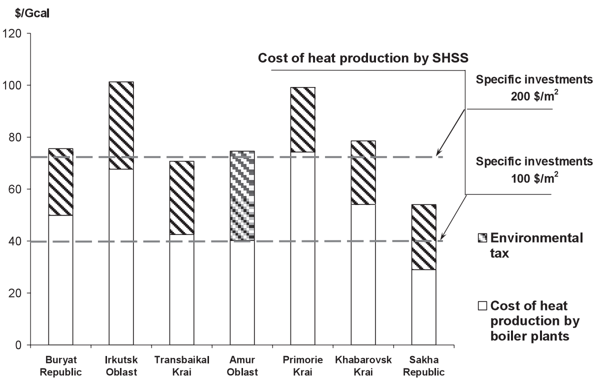
According to the research carried out for the southern territories every 100 m^2 of the solar collector`s area make it possible to replace 33-36 t of coal. This is equivalent to 5-5.5 t of the total ash, soot, sulfur and nitrogen oxide emissions into the atmosphere.

Tightening the environmental requirements for the fossil-fuel boiler plants through the environmental tax will essentially enhance the economic efficiency of SHSS. At present the cost of heat production by boiler plants and by solar heat supply systems is comparable only if the investments are lower than 100 $/m^2 (Fig.11) [8]. Introduction of the environmental tax in the amount of the environmental damage caused by harmful emissions from coal combustion at boiler plants will increase the economic efficiency of investments in SHSS almost twice, i.e. to 200 $/m^2.

Though in the current price situation solar power plants are not competitive we should not forget about a social factor which is impossible to estimate in money equivalent. Solar heat supply systems will make it possible to provide hot water supply which is often unavailable even for the education and healthcare facilities.

It is difficult to estimate the benefit of the advent of electric light or hot water in summer in the places inhabited by small groups of people, at the meteorological stations, camps of reindeer and cattle breeders, etc. because these have never been provided there.

Fig. 11 - Cost of heat production by solar heat supply systems and boiler plants



Application of solar power plants can be indispensable in the zones of special nature management (wildlife areas, national parks, holiday centers, sanatoriums, etc) where tight constraints on environmental pollution are imposed and no other kinds of renewable natural energy resources are available. Based on the studies Table 3 presents the maximum economically efficient specific investments in the renewable energy sources, which take into account transportation, construction and erection works for the conditions of the eastern regions.

The most competitive renewable energy sources in terms of current prices are wind power plants and small hydropower plants. The economic efficiency of solar power plants can be achieved by essentially decreasing specific investments: for solar heat supply systems - by 2.-2.5 times and for photovoltaic cells - by 4-5 times.

(3) Perspective utilization scales

Fig. 12 shows the zones of feasible RES utilization in the eastern regions of Russia in terms of the resource potential.

The most promising areas for wind energy development are Kamchatka Krai; the Kuril Islands of Sakhalin Oblast; Arctic coast of Krasnoyarsk Krai and Sakha Republic (Yakutia); the eastern part of Magadan

Fig. 12 - Zones of feasible RES utilization in the eastern regions of Russia

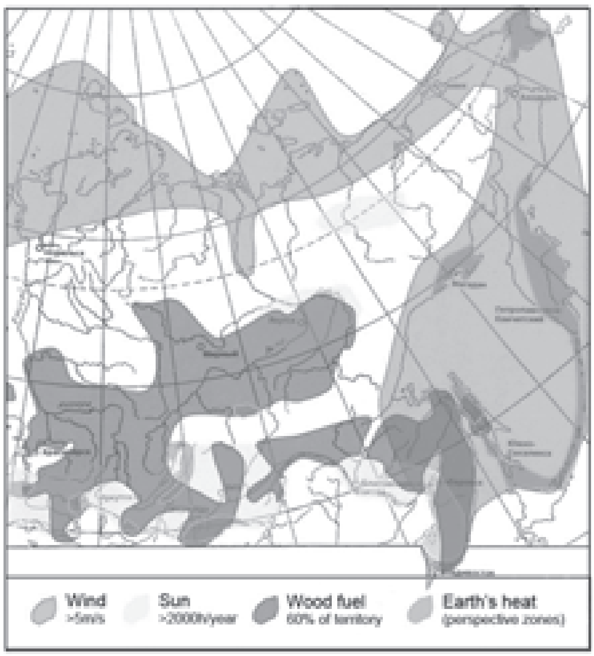
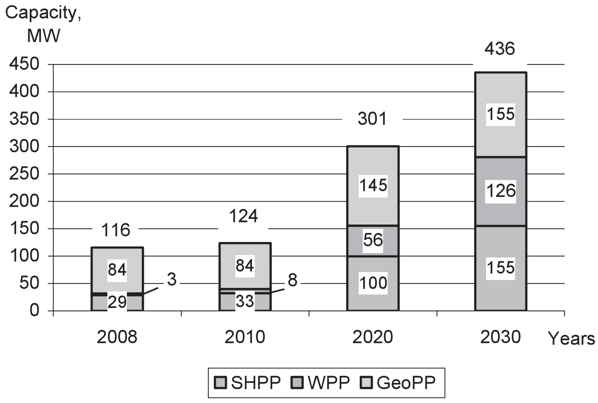


Table 3 - Comparison of the maximum and current values of economically efficient specific investments in renewable energy sources

Technology	Maximum values	Current values
WPP, thousand $/kW	1.2 - 2.5	2 - 2.5
SHPP, thousand $/kW	1.5 - 3.0	1.7 - 2
SHSS, $/m^2	80 - 100	200 - 250
PC, $/m^2	300 - 400	1000 - 1500

Fig. 13 - Location of perspective renewable energy sources in the eastern regions of Russia

Fig. 14 - Dynamics of installed capacity of RES in the eastern regions



Oblast; Khabarovsk and Primorie Krais; the northeast of Chukot AO.

The use of hydropower potential of small watercourses is reasonable in the north of Irkutsk Oblast and Transbaikal Krai; in the mid-latitude zone of Krasnoyarsk Krai and Sakha Republic (Yakutia); as well as in Kamchatka Krai, Buryat and Khakass Republics.

The best conditions for utilizing the solar power potential are in Buryat, Khakass and Tyva Republics; Transbaikal and Primorie Krais; Amur Oblast; Jewish Autonomous Oblast; the southern areas of Irkutsk Oblast and Khabarovsk Krai.

The major reserves of high-temperature geothermal resources of the region are concentrated in Kamchatka Krai and on the Kuril islands. The resources of low-temperature geothermal heat are concentrated on Sakhalin island, in Magadan Oblast, Buryat Republic and Chukot AO.

The rational scales of the use of renewable energy sources were determined on the basis of data on available energy resources on the territories, feasibility studies of RES utilization, the estimation of financial and economic efficiency of specific projects, the range of fuel prices and cost parameters for different types of RES. Fig.13 presents the first-priority sites for location of different types of renewable energy sources.

The total RES capacities to be put in operation in the eastern regions before the year 2030 are estimated at 230-320 MW, including WPP - 80-120 MW, SHPP - 90-130 MW and GeoPP - 60-70 MW [9]. Construction of RES on such a scale will require considerable investments - 22-30 billion rub.

Owing to the implementation of renewable energy projects the installed capacity of RES in the eastern regions of Russia in 2030 will rise by 3-3.8 times against 2007 and make up 436 MW including WPP - 13 MW, SHPP - 159 MW and GeoPP - 154 MW in the optimistic scenario (Fig.14).

By the end of 2030 this will make it possible to annually replace 300-450 thousand tce of fossil fuel to the amount of 6-8 billion rub.

However, the share of RES in the total electricity production in these regions over the period at issue will not change and remain at the level of 1%. Only in some areas of the Far East this value will considerably exceed the average index, for example in Kamchatka it will be 15%.

This so capital-intensive program of wide-scale utilization of renewable energy sources is difficult to implement without active government support focusing on the following points:

- Adoption of the law on state policy in the field of renewable energy utilization;
- Allocation of target subsidies and donations;

- Organization and encouragement of full-scale production of renewable energy equipment on the basis of domestic technologies;
- Creation of testing areas to test key elements of the technologies;
- Development of a system of preferential credits;
- Development and application of a system of tax privileges for those involved in the entire cycle - from equipment design to operation.

REFERENCES

1. National cadastre of Russia's wind energy resources and methodology for their determination. Nikolayev V.G., Ganaga S.V., Kudryashov Yu.I.// Ed. by Dr. V.G.Nikolaev. - M.: Publ. "Atmograph", 2008. - 584 p. (in Russian)
2. World map of solar thermal industry: big business with the sun [Text] // Sun, Wind, Energy. - 2007. - №4.
3. Reference book on resources for Russia's renewable energy sources and local fuels./ Indices by territory / - M.: "IAC "Energy", 2007. - 272 p. (in Russian)
4. Reference book on the USSR climate. Ch.1. Iss. 20-27, 33, 34. - L.: Hidrometeoizdat, 1967. (in Russian)
5. Atlas of solar and wind climates of Russia /Ed.by Borisenko M.M., Stadnik V.V. - St.P.: Main Geophysical Observatory, 1997. - 173 p. (in Russian)
6. *Ivanova I.Yu., Tuguzova T.F., Popov S.P., Petrov N.A*. Small energy of the North: problems and ways of development / Saneev B.G. ed. - Novosibirsk: Nauka, 2002. - 180 p. (in Russian)
7. *Saneev B.G., Ivanova I.Yu., Tuguzova T.F., Petrov N.A*. /The unconventional energy sector in energy saving of isolated consumers in the North areas / Problems of unconventional energy sector: Materials of the Scientific Session of the Presidium of the Siberian Branch of RAS / Russian Academy of Sciences, Siberian Branch. - Novosibirsk: Izdatelstvo SB RAS, 2006. - 201 p. P.55-70 (in Russian).
8. *Ivanova I.Yu., Tuguzova T.F., Simonenko A.N*. Effective directions of small-scale development in Russia's East / Energeticheskaya politika. - 2009. - Iss. 2.- P.45-52 (in Russian)