Efficiency of energy plantations

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***Abstract* — This paper presents an overview of the studies on creation and use of energy plantations. Their economic and environmental benefits are discussed. An economic-mathematical model for the efficiency analysis of energy plantations for fuel supply to remote settlements is briefly described. The results of the study based on this model are illustrated by an example close to the natural-meteorological and price conditions of the Irkutsk Region. Experimental calculations have showed that, at the existing prices, the supply of remote settlements in Siberian regions with fuel from energy plantations may be quite economically viable. The problem of selecting an optimal combination of biofuel from energy plantations and fuel sourced from other regions is discussed. The focus is made on three factors affecting the energy plantations efficiency: (i) the biofuel production, (ii) the delivered (traditional) fuel price, and (iii) the transportation factor depending on the configuration, required area of the energy plantation, and location of the economic center relative to the plantation. Special attention is paid to the problem of energy supply to the Baikal tourist and recreation zone.**

Index Terms - biofuel, renewable energy sources, fuel supply, ecology, energy plantations.

I. Introduction

At present, 81% of world energy production is based on non-renewable, exhaustible resources: solid (coal – 21%), liquid (oil – 38%), and gaseous (natural gas – 21%). Nuclear power plants produce 2% of the world energy, renewable energy sources (RES) – 18% [1].

Globally the RES potential exceeds manyfold the present-day level of energy consumption and may be regarded as the major source of energy production growth in the near future [2-3]. The main renewable energy sources are bioenergy and hydro energy [4]. According to the existing estimates, the bioenergy share equals 14% of the indicated 18% RES share. Other renewable energy sources (wind, solar, tidal) are of an essential local significance, but may hardly become substantial on the global scale [5].

Almost one third of the Earth population (about 2 billion people) still uses biomass in the form of wood [6] as the main energy source. Forests supply 87% of all the biomass used for energy production, agricultural products - 10%, and waste - the remained 3% [5].

Biomass is one of the most promising sources for energy supply to mankind owing to such properties as a substantial energy potential and sufficiently simple renewal both in a natural forest and on man-made energy plantations (where it usually grows faster).

There are two types of energy plantations according to the purpose of the produced energy resources. One of them is the motor fuel production from specially grown plants [7]. The other type to be considered in this paper involves plantations to cultivate wood intended for heating, household and industrial needs.

Biomass is most widely used to produce thermal energy in the household sector (8.9% of the above 14%), in the district heating system (1.2%), as well as for heating industrial premises (2.2%). In smaller scales, it is used for power production (0.4%) and in the transport sector (0.8%) as an alternative to hydrocarbon fuel [8].

Biomass may be an especially effective energy source for its supply to the settlements distant from large transport routes [9]. A high dispersion of settlements and low population density typical of the bulk of Russia's territory generate the need for the energy sources located to the energy consumers as close as possible to reduce transportation costs. By virtue of exhaustibility of hydrocarbons, and their steady price rise, heavy environmental problems caused by coal use, biomass from energy plantations should be regarded as a real prospect to solve the fuel supply problems in Russia. Its use in remote territories may provide their energy independence, increase ecological safety, and mitigate an adverse energy effect on the environment.

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II. Historical background

Since ancient times, wood has been the most important energy source. It was used to heat dwellings, cook meals, make weapons and household utensils. In the 19th century, fire-wood gave way to coal, and since the mid 20th century, oil and natural gas have become the main energy sources. Interest in wood as an energy source rose again in the 1970s as a result of the price shock in the world oil market [10]. Another fundamental reason for gaining interest in biofuel, generally, and in wood fuel, particularly, was aggravation of the environmental situation in the late 20th century because of an increase in harmful emissions into the environment due to the growth in the Earth population and production.

Since then, people have thought of searching for new types of primary energy resources, including renewable ones. The problem of using biomass and wood, in particular, for energy purposes has been studied intensively.

Search for the new biomass production technologies, analysis and optimization of the energy plantations efficiency have become the main avenues for research into energy plantations.

Among the studies on capability of energy forests, one should note those by Dr. V.A. Usoltsev. He is the author of more than 250 scientific works on testing and modeling biological reproductive property and structure of forest phytomass [11-12].

In Irkutsk (Russia), a team of researchers at the Siberian Institute of Plant Physiology and Biochemistry of SB RAS [13-15] develop an accelerated production of wood biomass for energy purposes. By the genetic engineering methods, they create plants which will naturally synthesize growth hormones in larger quantities than usually and, as a result, build up biomass much faster. This makes it possible to essentially reduce the biomass cost price. Another important component in the research is mathematical modeling of the entire process of biomass cultivation and stock on energy plantations for complex optimization of individual components of this process and selection of the means to improve cost efficiency of bioenergy plantations.

The problems of the cost efficiency of biomass production were addressed in a number of papers by foreign researchers [16-38]. O. Hellman, a Finnish mathematician, was the first to study this problem. In 1980, he analyzed the situation, when energy plantations consisted of several sectors [16]. The number of sectors equaled the number of years of wood ripening. Every year, in spring the forest was logged at one of the sectors, and in autumn it was cultivated there. Later, such a model was termed the Finnish model.

Further, O. Hellman evolved this model. In [17], he set the problem of searching for the optimal age to log forest. In 1982, O. Hellman studied the same problem for an energy plantation, on which new afforestation annually was unnecessary, as far as the system was self-reproducible [18]. Such a model cannot be viable because high risks of poor germinating ability of seeds. The absence of purposeful plantings implies chaotic growth of wood, which undoubtedly impedes logging.

In 1986, O. Hellman complicated the model including a possibility of cultivating several species of trees on one plantation [19]. His studies, however, did not consider specific features of cultivating different wood crops, possible variations in fuel production for reliable fuel supply from energy plantations.

In Poland and Sweden, E. Krasuska and H. Rosenqvist, M.Borzecka-Walker conducted large-scale research into assessing the cost price of the biofuel cultivated on energy plantations. They compared the production cost of the biofuel produced from such energy crops as willow, ribbon grass, hemp, silver grass and triticale [20-26]. The results of their research verify a higher economic feasibility of the willow cultivated on energy plantations, as compared with other energy crops.

Since 2006, the studies have been conducted in the Republic of Belarus to assess the cost-effectiveness of producing various types of biomass (willow, grain crops, perennial grasses) for energy purposes [27-32]. An interactive model was developed to calculate the benefit of cultivating energy crops and to evaluate the emissions in the environment. The economic and ecological efficiency of biofuel production from energy plantations was assessed by the example of willow.

In Russia, E.M. Romanov and E.M. Onuchin have been modeling the processes of biomass cultivation and harvesting. Their studies focus on developing the models for operation of bioenergy complexes to optimize technological processes of biofuel production in order to select the most effective technical solutions [33-38]. As a result, the quantitative relations between the parameters of bioenergy complexes and the technological parameters of equipment have been revealed.

Until today, little attention has been paid to a complex investigation into the entire chain of biofuel production, transportation and storage. The efficiency of fuel supply from energy plantations to remote settlements, whose supply with traditional fuels causes high transportation charges, has been insufficiently studied although it is topical for Russia.

The analysis of the efficiency of energy plantations for remote settlements should allow for the costs of the measures to be taken to reliably supply fuel from such sources. Previous studies did not consider effects of random factors that would influence the reliability of fuel supply. We addressed the issues of complex modeling and optimization of a set of measures on reliable fuel supply from energy plantations to remote settlements in [39-42].

III. Environmental benefits

The fuel produced from biomass may come from various sources. The main of them are waste of timber and farming industries, natural vegetation, and specially cultivated energy crops.

Debris and waste of timber and farming industries are ideal raw materials for biofuel production in terms of environmental protection. In actuality, however, their use often proves to be economically ineffective due to high harvesting and transportation costs, as well as unregulated organizational and legal issues concerning the use of logging debris and waste.

The use of natural forests as a biomass source for large-scale cutting down is undesirable, because they save biodiversity of flora and fauna, water resources, and protect soil from erosion.

The use of biomass from energy plantations has a number of environmental benefits compared to traditional energy sources [43]:

- mitigation of climate change problem;
- protection from soil erosion;
- reduction of water pollution;
- maintenance of conditions for the existence of forests, flora and fauna biodiversity.

Over the last 100 years, the mean air temperature on the planet has increased by 0.6°C [44]. For the daily temperature variation, this value is insignificant, but, for the global climate characteristics, this is too much. Combustion of traditional fuels leads to considerable emissions of harmful substances, first of all, carbon dioxide and methane. According to many scientists and politicians such emissions change the biosphere [45]. Replacement of traditional fuels with biofuel will contribute to mitigation of this negative effect [46]. The carbon dioxide is also released at plant biomass combustion. However, the plants release as many harmful substances as they absorb during their growth, which makes the carbon cycle closed.

Energy plantations may be located on the soils unsuitable for traditional agriculture, the places dividing the cultivated areas, or in the flooded territories [47]. Energy crops, like any other plants, reduce losses of nutrients from the soil.

Biomass has remained a major source of thermal energy, especially in the countryside. However, its harvest is often poorly arranged, logging of natural forests harms the ecosystem. Creation of special energy plantations may solve these problems [48].

IV. A model for analysis of the efficiency of energy plantations

We analyze an energy plantation split into the number of sectors, equal to the vegetation period of trees (in years). In one of these sectors, the trees are logged in spring, and the cultivated saplings are planted out in autumn. All process stages, from soil preparation before planting to fuel harvesting, transportation, drying and storage, are sequentially considered, coordinated and optimized. At the same time, an optimal mix of machinery for fulfilling the entire spectrum of necessary operations is selected. The necessary construction of roads, warehouses to store fuel, greenhouses to grow saplings, number of employees, their salaries, taxes, demand for petroleum products are determined. The choice of timber species, its vegetation periods (number of sectors in an energy plantation), a set of agrarian-technical measures are optimized as well.

The cost-effectiveness of an energy plantation, options of possible solutions to individual problems in its creation, and also the price of its products may be determined using the following index of production costs:

$$C=I \cdot E_N+CO, \quad (1)$$

where CO is the annual current costs for energy plantation operation, million RUB/year;   is the investment in energy plantation creation, million RUB;   is the profit-to-investment ratio (in the examples below, it equals 0.12).

The profit-to-investment ratio may be regarded as a value equal to the annual interest paid on borrowed funds (bank and public loans, in the form of bond issuance proceeds) to create energy plantations, or as a value of expected dividends of the investment in the created enterprise, if it is formed as a joint-stock company.

The use of this index of production costs as a minimized criterion to select the options is naturally appropriate in the case of a long-term stability of conditions, under which the considered plantation will function. In the event of highly variable conditions (for example, an essential year-to-year increase in fuel demand of the given settlement), it is pertinent to apply other related indices, for example, discounted costs.

Although, the goal of the research does not include consideration of organizational and legal forms of the companies supplying fuel to remote settlements from energy plantations, we find it appropriate to make some suggestions on this point. To tackle the problems of fuel supply to remote settlements from energy plantations, it seems expedient to establish a non-commercial (but, undoubtedly, self-sustained) enterprise, for example, a municipal one. The enterprise is to arrange the entire production cycle: establishment of a plantation, cultivation, processing, and transportation to the biofuel warehouses. The prices of the biofuel delivered to the population and other enterprises should cover all the incurred costs. At the same time, the targets of the enterprise should not include profit earning, since it will have a monopoly on fuel supply to the given settlement. The settlement's authorities must control its operation.

Calculations on the model for analyzing the efficiency of energy plantations are performed by the step-by-step determination of the values of individual endogenous variables on the basis of varying exogenous indicators (harvest estimates, characteristics and prices of some kinds of machinery, salary levels, etc.). These calculations are presented as calculation techniques for certain components of the investment and current costs.

The considered model allows an iterative selection of an optimal mix of equipment, technologies in certain production process stages, an optimal plant species and time of its cultivation, other partial and system problems. Let us present two of them.

Minimization of the costs of fuel supply to settlements from energy plantations:

$$C(\mathrm{x})\rightarrow\min \quad (2)$$

subject to

$$R(x) \geq Q, \quad (3)$$

$$x \in X, \quad (4)$$

where X is a set of the options of model variable values; $R(x)$ is the size of the annual biofuel production, tce (tons of coal equivalent); Q is the mean annual fuel demand, tce.

Selection of an optimal combination of using energy plantations and fuel sourced from suppliers in other regions:

$$C(x)+p_L L\rightarrow min \quad (5)$$

subject to

$$R(x)+L\geq Q \quad (6)$$

$$L\geq 0 \quad (7)$$

$$x\in X \quad (8)$$

where L is the volume of fuel sourced from suppliers in other regions, tce/yr; p_L is the price of this fuel, given the transportation costs, RUB/tce.

An emphasis should be placed on the following features of the model for analyzing the efficiency of energy plantations.

1. Nonlinearity of many relationships. For example, the relationship between the transportation volumes and the annual fuel production volume is nonlinear.
2. Discreteness of the values of certain variables, in particular, specifications and the number of different-type machinery pieces, number of workers, etc. The integrality conditions complicate the economic analysis, make it impossible to use such an important indicator as marginal costs. Therefore, in the calculations presented below, we apply a model modification, in which the integrality conditions are excluded. Such a modification provides the lower-bound cost estimates. Neglect of the integrality conditions may be justified by the possible partial lease of some kinds of machinery.
3. Uncertainty of the values of certain exogenous indicators (random nature of annual fuel demand; prices of machinery, petroleum products and lubricants) and necessary functional relationships for example, dynamics of woody biomass growth depending on certain weather conditions, etc.

The marginal costs are an important characteristic for economic analysis

$$MC(Q)=\frac{\partial\widetilde{C}(Q)}{\partial Q}, \quad (9)$$

where $\widetilde{C}(Q)$ is the minimum production costs for a specified biofuel volume $R=.Q$

The described model can be used to solve some partial problems in arranging the energy plantation operation, such as determination of an optimal age for the logged timber (number of sectors), selection of timber species that provide a set volume of biomass production at minimum costs, a comparative analysis of options for arranging and implementing agrarian and technical measures.

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V. Model testing

We present the results of a cost-effectiveness analysis for an energy plantation under natural, meteorological, and economic conditions close to those in the southern areas of the Irkutsk Region in recent years.

We consider the poplar plantations in the form of a circle with six sectors. The settlement is located in the circle center. Every six years, plants should be 4-5 m tall, and, in terms of 1 ha, yield about 10-15 tons of timber, which is equivalent to, approximately, 5 tce/ha [49]. In the calculations below, the price of the fuel delivered from other regions (considering transportation costs) is taken equal to 2500 RUB/tce. This assumption is valid if the fuel supplied from other regions is coal. The cost of coal from the largest deposits in the Irkutsk region (Cheremkhovo, Tulun, Zheron, Borodino) varies from 1200 to 1800 RUB/t, i.e. no less than 2000 RUB/tce. In terms of the costs of coal transportation to remote regions, its price equal to 2500 RUB/tce may be assumed for rough calculations.

If fuel is supplied to the settlement only from the energy plantation, then with a demand for fuel of 7950 tce (which approximately corresponds to a settlement with 6000 people), the plantation area should be a little less than 95.4 km^2, with a radius of 5.5 km. The required plantation area will vary proportionally to the change in fuel demand. In this case, the plantation radius, and correspondingly the average distance and the transportation volume in tkm will change nonlinearly. Therefore, the required investment and the current annual costs depend nonlinearly on the fuel demand. For example, for production of 7950 tce/yr, most of the investment (million RUB) falls on: (i) construction of roads (9.9), (ii) purchase of motor transport (9.8), (iii) purchase of tractors and logging equipment (6.6 each), (iv) construction of greenhouses (6.6), (v) purchase of equipment for sapling planting (0,06), and (vi) construction of warehouses (4,3). It is worth noting that, with a growth in fuel production, the investment in motor transport and construction of roads increases much faster than in all the others.

The greatest share in the current costs falls on remuneration of labor and taxes. For example, at the fuel production equal to 7950 tce/yr, the average annual costs of energy plantation operation are 6.7 million RUB/yr. Of this amount, the remuneration of labor is 5.2 million RUB/yr, and the costs of petroleum products and lubricants are about 1.5 million RUB/yr.

Relationship between the costs and fuel production volumes. Figure 1 presents this indicator obtained as a result of the model calculations. Starting with some argument value, the production costs are the increasing convex function of the biofuel production volumes. The costs of supply with the fuel delivered at a fixed price are the linear function of the consumption volumes. The Figure shows that the costs of fuel supply from energy plantations are lower than the costs of the fuel delivered from other regions, if the annual fuel demand is less than 13900 tce. The fuel sourced from other regions is more profitable in the case of large consumption volumes. However, it is valid only within the strict alternative: either supply with biofuel from energy plantations, or supply only with fuel delivered from other regions.

Figure 1 also illustrates that with an increase in fuel consumption, the difference between the costs of delivered fuel and the costs of the same fuel volume from an energy plantation rises at first and reaches the maximum value at a fuel consumption of 7950 tce/yr. At a further growth in the required fuel production from an energy plantation, this difference starts to reduce. It will be natural to assume that the indicated volume is "optimal" for an energy plantation, and its excess is inexpedient.

The data in Fig. 1 also show that energy plantations are unprofitable when they produce small volumes of fuel. This is explained by the availability of the minimum constant costs necessary for the plantation operation that do not depend on the fuel production volumes. In our example for a small settlement (no more than 200 inhabitants) with the fuel demand less than 250 tce/yr, creation of an energy plantation with a staff, machinery, special structures to maintain the plantation is inexpedient.

Selection of an optimal combination of energy plantations and delivered fuel. This problem can also be solved using the offered model. The selection logic is relatively simple: the fuel supply from energy plantations only is feasible for the volumes when the marginal costs of biomass production at energy plantations are below the price of alternative fuel, and when the marginal costs become equal to the alternative fuel price, it is feasible to supply with the delivered fuel (the "combined" option of fuel supply in Fig.1). Such a strategy obviously provides the least total costs on production of different volumes of fuel.

The fuel production volume at energy plantations, at which the marginal costs are equal to the price of alternative fuel, coincides with the above "optimal" volume for the given price of the alternative fuel. In the addressed example, the optimum volume of biofuel production is, as noted above, 7950 tce/yr, with the production costs of such a volume equal to 15.3 million RUB/yr. If this volume were covered with an alternative fuel, the costs would rise to 25.9 million RUB/yr. The difference of 10.6 million RUB/yr is the maximum effect of the energy plantation under the considered conditions, including the indicated price of the delivered fuel.

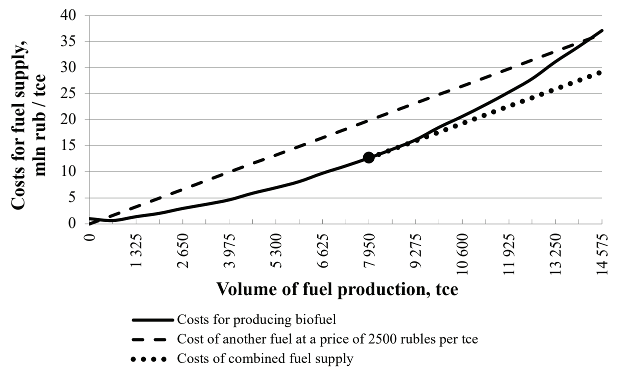

Fig. 1. Cost of delivered fuel and costs for biofuel production depending on the fuel production volume

The data in Fig.2 show that with a rise in the price of delivered fuel, the volume which makes it more profitable to supply fuel from energy plantations increases, and the optimal use of energy plantations rises with an increase in the delivered fuel price. Thus, with an increase in the delivered fuel price to 3500 RUB/tce (i.e. by a factor of 1.4), the optimal production volume increases to 10600 tce (by a factor of 1.3). The maximum effect of energy plantations, in that case, increases to 22.7 million RUB/yr (by a factor of 2.1). The delivered fuel price is essential for determination of rational scales of the energy plantations and their cost-effectiveness.

Transportation factor effect.

Creation of an ideal plantation in the form of a circle with a settlement in its center is not always possible. For example, settlements can often be located near the river or near another settlement. In other words, at the same volumes of fuel production from energy plantations, the

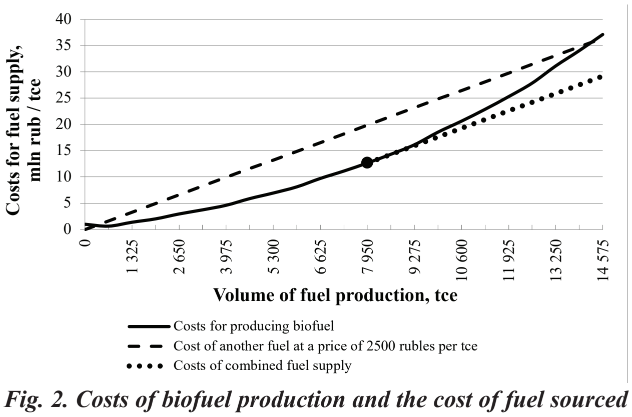

Fig. 2. Costs of biofuel production and the cost of fuel sourced from other regions at its varying price depending on production volume

transportation distance may essentially increase, which raises the production costs.

For example, with a fuel demand of 7950 tce and a double growth in the mean freight distance, the costs of biofuel production increase from 15.3 to 23.2 million RUB/yr (by factor of 1.5). The economic benefit will decrease from 10.6 to 2.7 million RUB/yr (by a factor of 3.9). If the optimal demand for fuel decreases from 7950 to 5300 tce (by a factor of 1.5), the maximum economic benefit will decrease from 10.6 to 6.8 million RUB/yr (only by a factor of 1.6).

The rise in the price of delivered fuel to quite a real value of 3500 RUB/tce with a double growth in the freight distance leads to the optimal fuel production at energy plantations being 5900 tce/yr. The economic benefit, in that case, equals 14.3 million RUB/yr.

The presented calculation results show that the supply of fuel from energy plantations to remote settlements may be fairly cost-effective even in Siberian regions. In addition, it is very important to consider territorial features of certain settlements, their natural and climatic conditions, and price situation.

VI. Expediency of using energy plantations for heat supply to the tourist and recreation zone of Lake Baikal

Over 1 million tourists and vacationers visit Baikal annually. This flow is expected to increase up to 5 million people in the nearest future. However, the region is not ready for such a flood of tourists. Many topical organizational and environmental problems have not been solved yet. Until recently, the main energy supply sources were:

- relatively inexpensive electric power;
- delivered coal (basically, only in sufficiently large settlements with special boiler plants);
- fire wood provided by logging firms and local population, including that from forest sanitation, from burnt places (by many estimates, this is one of the reasons for numerous forest fires).

Not long ago, relatively inexpensive electric power produced in the Irkutsk power system (mostly by hydropower plants) offset the cost-ineffectiveness of combined heat and power plants and provided low electricity rates for the population, which were almost three times as low as those in the adjacent regions. In the near future, the rate is expected to increase significantly (approximately by a factor of 3) in the Baikal near-shore areas of the Irkutsk Region. The rates will equal those in the rural areas of the adjacent regions and republics, which will make the large-scale electric power utilization for heating economically ineffective.

A wide use of coal in settlements, camp sites, and country houses in the territories adjacent to Lake Baikal is both expensive because of long distance transportation, and inexpedient due to environmental constraints. Lake Baikal is a UNESCO World Heritage Site, where the prohibitory regulations of the activities causing damage to the environment, are actively observed. It is hardly possible to provide expensive removal of carbon soot, carbon oxides, sulfur, nitrogen and other harmful emissions from coal combustion at low capacity boiler plants and, moreover, in household ovens.

There are several options of more environmentally acceptable fuel supply to the shore zone of Lake Baikal. These are: the use of natural gas, heat pumps, and timber cultivated on special energy plantations.

Natural gas supply to the Olkhon District is possible from the relatively close large Kovykta gas condensate field (Zhigalovo District of the Irkutsk Region). The distance to the latter equals about 300-400 km, depending on how it is measured: straightly or along roads. Since natural gas is the most environmentally clean fuel, its use at the Baikal shore is especially topical. According to the experts' estimates, there exists a high probability of relatively small gas fields in the Kachug District located closer to the Baikal shore (about 100 km). Based on the data of geologists, there may be small gas fields in the Ust-Orda National District, from which it is closer and easier to supply gas to the Baikal Natural Territory. These small fields may be quite sufficient to cover relatively small fuel demands in the Olkhon District and other territories at the Baikal shore even in the long term.

However, for some unknown reasons, the Kovykta field has not been used even for local needs for several decades. The built gas-fired boiler plants and gas pipelines in the settlements of Zhigalovo and Kachug have been standing idle. In the future, it is planned to construct gas pipelines to supply the Kovykta gas northwards to the export gas pipeline "Power of Siberia". Possibly, the supply of the Baikal shore with the natural gas from the gas field in the Irkutsk Region would be the best project, although it is not so scaled as export.

The use of heat pumps for the heating purposes of the local population and tourist camps located directly at the Baikal shore during wintertime is worthy of consideration. The Baikal water having a constant temperature (about +4°C) will be a heat-transfer agent in this case. Such a heating method is convenient because with a decline in the outdoor temperature, heat pumps will produce more thermal energy. At present, there are three heat pumps on Lake Baikal. Two of them successfully function at the Baikal Museum in the settlement of Listvyanka, the third was installed in the settlement of Tankhoy, but is not run because of the prohibition by the Prosecution Service due to the unresolved issue, whether the water abstraction for cooling in the heat pipes is harmful for Lake Baikal or not.

Thus, wood appears to be the main kind of fuel for the tourist and recreation zone of Lake Baikal, although the scale of its use is an unresolved issue. Campfires, bath houses, cooking over open fire require wood. To some extent, the needs for this fuel can be provided by reasonable use of forest resources in the adjoining territories, including forest sanitation. Undoubtedly, this must be accompanied by active afforestation (the "cut one tree – plant two" principle).

In the future, energy plantations should become the main firewood source to be specially created for this purpose. The areas particularly promising for energy plantations are those most attractive for tourism, i.e. the Maloye More shore (Island of Olkhon, and the Near-Olkhon Area, where the extensive Tazheran Steppe lies), the Bolshoye Goloustnoye area (the territory considered for constructing the so-called Baikal-City). All of these areas have huge land parcels suitable for energy plantations. It is worth noting that, currently, businesses are showing an increasing interest in establishing energy plantations in the Near-Baikal territories based on the results of this study.

VII. Conclusion

Biomass in the form of wood is one of the main energy sources and accounts for almost 14% of the world energy consumption. The use of wood produced at energy plantations may become rather promising for Russia due to the developed transport infrastructure.

Biomass has important environmental advantages over fossil fuels. Its application contributes to mitigation of the climate change problem, decrease in soil erosion, reduction in water basin pollution, maintenance of conditions for existence of forests, improvement in microclimate, to enhancement of the conditions for agricultural activity.

The presented results of the studies on the model for the analysis of the efficiency of energy plantations indicate that, in the existing price situation, energy plantations may be economically effective for fuel supply to the Siberian remote settlements, particularly, for fuel supply to the Baikal tourist and recreation zone. Consideration of environmental benefits of energy plantations in the monetary form, which was not addressed in this study, may provide additional benefits. In this case, one should also consider negative environmental effects of diesel fuel combustion by tractors and motor transport while maintaining energy plantations.

The obstacles to the use of energy plantations for fuel supply to the tourist and recreation zone are associated, strange as it may seem, with the nature protection legislation restricting industrial activity in the central ecological zone of the Baikal natural territory.

In the future, we plan to carry out an economic analysis of possible options and sub-options for energy supply to the tourist and recreation zone of Lake Baikal (including the mentioned gas supply, heat pumps, and other options).

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