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Development of a Geoinformation System for the Design of Wind Power Facilities in the Russian Arctic Conditions

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Abstract. The purpose of the work was to develop the geographic information system (GIS) for the design of wind power facilities in the Russian Arctic conditions, determine its structure and application area, taking into account climatic, topographic, geological, and other features in autonomous regions with extreme temperature values. Such a detailed research is carried out in order to design economically viable renewable energy facilities, reducing regional subsidies and the cost of electricity, as well as to determine the optimal location for the construction of energy complexes.

Analysis of the energy supply systems state in the Arctic regions showed that the main problem is the annual increase in the cost of electricity, which is caused by the limited transport accessibility for the diesel fuel (DF) delivery. An effective solution to the problems associated with improving the reliability of power supply, reducing the cost of electricity, as well as increasing environmental safety for the power supply of decentralized Russian regions with a high wind energy potential is building new wind-diesel power plants (WDPP) and modernization of the existing diesel power plants (DPP) for creation WDPP energy complexes (EC).

1. Introduction

The Russian Arctic region is different for its extreme climatic conditions, including permanent ice cover or drifting ice in the Arctic seas, low population density (1-2 people per 10 sq.km), as well as remoteness from major industrial centers, high resource intensity and the dependence of economic activity. and the sustenance of the population from fuel supplies (northern delivery), food and essential goods from the other regions of Russia. The population permanently living in the arctic climatic conditions is 517 million people, which is about 7% of the total population of the Earth. In Russia, the share of northerners living in the Arctic zone of the Russian Federation (AZRF) is about 1.7% [1]

Based on the annual reports of the regions, analysis of the energy supply state in decentralized territories showed that the energy supply in autonomous regions is carried out mainly by diesel power plants (DPP), which total number is more than 900 with annual output of 3000 MWh and the capacity of 1 GW. The use of DPP in remote northern regions has a number of problems, which are mainly related to the remoteness of the territories and specific climatic conditions [2-5]:very low reliability of energy supply, outdated equipment with a high run-out level of components and elements of DPPs, more than 35% of equipment has run-out level more than 75%, high specific consumption of diesel fuel (DF), complex transport logistics for the delivery of large diesel fuel amounts, the incremental

IOP Conf. Series: Earth and Environmental Science **302** (2019) 012064 doi:10.1088/1755-1315/302/1/012064

costs of local and regional budgets to cover the inter-tariff difference and the constant increase in subsidies, environmental pollution due to improper disposal of fuel barrels (table 1).

Table 1. DPP’s characteristics in various regions of the Russian Federation

The subject of the Russian Federation	DPP, PC.	Capacity, MW	Output, MW·h	Fuel delivery, ths. tons	Cost of fuel delivery, million rub.	Cost of diesel fuel, rub./ton	Cost of electricity, rub./ Wh
Arkhangelsk region	63	46	64440	7,6	523,8	68921,1	to 60
Nenets Autonomous Okrug	36	89	25000	11,12	560,5	50404,7	to 32
The Republic of Sakha (Yakutia)*	137	192,6	325215	740	31300	55500,3	to 36
Kamchatka Krai	181	152,15	151308	30	165	5500,0	to 54
Murmansk region	150	3,8	8500	-	-	-	to 50
Komi Republic	27	58,06	19400	-	-	-	to 15
Chukotka Autonomous Region	46	82,83	97352	145	-	-	to 10,45
Krasnoyarsk region	70	30	98806	62	313,1	5050,0	more 25
Yamalo-Nenets Autonomous District	42	185	1524335	89	4100	46067,4	-
Khanty-Mansi Autonomous Area	47	39,77	71764	11	500	45454,5	-
Sakhalin region	24	41,23	50500	-	-	-	to 16,13
Khabarovsk region	64	8,83	19297	24	1300	54166,7	to 29,02
Magadan Region	13	15,55	280000	-	-	-	to 36,96
TOTAL	901	944,82	2735917	1119,72	38762,4	to 68921,1	to 60

Based on the analysis of energy supply and the use of DPP in autonomous regions for expanding application of renewable energy sources and ensuring the energy self-sufficiency of remote settlements, as well as developing and implementing projects in the field of energy supply and energy efficiency, the main problem in the Arctic regions is identified - the annual rise in electricity price caused by limited transport accessibility for the importation of diesel fuel and other problems associated with the operation of DPP. The cost of imported diesel fuel in the autonomous regions is 615-1540 $/t, of which 30% - 80% is the transport component, and therefore, according to the Center for Energy Efficiency, the federal budget annually allocates more than 77 million dollars for subsidizing electricity tariffs in these regions. In four regions, namely: in the Magadan Region, the Kamchatka Region, the Nenets Autonomous Okrug and the Republic of Sakha, the share of expenditures from the regional budget is more than 50% [6]. Thus, these regions are priority and expedient for the introduction of technologies for improving energy efficiency and environmental safety.

According to the strategy of the AZRF development and ensuring national security for the period up to 2020, one of the key factors influencing the socio-economic development of the Russian Arctic is extreme climatic conditions.. Presently, the socio-economic state of the AZRF is largely characterized by the depreciation of fixed assets, especially the transport, industrial and energy infrastructure and the underdevelopment of the energy system, the irrational structure of generating capacity, the high cost of generation and transportation of electricity.

The relevance of this problem is also demonstrated in the following program documents: "General layout of generating facilities in Russia for the future until 2030", " Basics of the state policy of the Russian Federation in the Arctic for the period until 2020", " Concept for the development strategy of the power industry in the Far East until 2020" in which the key tasks of autonomous Arctic regions energy supply are: improving the reliability of energy supply to consumers and reducing electricity prices [7].

An effective solution to the problems associated with energy supply in the AZRF is the use of renewable energy sources, which will improve energy security by increasing the self-sufficiency of "local" energy resources, reduce energy losses for transportation and energy distribution due to the approach of energy production facilities and consumers, increase the reliability of energy supply and reduce the cost of electricity for the end user by reducing the amount of diesel fuel (northern delivery), improve environmental safety by reducing harmful emissions into the environment from DPP and the amount of diesel barrels.

Thus, in order to make optimal decisions improving energy safety and supply reliability, justify the feasibility of building renewable energy facilities in selected regions, as well as to optimize the design process of renewable energy facilities, in particular, the WPP and EC WDPP, it is proposed to use geo-information systems (GIS) and technologies in conjunction with the developed engineering methodology for assessing wind energy potential in arctic conditions using the WindPRO software package based on a 3-level methodology for estimating wind energy resources in conditions of insufficient climate data [8].

The construction of renewable energy facilities in decentralized areas will facilitate the confronting of difficulties related to energy supply in the AZRF according to the development strategy. The main task of GIS in the field of renewable energy in the AZRF is to create a GIS product, by which optimal economically feasible areas for the construction of renewable energy facilities due to the product's multi-layered nature will be determined.

In the field of development of renewable energy sources GIS are the actual cartographic database with a large amount of information necessary for the design, the formation of the information space about the energy supply object and visualization. Geographic information systems' analysis showed that the optimal software package for creating a GIS in the field of renewable energy for data visualization in the design of WPP and WDPP EC is QGIS (table 2).

Table 2. GIS Characteristics [9,10]

GIS	Access	Programming language	Project file format	Supported geodata formats		Export map to graphic image format
MapInfo	Commercial	development environment (IDE) MapBasic.	text can be viewed in a text editor.	WFS, WMS		bmp, emf, gif, jp2, jpg, png, psd, tiff, wmf. Vector export is limited
ArcGIS	Commercial	console Python, graphical development environments (IDE) for VBA, .Net.	binary file cannot be viewed.	WMS	Monitoring data integrity and topology, especially using a geodatabase (*GDB* – *Geodatabase*).	ai, bmp, emf,eps, gif, jpg, pdf, png, svg, tiff. Full export to vector.

QGIS	Free	console Python, QT Designer to create an interface.	XML, can be viewed in a text editor.	WFS, WMS	A large number of supported formats in the menu, control coding table vector layer.	dxf, ico, pdf, ppm, svg, tiff. Export to raster and few vector formats.

The GIS layers contain the necessary information: existing electrical networks and substations (consumer load charts, number of stations, capacity, electricity generation, amount of fuel delivered, cost of fuel delivery, cost per ton of fuel delivered, cost of electricity, amount of subsidies); resource information containing data on wind energy resources (RES): average annual speed and specific energy of wind flow, determined on the basis of a three-level methodology for the RES assessing in insufficient climate data conditions and engineering methodology for the RES assessing, developed at SEC "Renewable Energy Sources"; on the intended construction sites at different heights; climate information, including information on maximum, minimum and average annual temperatures; topographic and geological information [11-17].

The main GIS layers for the design of the WDPP EC and WPP are presented in the Figure 1.According to the presented layers at the design stage, it is possible to optimize the parameters and operation modes of the power complexes, determine the EC's adapting technology to the northern conditions using the necessary measures, as well as determine the economic efficiency and effective solutions for choosing the construction site [18].

Via the extensive climate information, such as wind speed, direction, frequency, etc., energy production can be determined, which directly depends on these factors.To obtain the resource information for estimating wind energy potential in arctic conditions an engineering methodology has been developed using the WindPRO software package based on a 3-level methodology for estimating RES in the conditions of insufficient climate data.

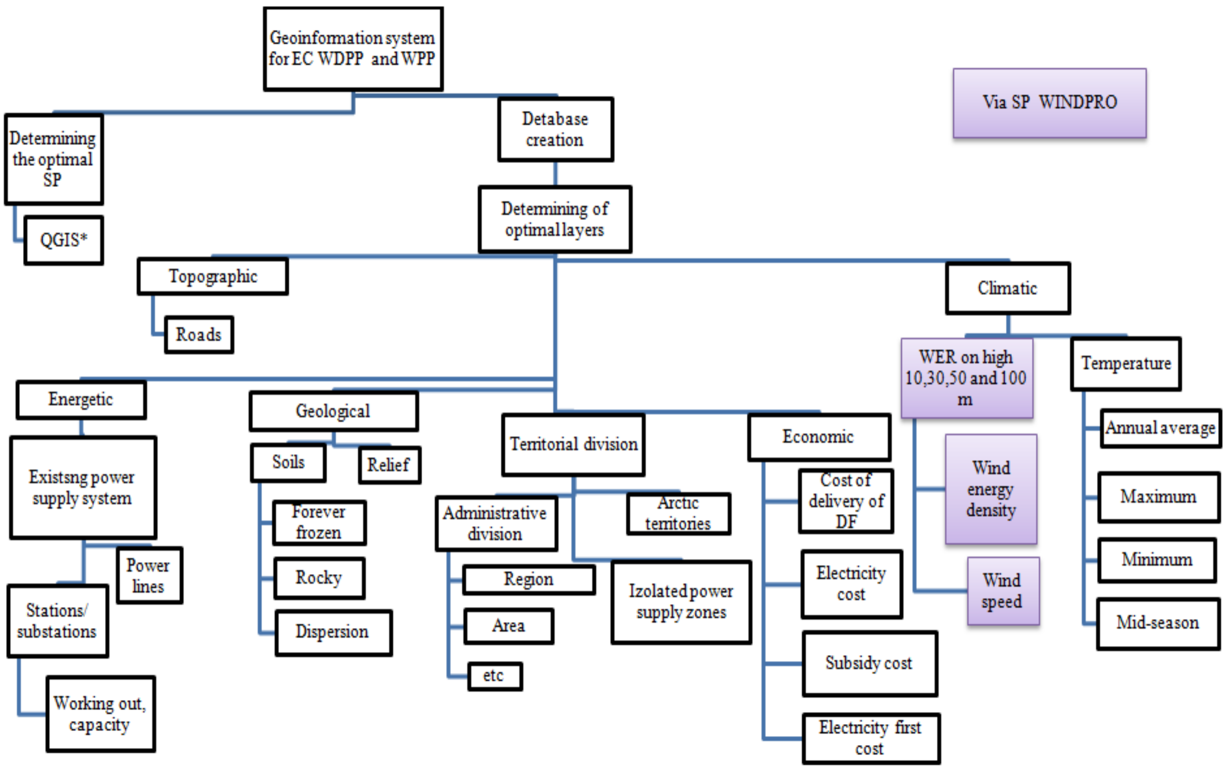

Figure 1 - GIS structure for the Arctic design of EC WDPP and WPP

IOP Conf. Series: Earth and Environmental Science **302** (2019) 012064 doi:10.1088/1755-1315/302/1/012064

The market of software products for conducting calculations in the field of wind energy analyzed. WindPRO was chosen as the main software product for evaluating wind potential in arctic conditions since the most accessible software with a wide database.In the calculation of the natural and technical wind energy potential, this software product allows to take into account the terrain relief, the roughness of the underlying surface, certain obstacles and already existing wind turbines. The methodology for estimating wind potential in the WindPRO software package is presented in the Figure 2.In parentheses are the names of objects in the software product, through which these steps were performed.The use of the WindPRO software allows accurately and reliably determine wind energy resources, optimize WPP configuration solutions, technical, energy and economic indicators, including in conditions of insufficient climatic information.

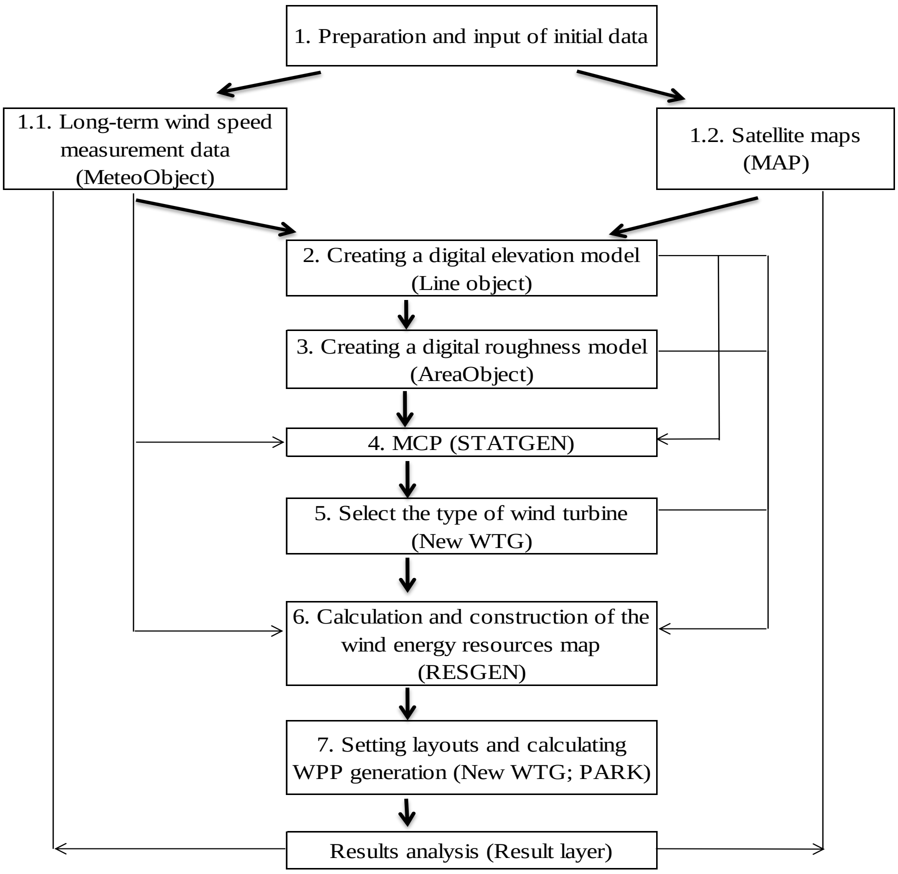

Figure 2 - The sequence of the WindPRO software applying for wind energy calculations.

2. Conclusion

As a result of the work, a software package was selected and priority layers were created to simulate a geographic information system to improve the quality, reliability and optimization of the design process of wind power facilities.

An engineering methodology was developed for estimating wind power potential in arctic conditions using the WindPRO software.

The creation of a detailed information space developed using QGIS and WINDPRO software allows obtaining for remote northern autonomous regions the necessary data to justify the construction of energy efficient EC WDPP despite the rare location of the meteorological stations network and the absence of multiyear field observations.

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