Czech Technical University in Prague
Faculty of Electrical Engineering
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Power supply system optimization of the Narym rural settlement

Master Thesis

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MASTER'S THESIS ASSIGNMENT

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Guidelines:

1. Describe current situation and available solutions of power supply in remote areas
2. Analyze the renewable energy sources and its potential in the considered settlement
3. Select and optimize the power supply system
4. Perform the economic analysis of proposed variants

Bibliography / sources:

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III. Assignment receipt

The student acknowledges that the master's thesis is an individual work. The student must produce her thesis without the assistance of others, with the exception of provided consultations. Within the master's thesis, the author must state the names of consultants and include a list of references.

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Declaration

I hereby declare that this master’s thesis is the product of my own independent work and that I have clearly stated all information sources used in the thesis according to Methodological Instruction No. 1/2009 – “On maintaining ethical principles when working on a university final project, CTU in Prague”.

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Abstract

There are many remote off-grid settlements around the world, power supply in which is implemented by diesel generators (DG). The work compares the hybrid power supply from the wind turbine with backup DGs, which will cover the demand in case of insufficient speeds, with the existing one. As is known, DGs run on diesel fuel, a source of CO_2, which pollutes the environment, also often the location of settlements makes the delivery of fuel expensive and difficult. That is why it is important to consider fuel independent energy sources based on RES. The purpose of the work is to choose the best option for power supply in the Narym rural settlement based on technical and economic analyses.

Key words

Diesel generator, hybrid renewable energy systems (HRES), net present value (NPV), off-grid, renewable energy sources (RES), wind turbine (WT).

List of abbreviations

CAPM	Capital asset pricing model
CF	Cash flow
DCF	Discounted cash flow
DG	Diesel generator
DPP	Diesel power plant
HES	Hybrid energy systems
HPS	Hybrid power system
HRES	Hybrid renewable energy systems
HPP	Hybrid power plant
HV	High voltage
NPV	Net present value
RES	Renewable energy sources
LV	Low voltage
TR	Power transformer
WT	Wind turbine

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Introduction

There are thousands of communities in Russia that do not have a centralized power supply and are currently supplied with energy from diesel and gasoline power plants. In such settlements the power supply is unreliable, depends entirely on the delivery of fuel, and requires high operating costs both for fuel and for maintenance and repair [1]. Delivery of the fuel, necessary equipment or material is difficult as usually such settlements are accessible once a year during the winter or they are remote what makes the cost higher. Moreover, quality and reliability of such electricity supply systems is low as most of the equipment is old and needs to be renewed. That is why I propose to modify and improve existing system with RES based energy supply. Introduction of RES can be beneficial in several ways. Firstly, such systems are less fuel dependent, as most part of the energy produced comes from renewable sources (wind, solar etc.). Secondly, amount of CO_2 emission can be decreased for the same reason.

However, it is also important to mention drawbacks of RES based energy supply systems. One of these is impossibility to precisely predict weather conditions (clouds, changing wind speed, etc.) and thus energy generation. It leads to necessity of either energy storage or fuel-based source to ensure continuous energy supply to the consumer.

In this paper, I consider Narym rural settlement, which consists of 5 villages. The Narym rural settlement's power supply system is an off-grid system, where electricity is supplied by diesel generators. This power supply system was installed in 1979 and modified in the beginning of 2000's. Thus, it requires renewal and improvement.

Since the object of the study is located in the Russian Federation, it is also necessary to take into account the global situation. Current political situation events have influence on possibility of implementation of the project. It effects on number of parameters, for example, the following parameters such as cost of equipment and inflation are affected and that is why it has to be considered.

The purpose of this work is to consider the decentralized power supply system on the example of Narym rural settlement, to improve the reliability of electricity supply of Narym rural settlement and reduce fuel consumption, as based on their geographical location the delivery of fuel is difficult and expensive, through the maximum use of wind energy potential.

Before introduction of RES based energy supply system, it is important to follow several steps. Firstly, it is necessary to do the energy potential analysis and decide on the main source of energy. Then there should be analysis of technical possibilities, meaning selection of suitable equipment and type of the power supply system to be used. Next step is to evaluate such system from economic point of view, by the economic analysis parameters such as NPV and minimum cost of energy. Finally, ecological benefits of RES based supply system introduction, represented by possible decreased amount of CO_2 emissions.

In order to do such work, a model should be created. Such model should take into account many input parameters, starting from wind speed and installed capacity and finish with discount rate or inflation. It should also perform technical and economic calculations of the whole project. In addition, this model should be designed in such a way so it can be used for other projects or opportunities regardless of their location or economy.

1.1 Autonomous energy in remote areas and its problems

Currently around 13% of the total population (IEA 2021) have no access to electricity grid. Majority of these people lives in small or remote settlements [2].

These so-called "off-grid" communities are mostly consist of low-income households, and it makes them economically unattractive to private sector energy suppliers or even government programs that must prioritize distribution of limited resources [3].

In order to make a profit, private distribution companies enter into concession contracts that limit the liability for servicing households that are relatively close to their network. There is no reason to include external consumers in utilities, as unit connection costs are high and, in general, poor consumers can receive tariffs below the marginal cost of the service [4].

Because the cost of connection in remote areas is high, this cost exceeds the income of many rural households, so the state is taking steps to cover a significant part of the capital cost of electricity. Despite these policies and billions of dollars, there are still people who do not have access to electricity services, mainly in sub-Saharan Africa and South Asia [3].

In Russia, the low population density and weak economic activity in large areas determine the autonomous nature of the energy supply of consumers [5].

Most of these areas are characterized by low quality of energy source, frequency of emergency shutdowns and high amount of broke down power generation equipment. These factors affect the economic, social and demographic state of the region and create challenges for local governments and energy companies [6].

Another issue relating to remote areas is outdated power transmission lines 10, 35, 110 kW. Large costs for auxiliary power, small electrical load, frequent accidents are the problems of such power lines. Network operators have to find significant resources for their maintenance, while the quality of electricity increases insignificantly [7].

Another important problem is power supply of autonomous consumers in regions where the reliability requirements of power supply systems must be very strict in harsh climates such as Siberia, the Far East, Kamchatka and the Kuril Islands. The total cost of electricity in these regions is over 0.25 USD / kWh, which is equivalent to the average European price level, but is 6-8 times higher than the price in Russia [8].

Many households have to depend on expensive fossil fuel-based sources, such as kerosene, diesel, which are energy inefficient and polluting to meet their needs [4].

Another issue relating to remote areas is outdated power transmission lines 10, 35, 110 kW. Large costs for auxiliary power, small electrical load, frequent accidents are the problems of such power lines.

Network operators have to find significant resources for their maintenance, while the quality of electricity increases insignificantly [7].

The problem of the increase in the outflow of young people and the increase in the proportion of elderly people among the remote regions of Russia is also one of the determining ones. The reason for it is that today the most trained and active people keep leaving as the economic and social attractiveness of work and life in the North for young people from other regions of the country disappears [9].

Thus, it is possible to point out the most urgent problems facing small-scale power engineering:

- deterioration of the reliability of functioning of autonomous power supply systems, caused by high wear and tear of power equipment and disruptions in the delivery of fuel and energy resources (the average wear and tear of the fleet of diesel power plants (DPP) is over 75%)

- limited use of local fuel and energy resources, including unconventional ones;

- low efficiency of production, transport, and consumption of fuel and energy resources

- the high cost of generated electric power;

- staffing;

- protection of the environment when using energy equipment [8].

1.2 Electrifying autonomous settlements

About 84% of people without electricity live in rural areas and over 95% live in developing regions of sub-Saharan Africa and Asia. In Canada, for example, around 72% of off-the-grid people use fossil fuels (oil: 71%, natural gas: 0.8%). The rest do not have sufficient resources to meet their electricity demand to meet their needs [10].

When discussing Russia, there are thousands of communities in this country that do not have a centralized electricity supply. However, since Russia is rich with resources such as oil and natural gas, fossil fuels are also commonly used here as the main source of energy. This fuel is used in diesel and gasoline systems. Unreliability and dependence on fuel supply and high operating costs of both fuel and maintenance and repair are the main drawbacks of such power supply [11].

Global experience shows that today many countries and regions have succeeded in solving abovementioned energy supply problems through the development of renewable energy [12].

Renewable Energy Resources (RES) are permanently located on Earth as a source of energy for natural processes and as a source of energy for the products of activities of plant and animal origin. The main feature of RES is its ability to recover its potential in the lifetime of a generation of human, which is considered short [9].

To increase use of renewable energy, countries adopt laws that motivate producers of "green" energy. The great success of renewable energy is determined by its efficiency compared to traditional fuels and power plants (diesel, petrol plants, etc.) [9].

Also, the most important advantages of renewable energy are the inexhaustibility of energy resources, environmental cleanliness, the absence of the fuel component in the cost of energy produced, as a rule, greater reliability, service life and lower costs for the operation of energy equipment [9].

There are number of disadvantages using RES. The first one is the unreliability of electricity supply due to change in weather conditions (e.g., solar radiation and wind speed), resulting in low power supply to consumer [13]. The second is high initial cost and long payback period [14]. Another limitation is geographical due to the need of utilizing large areas to obtain enough sunlight or wind to produce desired amount of energy [15].

For example, the low average annual wind speed in many areas leads to ineffective use of wind turbines (WT). However, wind energy conversion can be cost-effective for locations where during the year the average speed is 4 or more m/s. As for solar energy, solar panels produce energy whenever the sun shines [11].

Therefore, combining several RES into Hybrid Renewable Energy Systems (HRES) can be an excellent solution to problems mentioned [15]. Hybrid energy systems (HES) provide supply of energy to the consumers almost uninterrupted. These systems consist of several energy sources, such as wind-diesel, solar photovoltaic-diesel, wind-photovoltaic and wind-photovoltaic-diesel, with and without battery backup. The implementation of multiple sources allows to avoid the reduction of energy supply reliability [16].

According to the Global Hybrid Power System (HPS) Market Report (Zion Market Research, 2019), the market size was $477.71 million in 2017 and is expected to reach $836.92 million by 2024. This simply means that HPS are being used globally [12].

Local supply using HPPs can fully cover the demand of not only households but local industrial facilities in remote areas. With traditional power supply options, the high purchase and maintenance costs of equipment brings up restrictions on areas of use. Large subsidies are needed to make such systems available to the remote localities. The use of HPS systems in remote communities will significantly reduce the cost of electricity, save fossil fuels and increase the reliability of power supply, which increases the technical and economic characteristics of autonomous power supply system’s [11].

1.3 Methodologies

Paper [17] considers the autonomous hybrid renewable energy system (HRES) to meet the electric and hydrogen load on the example of a village in Western China. Such sources of RES as solar and wind were chosen as the best option for power supply, as well as the effectiveness of the use of storage batteries was confirmed. The work consisted of several stages: selection of the research object, evaluation of RES, load profile, technical components of the system, simulation in HOMER Pro software. Based on the simulation data, the optimal configuration of the power supply system is selected, the economic input data for the simulation process were the service life of the main renewable components, discount rate, and inflation rate. In this paper, the optimal configuration was selected according to the lowest net present cost (NPC), in addition to this parameter, cost of energy (COE) and cost on hydrogen (COH) were also evaluated. In the sensitivity analysis, was considered the share of power shortage as a sensitivity variable, since the main goal of the project was to provide a reliable power supply to the village.

In article [18] an analysis of hybrid wind and photovoltaic systems with batteries on the example of various settlements was performed. The aim of the study was to create a methodology for selecting a suitable location to use a hybrid system for power generation. Two different electricity production scenarios were compared: the first scenario provides daily power supply that covers necessary loads. Power supply was achieved by using batteries. The second scenario predicts a non-continuous power supply with the most cost-effective installation and maintenance expenses of the system as low as possible. As input parameters, metrological, demographic, geographic, geospatial, land use, and load data were used. The methodology of this study is based on the application of specific criteria that should be satisfied by the location, the load, the specific mix of RES used, the economic feasibility of the project. The main parameter for evaluating the economic efficiency is the net present value (NPV. The optimization method of the autonomous RES system is based on determining the objective function to be minimized under constraints, in this study, the main constraint was the coverage of the load, which depended on the chosen scenario. The objective function was based on the energy balance between energy produced, energy stored in batteries, losses and load. The scenarios differed in the constraints affected the objective function, which related to both load coverage and the size of the systems. The main variable for decision-making was the charge coverage factor. The study found that the first option had a significant advantage in all areas.

The study [19] looks at the integration of photovoltaic and battery systems and a diesel source for a remote settlement in Western Australia, comparing “diesel only”, “diesel-PV” and “diesel-PV-batteries” power supply options. The approach used in this study is based on Multicriteria decision analysis (MCDA), an Analytic hierarchy process (AHP) is applied. The main criteria were economic, environmental, technical and social. After analyzing the selected location, the optimal configurations of power supply options were selected using HOMER Pro software, then the above criteria were evaluated, where experts opinions were taken into account for each criterion. The results showed that the importance of technical and environmental criteria is almost equal, while the weight of economic criteria significantly prevails over all other criteria.

The paper [20] presents a methodology based on mixed-integer linear programming (MILP), which was adopted to meet the electricity demand of a mountain lodge located in a remote area of South Tyrol (Italy). This methodology was developed using algorithms implemented in Matlab software. Solar wind farms with batteries were chosen as the best choice. The MILP model inputs are the load requirements, the power supplied by the generator, and the power consumed by the battery, to provide the optimal value for the target function as an output. This is the target function, the total cost of the hybrid system. Selected for capital, operating and maintenance costs. The limit is the energy the battery can supply or consume, and the system will always generate enough energy to meet at least half of the load requirements, allowing the amount of energy generated to be a generator. HRES is not sufficient to meet this requirement and the total power generated by HRES must be equal to the total power required by the load in the considered period. The algorithms developed in this research determine the optimal design of the HRES system.

In peper [21] a power supply scheme for a village in Dera Ismail Khan, Pakistan is considered. In the first stage, a preliminary assessment was made using Homer PRO: analysis of energy resources, load profiling, design of preliminary configurations of the power supply system. In the second stage, a feasibility analysis is performed using real-time load data, simulating hybrid off-grid power systems. In the third stage, an additional sensitivity analysis is performed, which considers the price of solar electricity (selected RES), the price of diesel fuel, the cost of the battery, the exchange rate, the inflation rate and the discount rate as sensitive variables. Based on the results of the third stage, the effect of changes in the variables considered on the optimal hybrid system is evaluated. The analysis is performed by repeating and changing the simulation with the sensitivity variables obtained. The final step is to test the reliability of the HPP in two ways: by analyzing the power generation profile curve, which is to determine whether the proposed system generates enough electricity to meet load demand in the selected area, and by comparing the levelized cost of energy (LCOE) to the state tariff for commercial efficiency.

In paper [22] the renewable energy system based on solar, wind and biomass with biochar production on the example of Carabao Island in the Philippines, a stochastic multi-purpose decision support system and justification of economic and environmental feasibility of a hybrid system of renewable energy is proposed to determine the optimal design of the energy supply. The first step is to collect data on local RES, then input the raw data into energy conversion models. In the study under consideration, wind speed and temperature are needed to calculate the maximum potential of energy generated by wind. The maximum resource availability is used as a resource constraint in the optimization process. Power output, power demand data, price and cost data, and lifecycle greenhouse gas emissions data serve as inputs to estimate the economic and environmental performance of the system in the optimization model. Optimization solvers can be used to derive the optimal system design and the corresponding economic and environmental performance. The optimal decision variables then can be returned and the results of the optimal sizing of each component and the corresponding economic and environmental performance are obtained. TOPSIS analysis is used as a post-optimality analysis method for ranking a Pareto decision based on the decision maker's preferences. The results obtained from TOPSIS analysis can be used to help make the final decision.

The paper [23] presents a comprehensive feasibility analysis of a HRES for the electrification of agricultural areas in Dongole, Sudan. Different options for hybridization of solar photovoltaic, WTs, DGs, batteries and converters are simulated and compared, as well as a power system based on a DG as a base case, with the main goal of finding the most feasible and reliable solution with the lowest system cost and a realistic environmental impact, as well as a sensitivity analysis is performed. As input parameters for a

WTs, for example, capital, replacement and O&M costs, WT lifetime, WT power curve, cut-in and cut-off speeds, hub high were proposed. As optimization constraints for load demand the energy demand requested by the load; for resources is the availability of resources; for technical are the hourly operating reserve of the load, an hourly operating reserve of RESs; for reliability is an allowable capacity shortage; for emission is penalties over greenhouse gases (GHG) emissions. NPC minimization was chosen as an optimization function. Based on this model the optimal size of the power system is determined, i.e. size of PV, number of WTs, size of DG, size of the power converter, number of battery strings.

In all the reviewed articles there is a general tendency in the approach to the work. In the first stages, the analysis of RES resources in the area under consideration, based on this analysis the most accessible RES is selected, a DG is taken as a backup source, energy storage units are also used. Then an analysis is done to determine the necessary power generation, design the preliminary configurations of the power supply system. The main difference between the studies is in the approach to the decision-making methodology for selecting the optimal configuration of the power supply system. The works [17], [21], [24], [25] apply the HOMER Pro software package, which performs three main tasks (modeling, optimization and sensitivity analysis), proposing a suitable system design based on the net present value (NPV) given the input data. The overall NPV is the main economic outcome of HOMER, the value by which it ranks all system configurations in the optimization results, and the basis on which it calculates total annual costs and levelized cost of energy (LCOE) [26]. Articles [18], [27] use multi-criteria decision analysis (MCDA) along with the optimization model used in the HOMER Pro software package to select the optimal power system configuration. MCDA includes many methods, e.g., Analytical Hierarchy Process (AHP), Multi-criteria Optimization and Compromise Solution (VIKOR), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Elimination and Choice Expressing Reality (ELECTRE), Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), Analytic Network Process (ANP), Order Weighted Averaging Aggregation Operator (OWA), Complex Proportional Assessment (COPRAS) and Multi-Objective Decision Making Method for Linguistic Reasoning (MULTIMOORA). In [20] a methodology based on mixed-integer linear programming (MILP) is used. [22] uses a stochastic multi-objective decision support system and justification of economic and environmental feasibility, and [18], [23] is consistently applied criteria that must meet the specified parameters. After selecting the optimal configuration of the power supply system and economic analysis, sensitivity analysis and summarization are performed.

2 Description of the research object

2.1. Narym rural settlement

Tomsk region is located in the south-eastern part of the West Siberian Plain and has an area of 316.9 km^2. The maximum length of the Tomsk region from north to south is 600 km, from west to east is 780 km. There are 573 rivers in the region. They all belong to the basin of the Ob River. The population of the region is more than one million people, including urban - 66%. Climatic conditions in the region are typical of Siberian regions of Russia: the average annual temperature is minus 2 C°, the duration of the heating season is 8 months [28].

Figure 1 shows an administrative map of the Tomsk region.

1. Aleksandrovskiy rayon
2. Kargasokskiy rayon
3. Parabelskiy rayon
4. Bakcharskiy rayon
5. Chainskiy rayon
6. Kolpashevskiy rayon
7. Verkhneketskiy rayon
8. Molchanovskiy rayon
9. Krivosheinskiy rayon
10. Asinovskiy rayon
11. Pervomayskiy rayon
12. Teguldetskiy rayon
13. Zyryanskiy rayon
14. Tomskiy rayon
15. Shegarskiy rayon
16. Kozhevnikovsiky rayon

Figure 1 - Administrative map of Tomsk region [29]

The decentralized power supply zone is located mainly in the northeast of the region on the right bank of the Ob River [30].

The administrative-territorial division in Narym rural settlement is as follows:

- Narym village;
- Shpalozavod village;
- Lugovskoe village;
- Talinovka village;
- Alataevo village [31].

The village of Narym is the administrative center of the settlement. The total number of Narym settlement as of January 1, 2020 is 1,817 people, the number of each settlement is presented in Table 1. The distance between the settlements is also presented in Table 1 [32].

Table 1 - Composition of Narym rural settlement, the number of its settlements and distances from Narym village [32]

No	Settelment	Population as of 01.01.2020, people	Distance from the administrative center (Narym village), km
1	Narym village	908	-
2	Shpalozavod village	642	2
3	Lugovskoe village	119	5
4	Talinonka village	106	9
5	Alataevo village	42	23
	Total	1817	-

As can be seen from Table 1, the largest number of people live in the villages of Narym and Shpalozavod, less in the villages of Lugovskoe and Talinovka, the smallest number of people in the village of Alataevo (42 people). It should also be noted that the village with the smallest number is the most remote area from the administrative center.

Figure 2 shows the location of settlements of Narym rural settlement and the distance between them.

Figure 2 - Location of settlements [33]

Communication between settlements is carried out with the help of dirt roads, in winter by winter roads, and in summer by water transport, which significantly complicates the delivery of diesel fuel to operate the PP [32].

2.2. Power supply system of the Narym rural settlement

The Tomsk power system is part of the Unified Energy System of Siberia. The needs of the region in the centralized power supply are provided by "Tomskenergo" company [34].

Many northern and northeastern territories of the Tomsk region have no centralized power supply. It is obvious that with low population density and weak industrial development, inclusion of these territories in the centralized power supply system is inexpedient

Depending on the location of the station and the conditions of its operation, the cost of generated electricity varies. Today almost all types of transport are used for fuel delivery in Tomsk region: river, railway, automobile, aviation [28].

Equipment of most diesel power plants have long expired and need to be replaced. Frequent accidents in power supply lead to significant material losses. At the same time, social damage is inflicted on the population [28].

Consumers of Narym Rural Settlement are supplied with electricity from a diesel power plant located in the village of Narym. The installed capacity of the Naryms DPP is 2230 kW [35].

The main consumers of electric power are the population of the settlements, the public sector (school, club, village administration, etc.) and the housing [36].

Naryms DPP is equipped with four DGs, the characteristics of which are shown in Table 2. All generators are currently in operation, and most require major repairs or replacement.

Table 2 - Characteristics of DGs installed in the DPP [34]

Type of DG	Nominal power		Efficiency, %	Fuel consumption rate, g/kWh	Oil consumption rate, g/kWh	Load, kW		Year of commissioning
	kW	rpm				Min	Max	
G-72 M	800	375	0.95	234	1.22	320	910	2001
G-72 M	800	375	0.95	234	1.22	320	910	2002
DGA-315	315	500	0.95	240	1.5	30	100	1979
DGA-315	315	500	0.95	240	1.5	30	100	1983

The electricity generated by generators goes to step-up power transformers (TR) (Table 3), then electricity is distributed through overhead lines of 10 kV to the settlements of Narym (Narym village, Shpalozavod village, Talinovka village, Lugovskoye village, Alataevo village), voltage reduction is also performed by TR (Table 3). Transmission and distribution of 0.4 kV electricity is carried out by 0.4 kV overhead lines [35].

Table 3 - Type of the TR [35]

Type of the TR	Power, kVA	Voltage, kV		Number
		HV	LV	
TM-630	630	10	0.4	2
TM-400	400	10	0.4	4
TM-250	250	10	0.4	2
TM-160	160	10	0.4	5
TM-100	100	10	0.4	3

The dynamics of actual specific fuel consumption and total fuel consumption for the period from 2015 to 2019 is shown in Table 4 [36].

Table 4 - Value of actual specific fuel consumption and total fuel consumption [35]

Type of fuel used	Considered period, year	Specific fuel consumption, g/kWh	Total fuel consumption of the power plant, t
Diesel fuel	2015	424	945
	2016	423	954
	2017	424	942
	2018	424	923
	2019	423	935

As Table 4 shows, fuel consumption is about the same from year to year.

Based on the report of the Tomsk Oblast Administration [36], the following problems can be identified:

1. High cost of electric power;

2. High wear and tear of electric networks;

3. Decreasing volume of electricity consumption;

4. Low reliability of electricity supply in Alatayevo village. Alataevo, due to the high wear and tear of the distribution network from Narym village to Alataevo village.

3. Analysis of the energy potential of the Narym rural settlement

Tomsk region is located in the southeastern part of the West Siberian Plain. When comparing the energy potential of the West Siberian region with other regions of Russia, it can be noted that it exceeds other regions with the exception of the Far East in terms of energy resources distribution. Tomsk region has high rates of biomass, solar, wind and geothermal energy, which tentatively suggests that the Tomsk region is promising for renewable energy installations [28].

Further it is proposed to make a more detailed assessment of RES of Narym rural settlement. Data on weather conditions is assumed the same for all settlements, as the distance between settlements is small.

3.1. Biomass

This segment of RES uses biofuels is a fuel derived from biological raw materials as raw materials for the production of electricity and heat. There are three types of biofuel according to the type of feedstock: biological waste, lignocellulosic compounds and algae [37].

Of the first-generation biofuels, the most promising direction is the use of forest resources. A significant amount of waste from the enterprises of the timber industry in the Tomsk region can be used to generate heat and electricity, which in turn can reduce the need for imported liquid fuel [38], [39].

Despite the fact that the potential of woody biomass available within a radius of 30-50 km from the sources is able to cover the needs of decentralized consumers, the analysis of the state of the regional transport network shows that the low transport accessibility of territories of Tomsk Oblast does not allow to effectively use the potential of woody biomass [39].

For biofuel of the second generation requires a fairly large crop area. Due to the small area suitable for high-efficiency farming (compared to the chernozem regions), obtaining biofuel of the second generation on the territory of the Tomsk region has no prospects [29].

Third-generation biofuel is obtained from special algae with high oil content. Such types of algae are very sensitive to low temperatures and require high temperatures for active growth. Under conditions of long winter and an average annual temperature of 0.9°C this technology cannot be applied in open water bodies [37].

Thus, it can be concluded that in Tomsk region of the three types of biofuels, only the second is available. Despite the potential of wood biomass, which can cover the needs of decentralized consumers, the remoteness of such consumers and the lack of land communication for most of the year, make such a source of renewable energy as biomass not feasible.

3.2 Hydropower

Narym rural settlement is located along the Ob river and the Kopylovskaya Ket river, the largest villages of the settlement are located at the place where the Kopylovskaya Ket river flows into the Ob river. The rivers have a mixed snow, rain and groundwater supply and are characterized by high spring floods [40]. The ice cover formation near those rivers is observed for 5-7 months a year, which in turn prevents water flow in the cold season [41].

Despite the fact that Narym rural settlement is rich in water resources, the flat topography characteristic of most of the territory is unfavorable for the construction of dams and reservoirs on rivers. The interfluves are very poorly elevated above the water level in small rivers, the valleys of which are poorly incised and undeveloped [38].

3.3 Solar energy

The intensity of solar radiation depends on many factors: geographic latitude, angle of the receiving surface in relation to the sun, local climate, cloud cover, air dustiness, altitude, season and time of day [28].

This type of energy is based on the conversion of electromagnetic solar radiation into electrical or thermal energy. The potential of solar energy development in Tomsk region is determined by the fact that solar energy generation primarily depends on geographic latitude, weather and time of day and the need to clean panels of snow and dust [42].

Figure 3 shows a map of photovoltaic power potential of the Russian Federation [43].

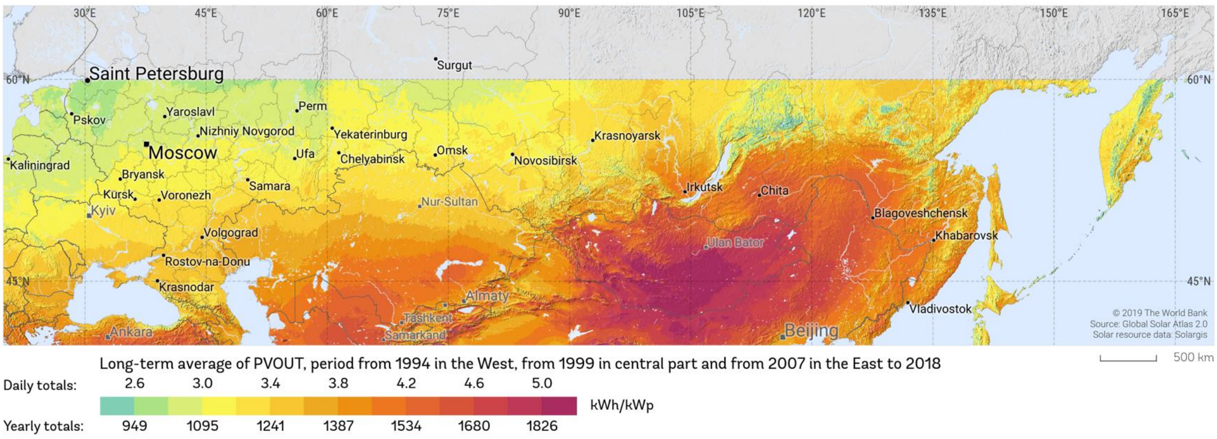

Figure 3 – Photovoltaic power potential [43]

When considering the Tomsk region, the following zones can be distinguished:

I - the southwestern part of the Tomsk region. Average annual sum of total radiation on the horizontal surface is 1100-1200 kWh/m2, with average values of cloudiness, atmospheric transparency and openness of the horizon. These conditions ensure stable operation of solar systems.

II - central part of Tomsk region. Average value of energy resources for the year is 1000-1100 kWh/m2, which mainly meets the requirements of operation of small and medium-sized solar systems.

III - northeastern part of the Tomsk region. Potential solar resources are 900-1000 kWh/m2. In this area conditions are unfavorable for the use of large and medium solar systems [9].

Narym rural settlement is located in the central part of the Tomsk region, based on the above map, this area is favorable for the use of small and medium solar systems.

Using the RETScreen software package there was obtained the values of the daily sum of horizontal solar radiation for Parabelsky district (Table 5) for 2020.

Table 5 - Daily sum of horizontal solar radiation for 2020

Month	Daily sum of solar radiation - horizontal, (kWh/m^2)/day
January	0.53
February	1.37
March	2.72
April	4.17
May	5.29
June	5.74
July	5.65
August	4.23
September	2.57
October	1.42
November	0.67
December	0.30

Based on the data from Table 5, a graph of daily solar radiation for Parabelsky district for 2020 was plotted (Figure 4).

The highest value of the daily sum of solar radiation is observed from mid-spring (April) to late summer (August), the maximum is in June, which suggests that the production of electricity at solar power plants can be carried out mainly in the summer. In the other months, due to the low altitude of the sun above the horizon and the weakening of solar radiation, the efficiency of the use of solar receptors is reduced several times. Taking this into account, the use of solar plants in the area under consideration is reasonable from mid-spring to the end of summer.

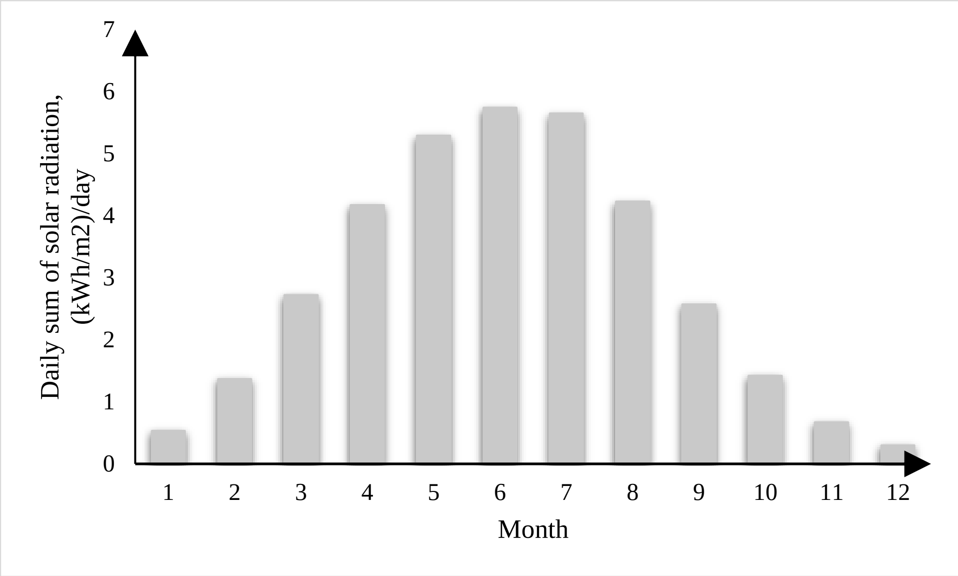

Figure 4 - Daily sum of solar radiation of Parabelskiy district

3.3. Wind power

Wind is characterized by speed, the main parameters allowing to estimate the wind potential of the region are:

- average annual wind speed, annual and daily wind speed;
- velocity repeatability, types and parameters of wind speed distribution functions;
- vertical profile of the average wind speed;
- specific power and specific energy of the wind;
- wind energy resources of the region [9].

Average annual wind speed is defined as an arithmetic mean value obtained as a result of speed measurements at equal time intervals during a given period: a day, a month, a year, several years:

$$V_{av} = \frac{1}{n} \cdot \sum_{i=1}^{n} V_i, \tag{1}$$

where

V_i is the wind speed in the measurement interval i;

n- the number of measurement intervals [9].

Table 6 shows the average wind speed values for the village of Narym from January 1984 to December 2013 [44].

Table 6 - Average wind speed [44]

Wind speed, m/s	
Month	Average value per month
January	5.95
February	6.05
March	6.15
April	5.91
May	5.69
June	5.10
July	4.94
August	5.02
September	5.23
October	5.58
November	5.70
December	5.90

Based on these values, a graph of wind speeds is plotted (Figure 5). As can be seen from this graph, the highest values of velocities are in spring (March) and the lowest values are in summer (July).

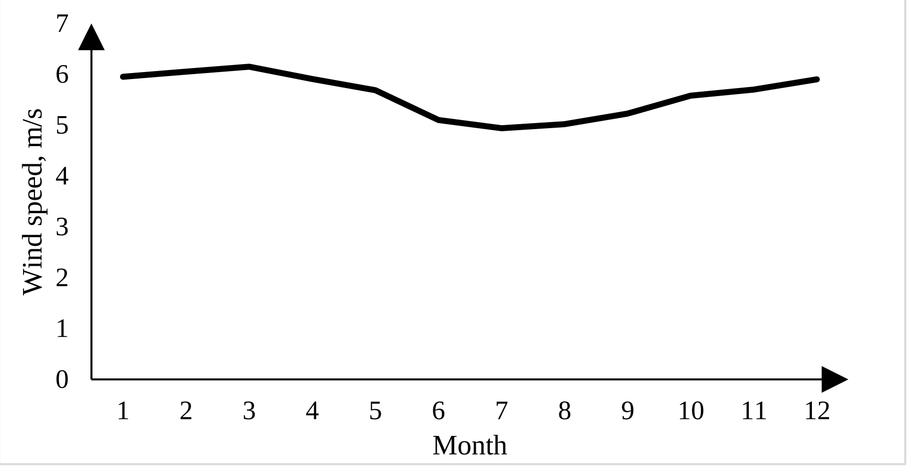

Figure 5 - Wind speed in the Narym village

Also, to estimate wind potential, it is necessary to know the wind repeatability, i.e. how many hours there were winds of a certain speed during a certain time interval. In the future, this will make it possible to determine at what speed of power the WT can operate. In 1895 M.M. Pomortsev established a regularity of wind repeatability depending on average annual wind speeds. Based on the recurrence of different wind speeds as a function of average annual wind speeds, a graph of the repeatability of wind speeds for the considered region for the year was made (Figure 6) [45].

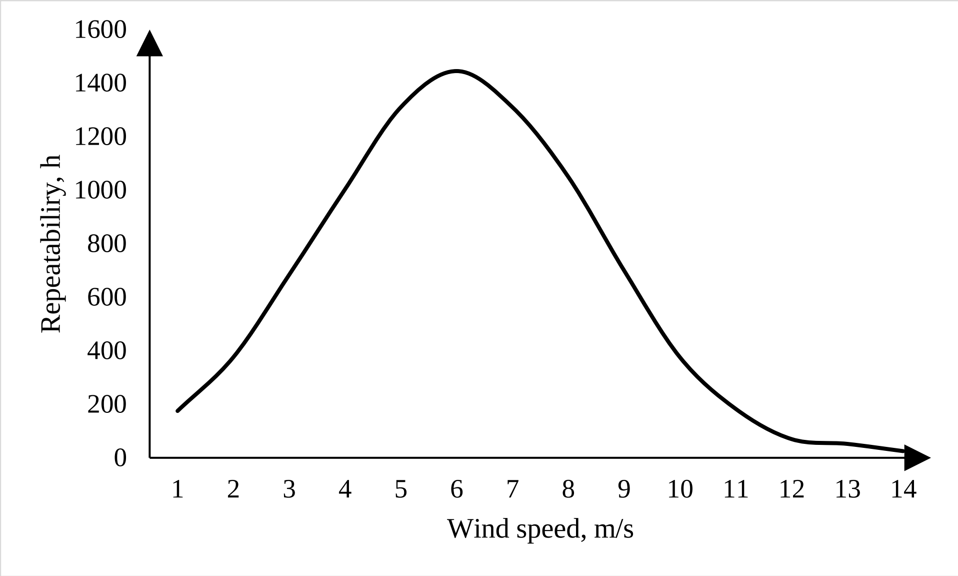

Figure 6 - Graph of the repeatability of wind speeds

Wind power plant is considered effective if the wind speed in the area under consideration is more than 4 m/s [46]. Average annual wind speed in Narym village is 5.6 m/s. Lugovskoe village, Shpalozavod village and Talinovka village are distant from Narym village at 5 km, 2 km and 9 km respectively, the wind speed in these villages will be approximately similar to the wind speed in Narym village. The efficiency of the wind farm is also related to the topography of the area. The wind farm should have a clear straight front of the prevailing wind, located over open water, flat land or on a flat hill [47]. Naryms district is a vast lowland area. Therefore, there are no obstacles to the wind here, and the construction of a wind farm here is justified.

Based on a comprehensive assessment of renewable sources at the target location, this paper considers only wind energy.

4 Demand and supply analysis

Based on the analysis of the potential of RES, such resource as wind is proposed as the main source of electricity supply for the considered settlement.

In this regard, it is proposed to consider two options for power supply and choose the best ones based on technical and economic characteristics:

1. Diesel generators only.

2. Wind generator (wind farm) with diesel generators.

4.1 Demand calculation

The first step is to specify the load to be covered. In this paper, I consider a rural settlement consisting of 5 villages. Based on [33], the number of residential houses, as well as various administrative buildings was determined. The data for each settlement is shown in Table 7.

Table 7 – Number of buildings for each village [33]

Building type	Narym	Shpalozavod	Lugovskoe	Talinovka	Alataevo	Sum
House	222	223	45	44	10	544
Shop	6	6	0	0	0	12
School	1	1	0	0	0	2
Hospital	1	1	1	1	0	4
Club	2	1	0	1	0	4
Administration building	2	0	0	0	0	2
Kindergarten	1	0	0	0	0	1
Church	1	1	0	0	0	2
Cafe	1	0	0	0	0	1

Based on result from Table 7, it is possible to identify two types of consumers of electrical energy:

- residential buildings;

- hospitals, schools, clubs, stores and other enterprises serving the settlement.

Probabilistic-statistical methods of determining design loads are widely used in the rural electric power industry. The real process of changing electric loads is usually considered as a non-stationary random process, in which it is possible to distinguish recurring daily, weekly and annually cycles. Changes in loads during each cycle are also considered as a non-stationary random process. These statements form the basis of the probabilistic-statistical models used to determine the estimated electrical loads. Based on many years of experimental research, the probabilistic characteristics of rural consumer loads are determined [48]. Using this data, the loads consumed by the considered community specified.

Houses are heated by burning wood and coal, administrative buildings are heated by a coal-fired boiler house, so they are not included in the calculations. Based on statistical data of daily and nightly peak loads [49], the power consumed by each typical consumer was calculated (Table 8). An example of the calculations for house for Narym village is shown below:

$$P = N \cdot Max\{P_{day}; P_{night}\} = 222 \cdot Max\{3.5; 6\} = 1332 \ kW, \qquad (2)$$

where

N – numbers of buildings;

P_{day} – daily maximum load, kW;

P_{night} - night maximum load, kW.

Table 8 – Power consumed by each village per day

Power, kW						
Building type	Narym	Shpalozavod	Lugovskoe	Talinovka	Alataevo	Total
House	1332	1338	270	264	60	3264
Shop	24	24	0	0	0	48
School	20	20	0	0	0	40
Hospital	30	30	30	30	0	120
Club	28	14	0	14	0	56
Administration building	30	0	0	0	0	30
Kindergarten	12	0	0	0	0	12
Church	0.5	0.5	0	0	0	1
Cafe	5	0	0	0	0	5
Total for each village	1332	1338	270	264	60	3264

Total installed capacity is equal to 3264 kW. In real practice, the load consumers installed in a circuit of one electrical installation never operate simultaneously, i.e. there is always some degree of non-simultaneous operation, and this fact is taken into account in estimating the required capacity by using a contemporaneity factor [50]. The contemporaneity factor is the ratio of the calculated load of a group of several electric consumers to the sum of their maximum loads. The loads are usually determined separately for daytime and evening peak modes. If only industrial consumers are supplied from the network, then the calculation can be made only for the daytime hours. If the consumers are only household consumers, then calculation can be made only for the nighttime hours. Contemporaneity factors are given in Table 9 [49]. This table is used to determine the estimated electrical loads on consumer inputs when calculating 0.4 kV electrical circuits.

Table 9 - Contemporaneity factor

Number of consumers	Residential buildings with a load		Residential buildings with electric stoves	Industrial customers
	Up to 2 kW per home	More than 2 kW per home		
2	0.76	0.75	0.73	0.85
3	0.66	0.64	0.62	0.8
5	0.55	0.53	0.5	0.75
10	0.44	0.42	0.38	0.65
20	0.37	0.34	0.29	0.55
50	0.3	0.27	0.22	0.47
100	0.26	0.24	0.17	0.4
200	0.24	0.2	0.15	0.35
more than 500	0.22	0.18	0.12	0.30

Equations for calculating the estimated capacity [49]:

$$P = k_{cf} \cdot P_{Dmax}, \tag{3}$$

where

k_{cf} - contemporaneity factor;

P_{Dmax} – the summed power of individual consumers for daytime, kW.

Since the load on the 0.4 kV consumer inputs is determined, I assume for each house that the number of people living in each house is 3. Then the coefficient of simultaneity will be 0.62. For other types of buildings, the coefficient is 0.55. Then the estimated capacity will be equal to 2182 kW for Narym rural settlement (result of calculation shown in Table 10), for convenience of calculations I take 2200 kW.

Table 10 – Power recalculated according to the contemporaneity factor

Type of building	Narym	Shpalozavod	Lugovskoe	Talinovka	Alataevo	Sum, kW
Hous	777	781	158	154	35	1904
Shop	24	24	0	0	0	48
School	20	20	0	0	0	40
Hospital	30	30	30	30	0	120
Club	28	14	0	14	0	56
Administration building	30	0	0	0	0	30
Kindergarten	12	0	0	0	0	12
Church	1	1	0	0	0	2
Cafe	5	0	0	0	0	5
Sum, kW	927	870	188	198	35	2217

The daily load diagram of Narym rural settlement is shown in Figure 7. This diagram is built using seasonality coefficients for each month [48]. Result of calculations of energy for each season shown in Appendix 1.

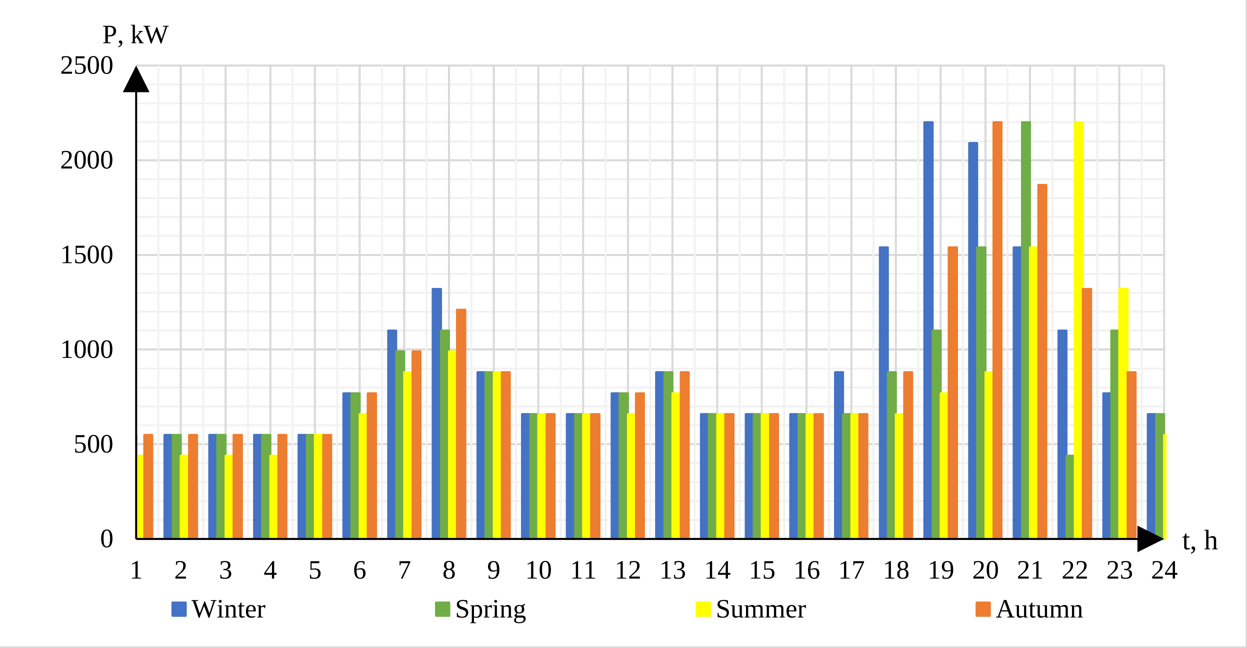

Figure 7 – Daily load diagram

The annual electricity consumption for each season for each village is shown in Table 11. An example of the calculations for winter for Narym village is shown below:

$$E = N \cdot P \cdot \sum_{i=1}^{24} k = 90 \cdot 0.927 \cdot (0.25 + 0.25 + ... + 0.3) = 855.16 \ MWh, \quad (4)$$

where

N – number of days in season;

P – sum of energy consumed in one day by exact village, MW;

k – seasonal coefficient for each time i which is measured in hours.

Table 11 - Consumption of energy for each settlement

Consumption of energy, MWh						
Settlement	Narym	Shpalozavod	Lugovskoe	Talinovka	Alataevo	Sum
Winter	855	802	173	183	32	2045
Spring	776	728	157	166	29	1856
Summer	738	692	149	158	28	1764
Autumn	827	775	167	177	31	1977
Total	3196	2997	646	683	121	7643

In this chapter, the estimated capacity of the Narym rural settlement was calculated, which is equal to 2200 kW, this value will be used for further calculations and equipment selection, in the next step is to consider a possible increase in capacity due to an increase in the number of residents. Additionally, in choosing equipment it is important to consider minimum and maximum power depend on time of day because equipment should be able to ensure reliable operation under all conditions. Also, Table 11 shows that the annual consumption of energy for all settlements is equal 7643 MWh, this value will be used for technical and economic calculations to determine the annual power generation of DGs and WTs.

4.2 Wind turbine supply calculation

The load coverage of the WT depends on the selected power supply scheme. In this chapter I select the WT on the basis of the power it generates.

Possible energy production at known distribution of wind speeds can be determine by following formula [51]:

$$P(v) = \begin{cases} 0\, if\ v < v_c \\ (a + b \cdot v^k)\, if\ v_c < c \le v_r \\ \mathrm{P_r}\, if\ v_r < v < v_f \\ 0\, if\ v \ge v_f \end{cases}, \tag{5}$$

where

v – wind speed, m/s;

P – Power output of the WT, kW;

P_r – Rated power of WT, kW;

v_c – cut-in speed, m/s;

v_f – cut-out speed, m/s;

v_r – rated wind speed, m/s;

k – Weubull shape parameter.

Coefficients a and b can be calculated using these formulas [51]:

$$a = \frac{P_r \cdot v_c^k}{v_c^k - v_r^k}; \tag{6}$$

$$b = \frac{P_r}{v_r^k - v_c^k}. \tag{7}$$

Weibull density function is one of the functions that can be used for description of wind energy frequency. For further calculations k = 2 which used for a typical wind distribution found at most sites. In this distribution more days have lower than the average speed and few days have high wind [51].

I consider the following WTs of different capacities (Table 12), which were chosen based on speed characteristics.

Table 12 – Wind turbine [52]

Turbine	Nominal power, kW	Cut-in wind speed, m/sec	Rated wind speed, m/sec	Cut-out wind speed, m/sec	D, m	H, m
Hummer H21.0-100KW	100	2.5	10.5	20.0	21.0	40.0
Argolabe Turbec-100	100	3.5	10.5	20.5	22.5	37.0
AN Bonus 150/30	150	3.5	12.5	25.0	23.0	30.0
Hummer H25.0-200KW	200	2.5	11.5	20.0	25.0	40.0
Aeolia Windtech D2CF 200	200	3.0	10.9	20.0	28.0	40.3
Micon M530	250	5.0	14.5	25.0	26.0	30.0

Since the wind speed increases as the distance from the underlying surface increases and the airflow increases, it is necessary to recalculate the wind speed for different heights because WTs have different heights:

$$V_h = V_v \cdot \left(\frac{h}{h_v}\right)^{\alpha}, \qquad (8)$$

where

V_h - wind speed at height h, m/s;

V_v - wind speed at the height of the weather vane, m/s;

h_v = 10 m - height of the weather vane;

α is a coefficient that depends on the average wind speed at the height of the weather vane [28].

The values of α are chosen from Table 13 [53].

Table 13 - Dependence of α on wind speed V_v [53]

V_v, m/s	0-3	3.5-4	4.5-5	5.5	6-11.5	12-12.5	13-14
A	0.20	0.18	0.16	0.15	0.14	0.35	0.13

For the selected WTs, the power output is calculated and the power output characteristics are plotted (Figure 8).

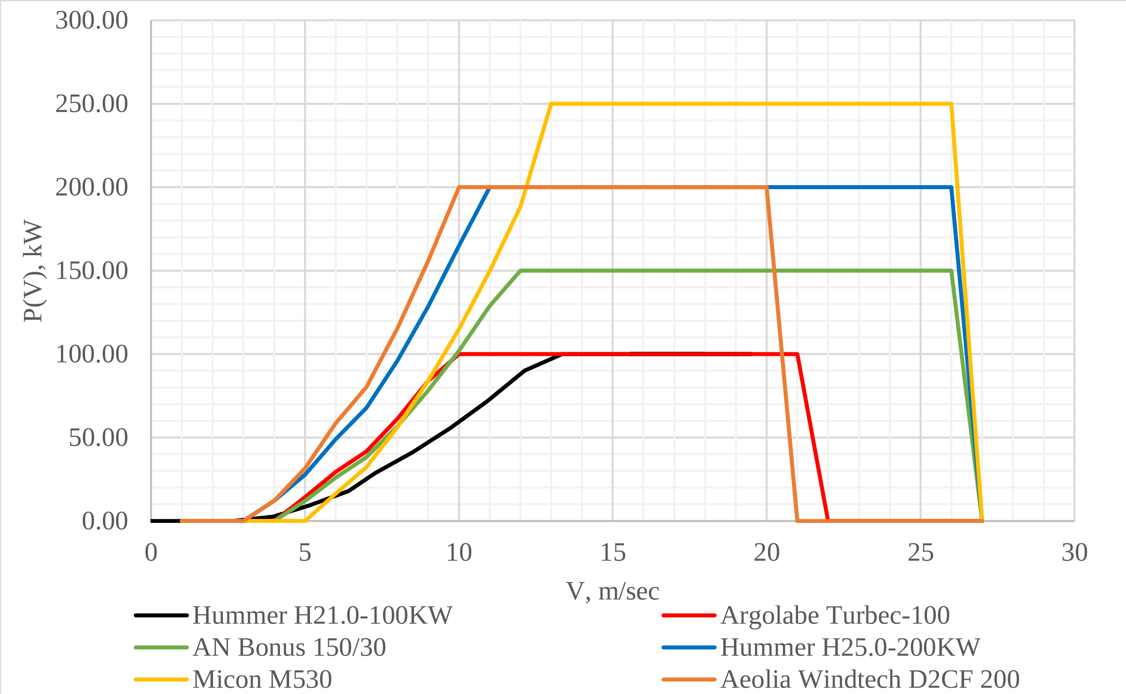

Figure 8 - Power output of WTs

Then the power generated by WTs during year is calculated (Table 14), for this it is necessary to take into account the repeatability of wind speeds (Figure 6). Also, it is necessary to include windless days, for this need to subtract 15% of the power [46].

Table 14 – The generated power by one wind turbine depending on the wind speed

Energy production, MWh						
Month	Hummer H21.0-100KW	Argolabe Turbec-100	AN Bonus 150/30	Hummer H25.0-200KW	Aeolia Windtech D2CF 200	Micon M530
January	25.246	22.919	20.962	41.675	44.652	16.275
February	25.639	23.712	21.768	42.325	45.704	18.374
March	31.608	29.672	27.321	52.179	56.704	24.514
April	27.372	25.301	23.225	45.186	48.783	19.559
May	25.505	23.195	21.221	42.104	45.144	16.612
June	18.786	16.189	14.643	31.012	32.519	8.550
July	18.158	15.398	13.878	29.975	31.227	7.282
August	16.790	13.946	12.510	27.717	28.636	5.831
September	19.509	16.956	15.365	32.205	33.888	9.572
October	25.016	22.676	20.732	41.296	44.218	15.992
November	28.359	26.348	24.211	46.814	50.651	20.836
December	26.572	24.327	22.287	43.864	47.164	18.023
Year	288.560	260.639	238.124	476.353	509.290	181.421

Next, the utilization coefficient of the WT is determined (Table 15). Utilization factor is relation between power produced by WT in a year at average annual wind speed and nominal power of WT:

$$k = \frac{P(V_{an})}{P_n}. \quad (9)$$

Table 15 – Utilization coefficient for WTs

Turbine	k
Hummer H21.0-100KW	0.397
Argolabe Turbec-100	0.360
AN Bonus 150/30	0.218
Hummer H25.0-200KW	0.328
Aeolia Windtech D2CF 200	0.351
Micon M530	0.100

In this chapter the power output of one wind turbine was determined for different models. According to the power output of WTs (Figure 8), each WT turbine starts generating nominal power at different speeds, which depend on the characteristics of the wind turbines. It is also important to consider cut-in wind speed, which is the minimum speed necessary for a WT to start generating power. Narym rural settlement is located in an area where speeds are not very high (average annual wind speed 5.6 m/s), so in this case, the lower cut-in wind speed the better for the considered case. Cut-out wind speed is the speed at which the breaking system of wind turbine is operated to bring the rotor to a standstill, which does not endanger the power supply system, since the wind in the considered area does not exceed cut-out wind speed of the considered WTs. Based on the obtained values of the utilization coefficient I plan to consider 5 models of WTs, Micon 5390 will not be considered further because it has lowest utilization coefficient due to high cut-in wind speed for this region.

5. Electricity supply options

5.1 Power supply with diesel generators only

At the moment, the power supply of the villages is carried out with the help of diesel power plant. Due to lack of data about utilization time and rate of wear, I suggest to replace the existing DGs with new ones and add back-up DGs. Based on the need to provide consumers with electricity in all situations, the number and power of DGs should be selected taking into account the following requirements [46]:

1. The total capacity of the equipment must be 25% more than the daily maximum load: $P_{\sum} \geq 1.25 \cdot P_{\max}$

2. All generators that will be selected should be the same in terms of power.

3. Operation range for the load of DGs should be within 25-80% of the nominal load.

4. The number of diesel power generators should be sufficient to allow the units to be taken out of operation for maintenance.

5. The operating conditions of DGs must comply with the climatic characteristics of the area.

In the case of fluctuating daily or seasonal value of power consumption (several times) is necessary mode of parallel operation of DGs, because the specifics of the DG is that the continuous minimum load on it should not be less than 25%. For these reasons, a set of several DGs, operating synchronously for a common load and turning on or off automatically, depending on the load value, is used. In the case of parallel operation of power systems consisting of two or more DGs, it is necessary to use programmable controllers, designed for their synchronization and parallel operation, capable also of controlling the process of switching on and off the DGs, depending on the load power [54].

Based on the above criteria, I select to install 6 diesel power stations model AD-550S-T400-2PM22. The selected capacity of the DG meets the minimum load of the consumer, i.e. in case of minimum load equal to 440 kW, the DG will be able to operate under conditions that do not exceed its operating rules (the minimum load of the DG should not be below 25%). Then the total capacity of DGs in operation is equal to P = 2750 kW, and the power of backup generator is equal to P = 550 kW. Table 16 shows the main characteristics of the DG.

Table 16 - Characteristics of diesel power station AD-550S-T400-1RNM22

Type	AD-550S-T400-1RNM22
Power, kW/kVA	500/687.5
Voltage, V	230/400
Efficiency coefficient	0.8
Friquency, Hz	50

The selected DPP is equipped with a control panel with a circuit breaker, an automatic transfer switch and a controller, which is designed for synchronization and parallel operation with other DPP, is also able to control the process of switching on and off the DGs, depending on the load power [55].

Ballast load is used for disposal of excessive electricity. The ballast load accepts possible extra energy that is not demanded in the current time interval by the load [46]. As a ballast load are used load modules (ballast resistance), which are devices that provide electrical load to DGs and uninterruptible power sources. The purpose of this equipment is to accurately simulate the load applied to the power source during operation [56]. I chose the HM-500-T400-K2 model as the load module [57] due to cover the minimum possible load for one DG.

Also, to account for DGs in the economic model, it is necessary to know the fuel consumed during the year. Specific fuel consumption calculated by using following formula [46]:

$$G_i = K_{idle} \cdot G_{nom} + (1 - K_{idle}) \cdot G_{nom} \cdot \frac{P_i}{P_{DG}}, \qquad (10)$$

where

G_i – current fuel consumption, g/kWh;

G_{nom} – nominal fuel consumption, g/kWh;

P_i – actual power of DGs, kW;

P_{DG} – nominal power of DGs, kW;

K_{idle} – idle mode coefficient (fuel consumption at idle mode is equal 0.3).

In further calculations it will be necessary to know the amount of annual CO_2 emissions. Annual emission of CO_2 is calculated by following formula [58]:

$$E = M \cdot K_1 \cdot NCV \cdot K_2 \cdot \frac{44}{12}, \qquad (11)$$

where

M – annual real fuel consumption, t;

K_1 – oxidation coefficient which takes into account incomplete fuel consumption, average value for diesel fuel is 0.99;

NCV – net calorific value, for diesel fuel is 43.20 TJ/Gg;

K_2 – CO_2 emission coefficient, for diesel fuel is 19.98 tC/TJ;

44/12 – recalculation of carbon emission.

Table 17 shows the results of calculations of electricity generated by diesel generators for each month, as well as the amount of fuel consumed and CO_2 emissions. The WT column shows the energy generated by the WTs, since there are none in this option, it is 0. The W.DT column shows the energy generated by DGs.

Table 17 - Energy generated by DGs and fuel consumed by DGs

Month	Consumption, MWh	Gg, g/kWh	0	Amount of wind turbine		
			WT, MWh	W.DT, MWh	Fuel consumption, t	CO2 emission, t
January	682	163.4	0.0	682	111	348
February	682	163.4	0.0	682	111	347
March	619	163.4	0.0	612	101	315
April	619	163.4	0.0	619	101	315
May	619	163.4	0.0	619	101	315
June	588	163.4	0.0	588	96	300
July	588	163.4	0.0	588	96	300
August	588	163.4	0.0	588	96	300
September	659	163.4	0.0	659	108	336
October	659	163.4	0.0	659	108	336
November	659	163.4	0.0	659	108	336
December	682	163.4	0.0	682	111	348
Year	7,643		0.0	7,643	1,249	3,897

In this chapter the option of power supply from diesel generators was considered. I have chosen DGs total operating power is equal to 2750 kW. It was important to take into account the possible increase in demand for electricity in the considered settlement, which may be due to increase of population, for this reason, the total operating power of the selected DGs exceeds the estimated capacity of Narym rural settlement. An important part of the power supply system is to provide back-up power, which is necessary in case of power outages from the main power source for the period of repair or recovery of the normal operation of the power system, as a standby DG was selected similar DG capacity of 550 kW. The capacity of the backup DG was selected in order to supply power to the most important facilities (hospitals, schools). In order that the power supply system can exist under different conditions, for example, in case of reduction of the required electricity, it is also necessary to select the ballast load, which will consume extra electricity. As ballast load I chose power module HM-500-T400-K2, it will be necessary not only for power supply from DGs, but also further, when options of power supply from WTs with DGs are discussed.

Diesel fuel is used to operate the diesel generators. For further economic evaluation of this option it is necessary to estimate the amount of diesel fuel consumed by DGs. To calculate the consumed fuel for the year the formula (10) was used. According to the results of the calculation, when the electrification of Narym rural settlement from the selected generators, the amount of diesel fuel consumed per year is equal to 1,249 t, and the amount of emissions is equal to 3,897 t. In Chapter 7, I will calculate and compare the consumption of diesel fuel and CO_2 emissions for the options considered as well as for the option of electricity supply which exist now.

5.2 Wind generator (wind farm) and synchronization with the diesel generator

This power supply scheme allows the use of weak winds by supplementing the lack of power from the DG. In case of no wind, the electrical loads are powered by the DG [46].

In my work I consider 5 models of WTs. In the case of combined operation of DG and WT, additional equipment is required, such as an uninterruptible power supply to enable switching between WTs and DGs and a power module for the UPS. DELTA NH Plus 120 kVA was selected as the UPS [59], DELTA NH-Plus 20 kVA was selected as the power supply for the UPS [60], there are 5 power supplies for one UPS.

In order to select the one best option, it is necessary to evaluate the load coverage with turbines. To do this, it is necessary to plot the annual load coverage by WTs. For the accuracy of the calculations it is necessary to know the daily wind speeds in the region in order to calculate the daily power generation and then the monthly power generation.

Due to the lack of such data on wind (average value of wind speeds every day throughout the year) in Narym rural settlement, I consider the data, which was recorded by weather station of airport "Bogashevo", which is in the Tomsk region, since wind speeds in the Tomsk region are about the same this simplification is considered acceptable.

As mentioned earlier (Chapter 3.3) a wind farm is considered efficient when the wind speed is higher than 4 m/s. As can be seen from the graph of wind speeds in Narym rural settlement (Figure 5), the lowest wind speed statistically is during July, and the highest are during March. From [61] it was found that the highest speed for the 2021 year at Bogashevo airport was registered on March 4 (the best case), and the lowest on July 12 (the worst case). Based on this data, the power that would be generated by one WT depending on the wind speed is determined. Based on the daily load diagram (Figure 7), the highest and lowest power consumption are in winter and summer, respectively.

Then it is necessary to calculate the energy produced by WTs for the best and worst days, the calculations take into account wind speeds at different heights, as the height of WT is different. Based on the calculations made, the amount of WT needed to cover the energy demand for each case was determined, the results are shown in Table 18.

Table 18 – Amount of WT necessary to cover demand

Amount of WT, pcs.		
Model of WT	Best case	Wors case
Hummer H21.0-100KW	15	42
Argolabe Turbec-100	15	53
AN Bonus 150/30	15	52
Hummer H25.0-200KW	9	16
Aeolia Windtech D2CF 200	8	25

However, the number of turbines, shown in Table 18, is calculated taking into account the total energy needed per day, which is an inaccurate value, because according to the daily load diagram the option with 42 turbines would exceed demand by several times during best case weather conditions. In addition, the system does not provide storage batteries, thus number of turbines will be irrational. In order to consume extra energy, it was decided to use power modules. Its number will depend on amount of extra energy, I choose power module with power equal to 500 kW. It means that if there is a 1000 kW extra energy the system would require 2 power modules. Extra energy will also depend on wind speed, model of WT and demand. The idea is that the energy generated by turbines and DGs must match the demand at each point in time. In this model, the variable component is the energy generated by the WTs, which in turn depends on the wind speed. In order to ensure that the designed power supply system can meet the demand for electricity under all conditions. From formula (11) we see that the demand to be covered is equal to the sum of the energy produced by WT and DG excluding the power of the load module, since the extra energy cannot be sold to the grid.

$$\sum E_{DG}(i) + \sum E_{WT}(i) - \sum E_{LM}(i) = E_L(i), \qquad (11)$$

where E_{DG} - energy at given time, generated by DGs,

E_{WT} - energy at a considered point in time, generated by WTs,

E_{LM} - energy at given time, consumed by the load modules in the case when the electricity generation exceeds the demand,

E_L - electricity demand at given time.

The number of DGs operating at a certain moment can vary from 0 to 5, as well as the load of one DGs (from 25% to 80%). It is assumed that the operating DGs share the load equally. The number of turbines can vary from 0 to maximum number of WTs determined by worst case.

In Appendix 2 there are charts for power supply and demand for each model of WT. In the case of maximum demand for electricity in the best case when wind speed is highest, power generated by WTs exceeds demand and this extra energy consumed by load modules. In the same demand in the worst case when wind speed is lowest, energy from WT is not enough to cover demand and power deficit is covered by DGs (minimum quantity is 1 piece, maximum quantity is 4 pieces). When demand is minimal and wind speed is high, the energy produced by the turbine also exceeds the demand and, in this case, extra energy also consumed by power module. In the worst case (low wind speed) with minimum consumption there is a similar situation as in case of maximum consumption, energy produced by WTs is not enough. At high winds for maximum amount of WT the power generation exceeds the demand in both cases, which is an irrational waste of electricity, since this project does not provide storage batteries, and the network is decentralized and the sale of electricity to the network is not possible.

Next, I plan to choose the best option for power supply through economic analysis. I will compare the power supply of Narym rural settlement only DGs, as well as from the combined operation of WTs and DGs.

6. Economic assessment

6.1 Methodology for economic evaluation of the project

In order to implement the project, it is necessary to estimate a set of economic parameters. In my work I consider NPV (net present value) and minimum price of energy.

NPV is the criterion that allows to decide whether it is reasonable to invest in a project. NPV estimates the difference between the present value of cash inflows and the present value of cash outflows. However, there are no cash flows (CF) in the current project. Because the NPV calculation is purely cost-based, the NPV for all measures will be negative, and a closed to zero NPV would be more desirable [62].

NPV is calculated according to following formula [62]:

$$NPV = C_0 + \sum_{t=0}^{T} \frac{C_t}{(1+r)^t}, \tag{11}$$

where C_0 – initial investment in the project,

T – life time of a project,

t – number of time periods,

C_t - summary CF in the period t,

r – discount rate.

Minimum price of energy is the cost of 1 kWh produced energy. It calculated based on principal that NPV is equal 0.

6.2 Economic inputs

The data for the calculations is taken at the time of January, which was before the current events. The change of parameters and their influence on NPV will be reflected in the sensitivity analysis. I also assume that all equipment and technology remain available at the time of the project.

The discount rate refers to the interest rate used in discounted cash flow (DCF) analysis to determine the present value of future CF [63]. To determine discount rate, I use capital asset pricing model (CAPM). CAPM describes relations between risk and expected return[62]:

$$r = r_f + \beta_L \cdot MRP, \tag{12}$$

where r – discount tare, %,

r_f – risk-free rate, %,

β_L - sensitivity to market changes, MRP – market risk premium, %.

The risk-free rate of return is the theoretical rate of return of an investment with zero risk. The risk-free rate represents the interest an investor would expect from an absolutely risk-free investment over a specified period of time [64]. I take risk-free rate of governmental Russian bonds for 20 years $r_f = 8.97\ \%$ (20.01.2022) [65]. $\beta_L = 0.85$ for power industry. MRP of Russia is 8.1% [66].

$$r = r_f + \beta_L \cdot MRP = 0.0897 + 0.85 \cdot 0.081 = 0.159. \quad (13)$$

Inflation is the rate at which the value of a currency is falling and, consequently, the general level of prices for goods and services is rising [67]. It will be taken into account to estimate changes in the cost of equipment maintenance, as well as to account for changes in employee salaries.

In Table 19 there are data about inflation for last 15 years.

Table 19 – Inflation in Russia from 2006 to 2021 years [68]

Year	2006	2007	2008	2009	2010	2011	2012	2013
Inflation	11.18	11.87	15.14	13.98	8.78	9.61	6.58	6.45
Year	2014	2015	2016	2017	2018	2019	2020	2021
Inflation	11.36	12.91	5.38	2.52	4.27	3.05	4.91	8.39

Based on Table 19 there was created Figure 9.

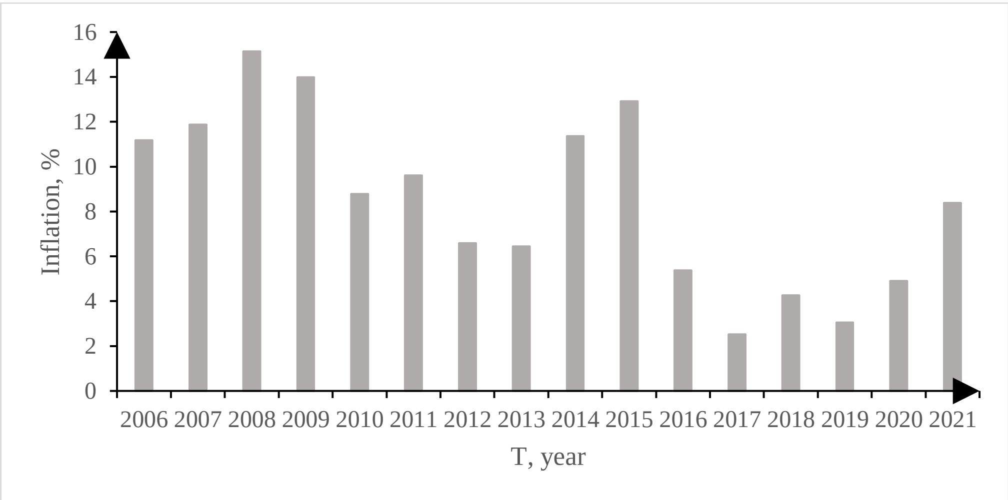

Figure 9 – Inflation in Russia

The Russian Federation has experienced major crises twice in the last 20 years, in 2008 and in 2014 [69]. As can be seen from Figure 9, in 2008 it took about 3 years to recover to the normal level of inflation. Report of Bank of Russia of April 2022 [68] also shows that recovering after current situation will tale for Russia about 3 years.

In my paper I will consider 2 possible scenarios for inflation. In the first case, inflation will have a constant value throughout the lifetime of the project, it will be equal to 4%, which is the target inflation set by the Central Bank of Russia [68]. In the second case I will assume inflation for 2022 equals to 16.7%, which is equal to the current inflation rate declared by the Central Bank, inflation for 2023 equals to 7.6% and for 2024 is equal 5%. By the end of 2024 and beginning of 2025 inflation will be set at the 4% target [69].

The cost of diesel fuel is assumed to be 55.6 RUB per liter (the data are taken for 2022 year) [70]. To take into account the changes in the cost of fuel the results of the forecast growth of diesel fuel for the Tomsk region were taken [71], based on this data the fuel growth factor is taken as equal to 9.68% for each following year.

Table 20 shows the cost of equipment. The amount of equipment depends on the number of WTs, the number of DGs and load modules.

Table 20 – System components

Equipment	Model	Amount, pcs.	Price per one unit, $	Price per one unit, RUB	Exchange rate	Life time, years
			20.01.2022			
Diesel power station	AD-550S-T400-1RNM22 [72]	6	79,217.2	6,089,400.0	76.8697	20
Load module	HM-500-T400-K2 [73]	1	7,285.1	560,000.0		20
UPS	UPS DELTA NH Plus 120kVA [59]	1	12,962.3	996,408.0		20
Power module for UPS	Delta NH-Plus 20 kVA/16 kW [60]	5	306.6	23,566		20
Wind turbine	Hummer H21.0-100KW [74], [75]	1	103,000.0	7,917,579.1		20
	Argolabe Turbec-100 [74], [75]	1	103,000.0	7,917,579.1		20
	AN Bonus 150/30 [74], [75]	1	154,500.0	11,876,368.7		20
	Hummer H25.0-200KW [74], [75]	1	206,000.0	15,835,158.2		20
	Aeolia Windtech D2CF 200 [74], [75]	1	206,000.0	15,835,158.2		20
	Micon M530 [74], [75]	1	257,500.0	19,793,947.8		20

The project lifetime is assumed to be 20 years, as the average lifetime of a WT is 20 years [76]. As for diesel generators, on average DGs last from 10,000 to 30,000 hours, usually corresponding to about 20-25 years of operation [77].

Equipment prices were taken from the official source of the equipment supplier. For WTs, the price was taken from a Bloomberg New Energy Finance study [78], where according to the price index for WTs, a 1 MW wind turbine costs $1.03 mln. $, which equals 79.2 mln. RUB. This cost also includes the cost of transportation and the cost of the towers but not cost of installation.

Calculations are made in the currency of the country for which the project is considered, that is, in Rubles. Exchange rate is equal to 76.8697 Rub/$ (20.01.2022 year) [79].

Construction and installation works are 20% of the total cost of the equipment, the cost of RES maintenance is 2% of the cost of the main equipment for each year. The maintenance costs for the DPP are 5% per year for the case when the DPP is the only power source and in case of hybrid power generation is 2.5 % [46].

Wages for one employee is taken as equal to 30,000 rubles based on the data on the average wage of an electric power engineer in the Tomsk region [72]. Based on [80] the super gross salary is equal 45000 RUB. At the power plant should be organized 24-hour operating mode control, at the work schedule of 12 hours per shift, the minimum number of personnel of appropriate qualifications at the plant is assumed to 2. At the 2/2 work schedule, the minimum number of employees is assumed to be 8 [81]. I accept an annual growth in the super gross salary equal to inflation.

In the case carbon tax is not considered, since there are no such payments at the legislative level in Russia. To further assess the impact of carbon tax on the choice of the best configuration will be taken into account the average value of carbon tax for the EU because for different countries there is different value of carbon tax (it can vary from $ 0.08 to $ 137. For the EU, the average value of carbon tax is $ 42.29 (3,250.8 RUB) per ton of CO2 [82].

6.3 Economic model calculation

In my work, I consider three basic scenarios:

1. Inflation is 4%, carbon tax is not included.

2. Inflation is 4%, carbon tax is included.

3. Inflation changed as described in Chapter 6.2, carbon tax is not taken into account.

I decided to include carbon tax into calculation for scenarios with equals inflation in order to reflect its influence on NPV. Also, to calculate payments for the carbon tax, it is necessary to know the annual CO_2 emissions. The amount of emissions will depend on the diesel fuel consumed by the DGS. The methodology for calculating annual CO_2 emissions is given in Chapter 5.1.

All calculations are performed for 5 different types of WTs and for different number of WTs. The paper assumes that the project has no revenue, that is, it is considered from the project point of view.

As it can be seen from Figure 3.1 to Figure 3.5 with increasing number of wind turbines the NPV also increases, the increase of NPV with increasing number of wind turbines occurs as long as wind turbines cover the demand for electricity, as soon as the total energy generated by wind turbines exceeds the demand, the NPV begins to decrease. This is due to the fact that the sale of electricity to the grid is not possible, as the power supply system is decentralized, respectively, there is an increase in investment costs for the purchase of wind turbines, as well as additional ballast load to consume extra energy. From the graphs in Appendix 3 it is possible to determine the optimal number of WTs for each type. The results are shown in Table 21.

Table 21 – Results of NPV calculation

WT	Hummer H21.0-100KW		Argolabe Turbec-100		AN Bonus 150/30		Hummer H25.0-200KW		Aeolia Windtech D2CF 200	
Case	NPV, RUB	N	NPV, RUB	N	NPV, RUB	N	NPV, RUB	N	NPV, RUB	N
1	-427,635,307	26	-465,660,085	28	-666,810,544	28	-492,531,654	16	-473,562,898	15
2	-432,120,060		-471,629,105		-680,255,846		-497,272,628		-478,091,343	
3	-426,723,519		-464,446,533		-663,318,836		-491,285,355		-470,238,102	

As can be seen from Table 21, the best option (the value with the highest NPV) is the WT model Hummer H21.0-100KW in the amount of 26 pieces.

It is also important to note that depending on the scenario, there are different NPVs for the same case, which can be seen in both Table 21 and Appendix 3. If comparing Scenario 1 and Scenario 2, the NPV is lower in Scenario 2, which is due to the additional cost of the carbon tax. If comparing Scenarios 1 and Scenario 3, the NPV in Scenario 3 is higher, this is due to the fact that with a negative NPV a higher value of inflation has a positive effect, if the NPV was positive, the effect would be the opposite. Regardless of the scenario, the result remains the same, the best option is Hummer H21.0-100KW at 26.

One of the parameters for the economic evaluation of the project is the minimum cost of electricity. Table 22 shows the c_{min} values for the different WT models for the optimal number for the three scenarios.

Table 22 - Results of calculations of the minimum cost of electricity

WT	Hummer H21.0-100KW	Argolabe Turbec-100	AN Bonus 150/30	Hummer H25.0-200KW	Aeolia Windtech D2CF 200
Case	c_{min}, RUB/kWh				
1	7.62	8.30	12.02	8.79	8.29
2	7.70	8.41	12.18	8.86	8.52
3	7.79	8.47	12.27	8.98	8.59

According to the results of the calculations of the minimum cost of energy the best option is Hummer H21.0-100KW. It is important to note that the calculated c_{min} does not include the costs of transportation and distribution of electricity, but only the costs of its production. The cost of electricity in Narym rural settlement is 20.10 RUB/kWh [34]. The cost of electricity is all costs related to the production, transportation and distribution of electricity [83]. It is also important to note that the cost of electricity and the tariff are not the same, the tariff for residents of Narym rural settlement for 2022 is 3.85 RUB/kWh [84]. In the case of electricity supply in decentralized areas, most of the expenses are covered by the government. As can be seen from Table 20, in all considered cases the minimum cost of electricity does not exceed the cost of electricity for Narym rural settlement.

6.4 Sensitivity analysis

Sensitivity analysis is a method of quantitative risk analysis and modeling used to identify the risks with the greatest possible impact on the project. The method involves assessing the impact of changes in various input variables on the resulting indicators of project implementation [85].

In this paper I will consider next parameters that can affect the economic feasibility of an optimal hybrid system:

- discount rate;
- fuel price;
- inflation;
- WT cost;
- DG cost.

It is important to consider changes in the discount rate from the point of view of the profitability of the project. Many parameters influence the discount rate, for example, in my work I calculated the discount rate based on the CAPM model, where the parameters that influence the discount rate are risk-free rate, sensitivity to market changes and market risk premium. It is also important to consider that the discount rate will be different depending on the country of the project implementation.

The Russian Federation is not much affected to changes in fuel prices, including diesel, as it is the world's main fuel exporter. Accordingly, I consider such a range for changes in the price of diesel fuel, which takes into account both a decrease and an increase in the cost per liter of fuel.

Inflation is one of the most important parameters affecting the final cost of a project. In the context of current events, I think it is important to reflect the increase in inflation, which has already affected many countries, including the Russian Federation. According to analysts' predictions, inflation in the Russian Federation may reach 20% by the end of 2022 year[69], which I would like to reflect in the sensitivity analysis.

Change of equipment cost is also the main parameter for project implementation, change of equipment cost influences not only the change of initial investment costs, but also the cost of installation, annual maintenance and transportation of equipment.

In my work I analyzed the influence of the above parameters on the change of NPV. Sensitivity analysis was performed for three scenarios for optimal number of wind turbines (Table 19) for 5 different models. As the sensitivity analysis showed, the change of all the parameters investigated has the same effect on the change of the NPV in different wind turbine configurations. In Figure 10 to Figure 14 graphs of dependence of NPV on the mentioned above parameters for the power supply option selected by me as optimal on the basis of economic analysis are shown (Hummer H21.0-100kW in amount of 26 pieces with DGs as back up).

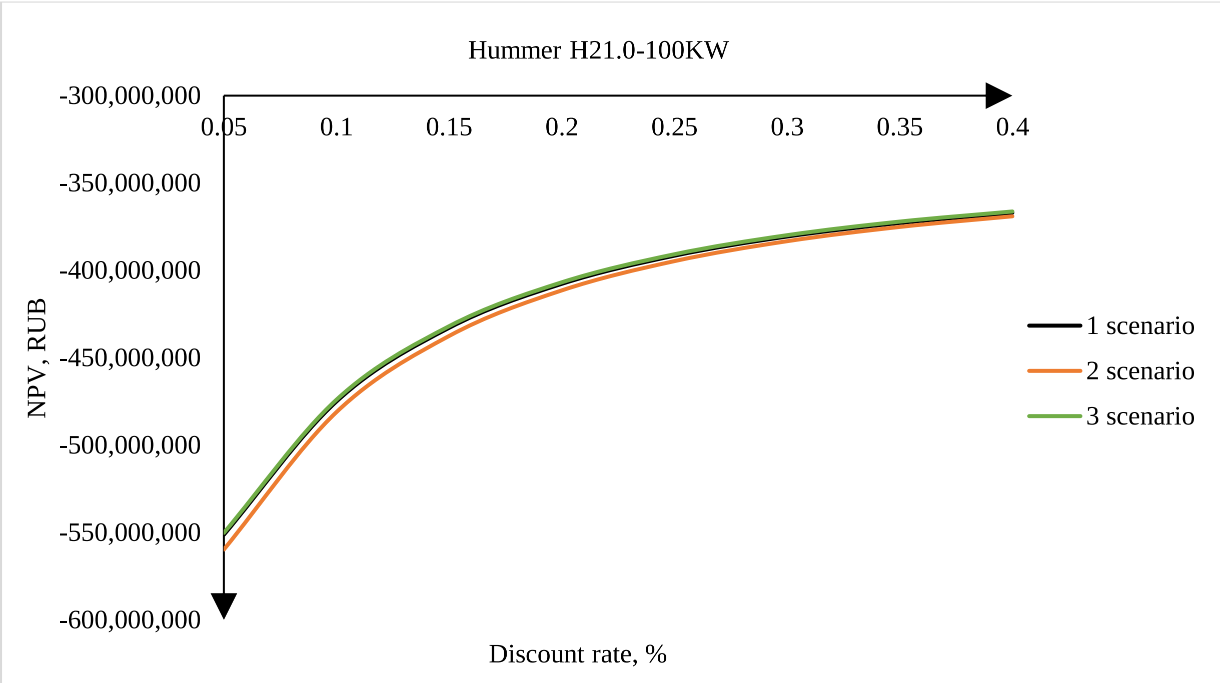

Figure 10 – Dependence NPV on discount rate

According to Figure 10, as the discounted cash flow increases, the NPV increases, which is explained by the growth of discounted cash flow, as can be seen from the formula for the NPV (11). The shape of the graph is related to negative CF.

The change in the cost of diesel fuel has a greater impact compared to the previous parameter, this is due to the fact that the NPV is directly dependent on the price of fuel, an increase in one will reduce the other (Figure 11).

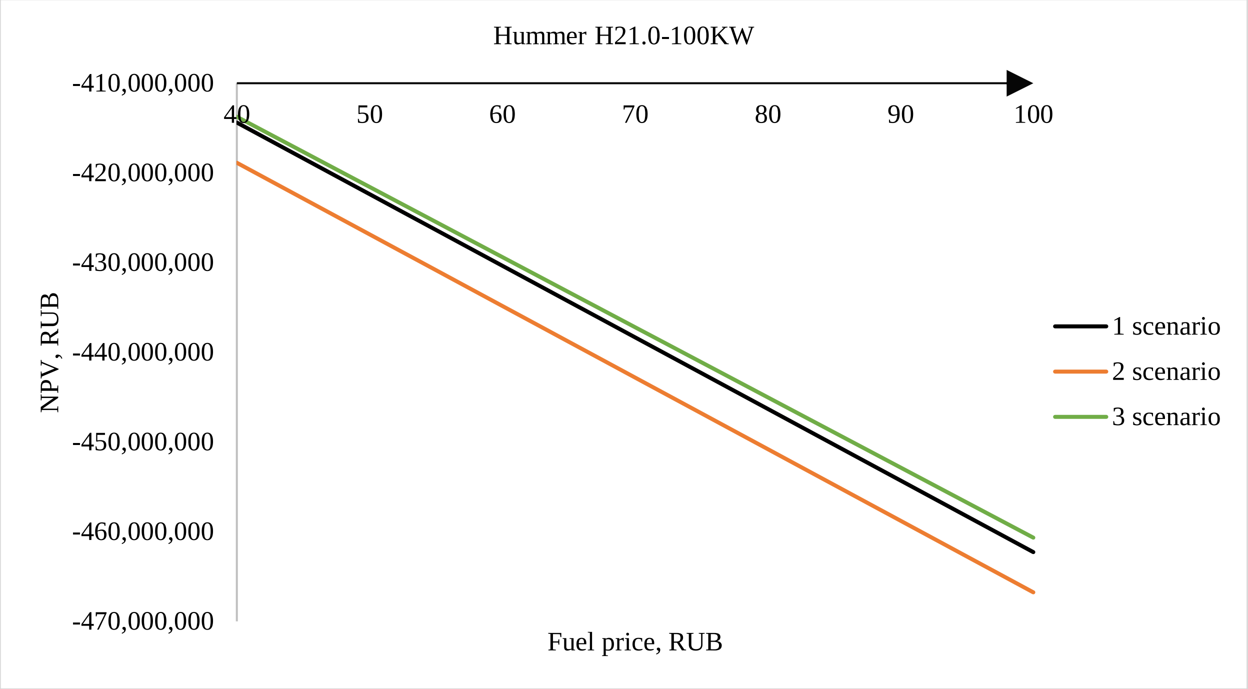

Figure 11 - Dependence NPV on fuel price

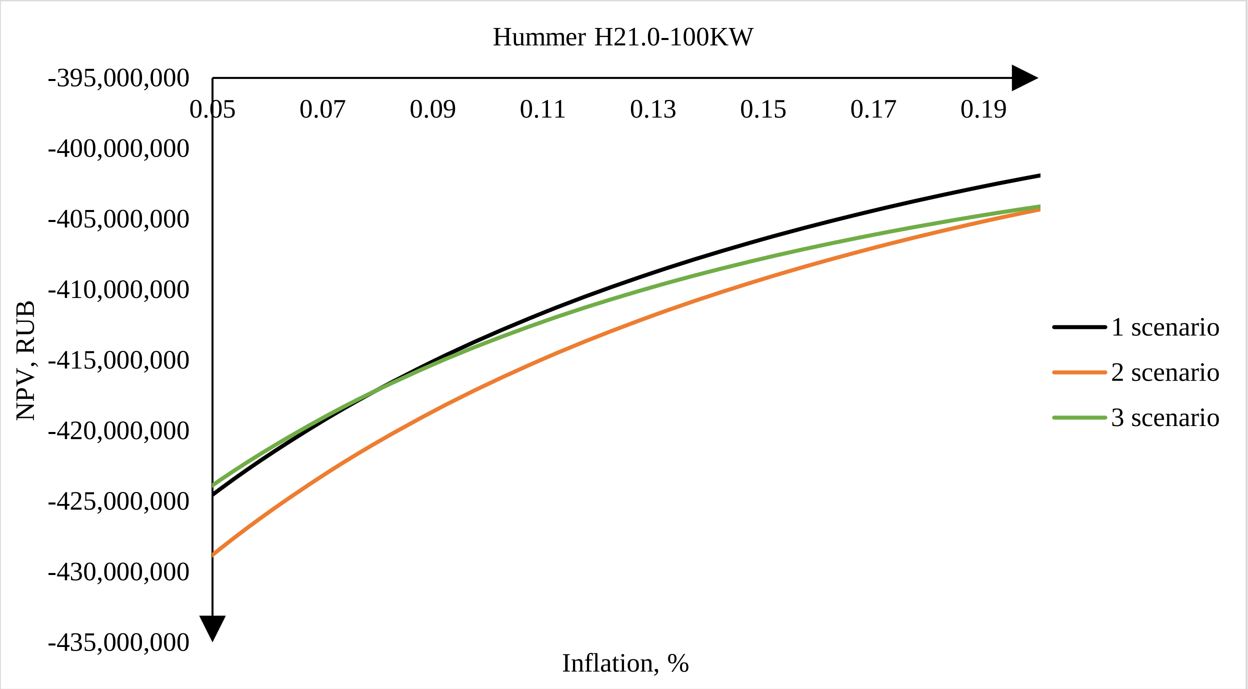

Figure 12 - Dependence NPV on inflation

As can be seen from Figure 12, with an increase in inflation the NPV also increases, it is related to the negative CF, in the case of a positive CF the result would be the opposite.

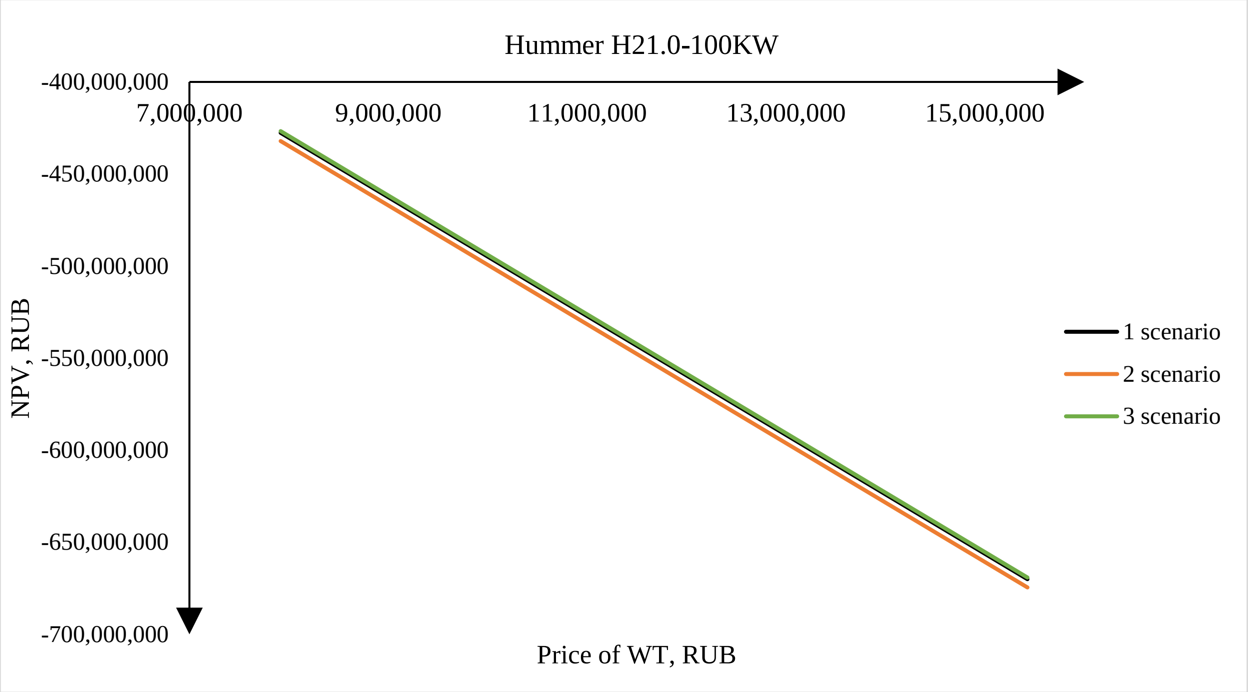

Figure 13 - Dependence NPV on cost of WT

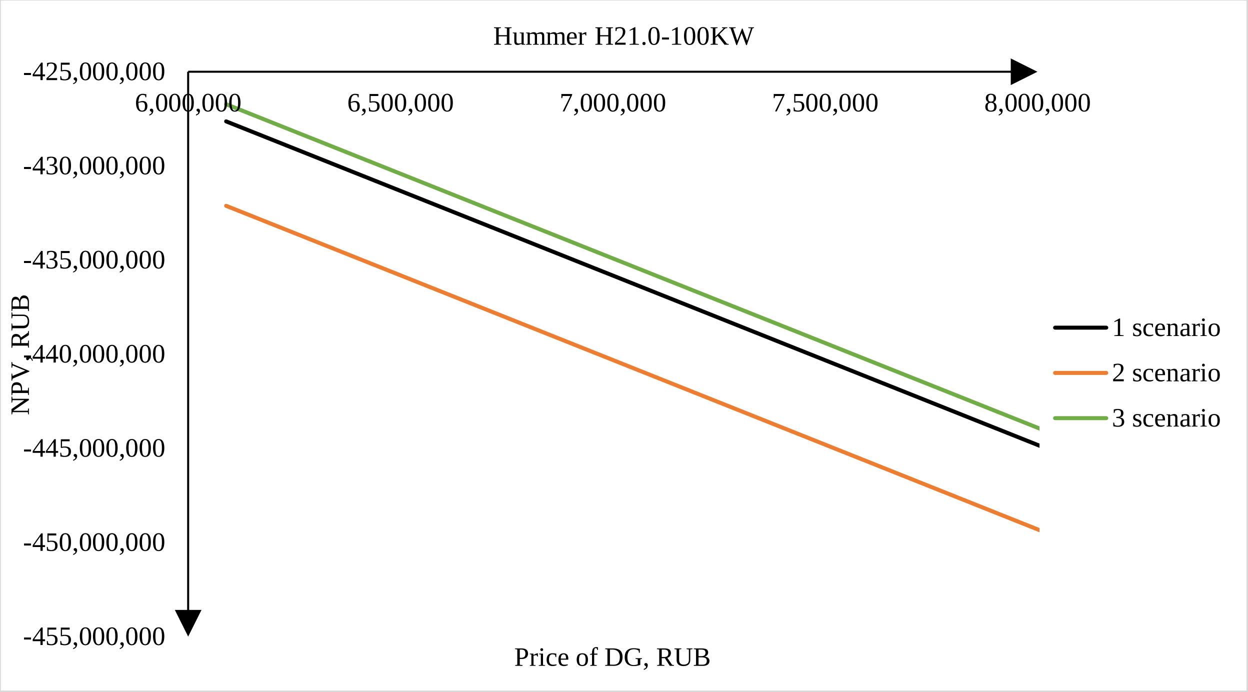

Figure 14 - Dependence NPV on cost of DG

Figure 13 and Figure 14 show the dependence of the NPV on the cost of WT and DG, respectively, an increase in the cost of equipment results in a decrease in the NPV, as there is an increase in cash outflow.

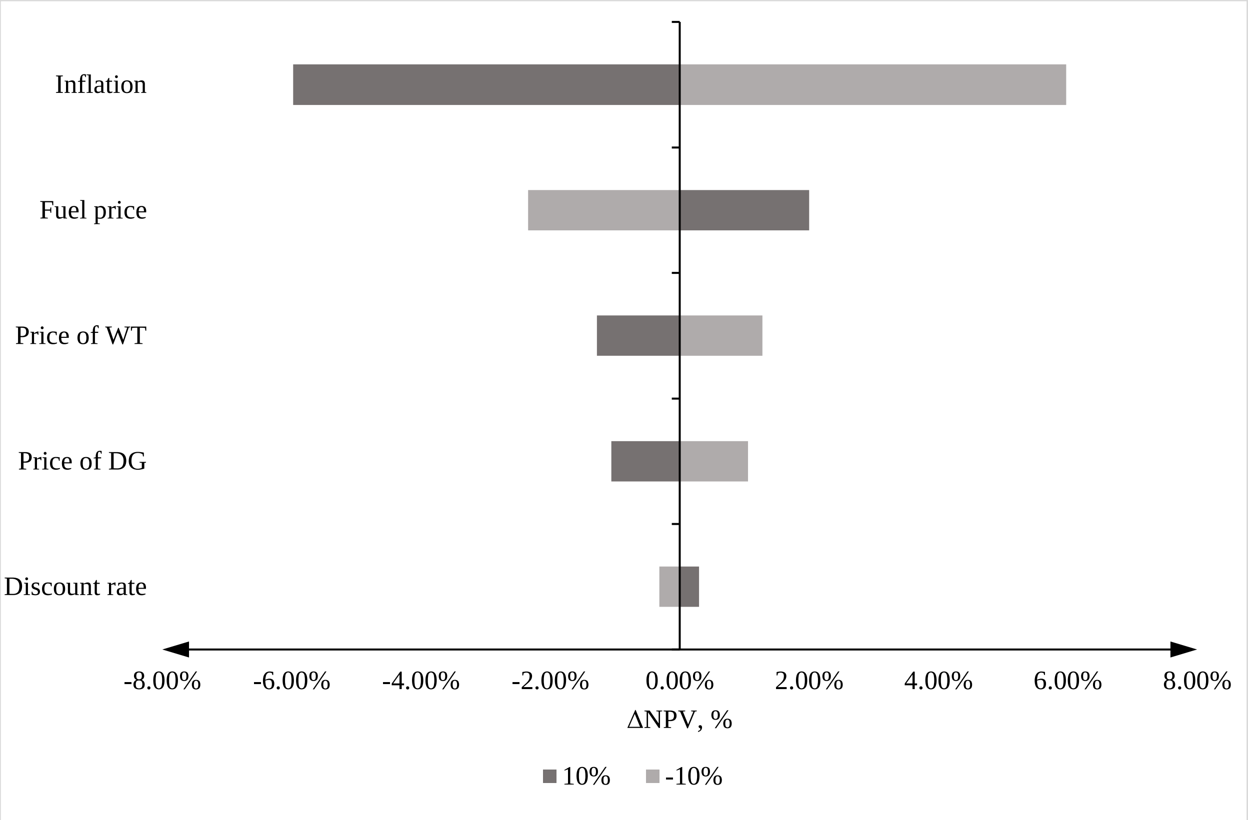

Figure 15 – Tornado diagram

According Figure 15, the resulting tornado diagram clearly shows that inflation has the greatest impact on this project, which is a relevant fact especially in view of current situation. Inflation in many cases significantly affects the value of the effectiveness of the investment project, the conditions of financial feasibility, the need for financing and the effectiveness of equity participation in the project. An increase in inflation leads to an increase in market interest rates and a decrease in the systemic efficiency of the business.

The price of diesel fuel has a lower influence on NPV, although this parameter is no less important, because if the main source of electricity is DGs, then the cost of fuel will make a greater impact on the cash outflow.

The cost of equipment affects the NPV approximately equally, although with the increase in the number of WTs, the cost of WTs would have a greater impact on the NPV than the cost of DGs, since DGs in my project is a constant.

Thus, based on the sensitivity analysis it can be concluded that changing the input parameters chosen for the analysis has no effect on the final decision.

7. CO2 emissions estimation

Combustion of any kind of fuel releases CO_2, which affects global warming and has a negative impact on the environment and human health [86].

In this chapter, I aim to compare emissions of CO_2 from diesel fuel for the existing system of power supply with diesel generators and for the system of combined power supply from 26 wind turbines model Hummer H21.0-100KW and diesel generators that was I suggest.

To calculate the CO_2 emissions from diesel combustion it is first necessary to calculate the amount of diesel consumed, formula (10) is used for this purpose. To calculate CO_2 emission formula (11) is used.

Table 4 shows the diesel consumption of Narym diesel station for the period from 2015 to 2019, the average value of diesel consumption is 940 t per year. Calculation of CO_2 emissions is given below:

$$E = M \cdot K_1 \cdot NCV \cdot K_2 \cdot \frac{44}{12} = 940 \cdot 0.99 \cdot \frac{43.20}{1000} \cdot 19.98 \cdot \frac{42}{12} = 2{,}811\ t. \tag{14}$$

Then the consumption of diesel fuel in the case of combined power supply from HTPs and DGs is calculated. Table 23 shows the calculated data on the energy generated by WTs and DGs for each month, as well as the annual fuel consumption and CO_2 emissions.

According to Table 23, most of the necessary energy is generated by wind turbines, the lacking part is covered by diesel generators. The final consumption of diesel fuel in this option of power supply system is 93 t per year, and the emissions are equal to 290 t per year.

Table 23 – Result of calculation of supplying by WTs and DGs

Month	Consumption, MWh	Gg, g/kWh	26	Hummer H21.0-100KW		
			WT, MWh	W.DT, MWh	Fuel consumption, t	CO2 emission, t
January	682	163.40	656	25	4.1	12.9
February	682	163.40	667	15	2.5	7.7
March	682	163.40	822	0	0	0
April	619	163.40	712	0	0	0
May	619	163.40	663	0	0	0
June	588	163.40	488	100	16.3	50.8
July	588	163.40	472	116	19	59.1
August	588	163.40	437	152	24.8	77.3
September	659	163.40	507	152	24.8	77.4
October	659	163.40	650	9	1.4	4.4
November	659	163.40	737	0	0	0
December	682	163.40	691	0	0	0
Year	7,643		7,503	569	93	290

On average, the amount of CO2 emissions during operation of the Naryms DPP is 2870 t per year. In case of the proposed project the annual fuel consumption will be 93 t, which will result in CO_2 emissions of 290 t per year, which is almost 10 times less compared to the existing option.

Conclusion

In this thesis, HRES based on diesel generators and wind turbines was designed to supply remote rural settlement Narym. I performed technical analysis that showed that population of 1817 people leads to installed capacity equal to 2230 kW. Then I analyzed energy potential of the considered region. This analysis took into account several RES such as solar, wind, biomass and hydropower. Solar irradiance in the region is too low during the year with maximum value of 5.74 kWh/m^2/day in June. Thus using PV installations in this region is not feasible. Hydropower is also not feasible as there is a flat topography characteristic of most of the territory and low flow of water. Which makes it unfavorable for the construction of dams and reservoirs on rivers. Biomass however can cover the energy demand, but remoteness of such consumers and the lack of land communication for most of the year, makes such a source of renewable energy not feasible. Wind power is considered feasible as annual average wind speed is 5.6 m/s and it is higher than minimal possible wind speed for wind farms of 4 m/s. Therefore, HRES is based on wind power as it is the only available feasible source and it will be connected to existing energy supply.

The HRES consists of diesel generators, wind turbines, UPS and load module for excessive energy. I to install 6 diesel power stations model AD-550S-T400-2PM22 as this model is designed for such climate conditions as they are in considered region. Power of DG is 550 kW so it can operate during time of minimal consumption [46]. However, there are several alternatives for WT (Hummer H21.0-100KW, Argolabe, Turbec-100, AN Bonus 150/30, Hummer H25.0-200KW and Aeolia Windtech D2CF 200), as selection is based on economic analysis. Moreover, each WT alternative generates different amount of energy, meaning that it will affect the number of power modules for excessive energy, but power for one module is the same and equals to 500 kW. With such a set of equipment and defined supply system it is possible to build and analyze demand-supply diagram. This diagrams (Figure 2.1, Figure 2.2, Figure 2.3, Figure 2.4, Figure 2.5) show that wind and diesel energy can provide enough energy, but in the same time raises the question of economic feasibility of the project.

Economic analysis was based on such parameters as NPV and minimal cost of energy. Both technical and economic analyses showed that the best configuration is combined energy supplying by wind turbines Hummer H21.0-100kW in amount of 26 pieces with DGs. The project's NPV is equal -427,635,307 RUB, minimal cost of energy is equal 7. 62 RUB/ kWh. The sensitivity analysis also showed that regardless of changes in the input parameters (discount rate, the cost of diesel fuel, inflation, the cost of the wind turbine and the cost of the diesel generator), the best option remains the same. The sensitivity analysis showed that the project is more sensitive to changes in inflation.

During the economic analysis I also considered current political and global situation. Current events have direct influence on not only local but global economy. It influences prices on energy in Europe, difficulties with logistics e.g. transportation of purchased equipment for the project and inflation in Russia.

After introduction of HRES CO_2 emissions dropped by 2777 t per year. As fuel consumption decreases, meaning that HRES is beneficial technically, economically and ecologically.

Finally, I want to emphasize the importance of implementation of RES based energy supply. Considered region is not that rich with RES as other places on the planet, which means that if this project is technically and ecologically feasible in Narym we can implement such systems in remote areas with richer sources i.e. higher solar irradiance, higher wind speed or appropriate topography or water flow for hydro power. The experience of this project can be used for introduction of more enhanced and robust RES based electricity supply systems. The project, developed on the example of the Narym rural settlement, shows that similar systems can exist in other parts of the world as well. Possible solutions may vary depending on the location of the facility, the prevailing source of renewable energy, system capacity, etc. In addition, I can conclude that introduction of HRES can bring independence from fossil fuels.

As a result, the work has achieved all the objectives, a review of the current situation in the world with off-grid systems, an analysis of the existing power supply system and the analysis of renewable energy sources, were developed possible options for the implementation of electricity supply and based on economic analysis was chosen the best option.

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Appendices

Appendix 1

Table 1.1 – Consumed energy depending on the season

Energy, kWh				
Hours	Winter	Spring	Summer	Autumn
1	550	550	440	550
2	550	550	440	550
3	550	550	440	550
4	550	550	440	550
5	550	550	550	550
6	770	770	660	770
7	1100	990	880	990
8	1320	1100	990	1210
9	880	880	880	880
10	660	660	660	660
11	660	660	660	660
12	770	770	660	770
13	880	880	770	880
14	660	660	660	660
15	660	660	660	660
16	660	660	660	660
17	880	660	660	660
18	1540	880	660	880
19	2200	1100	770	1540
20	2090	1540	880	2200
21	1540	2200	1540	1870
22	1100	440	2200	1320
23	770	1100	1320	880
24	660	660	550	660

Appendix 2

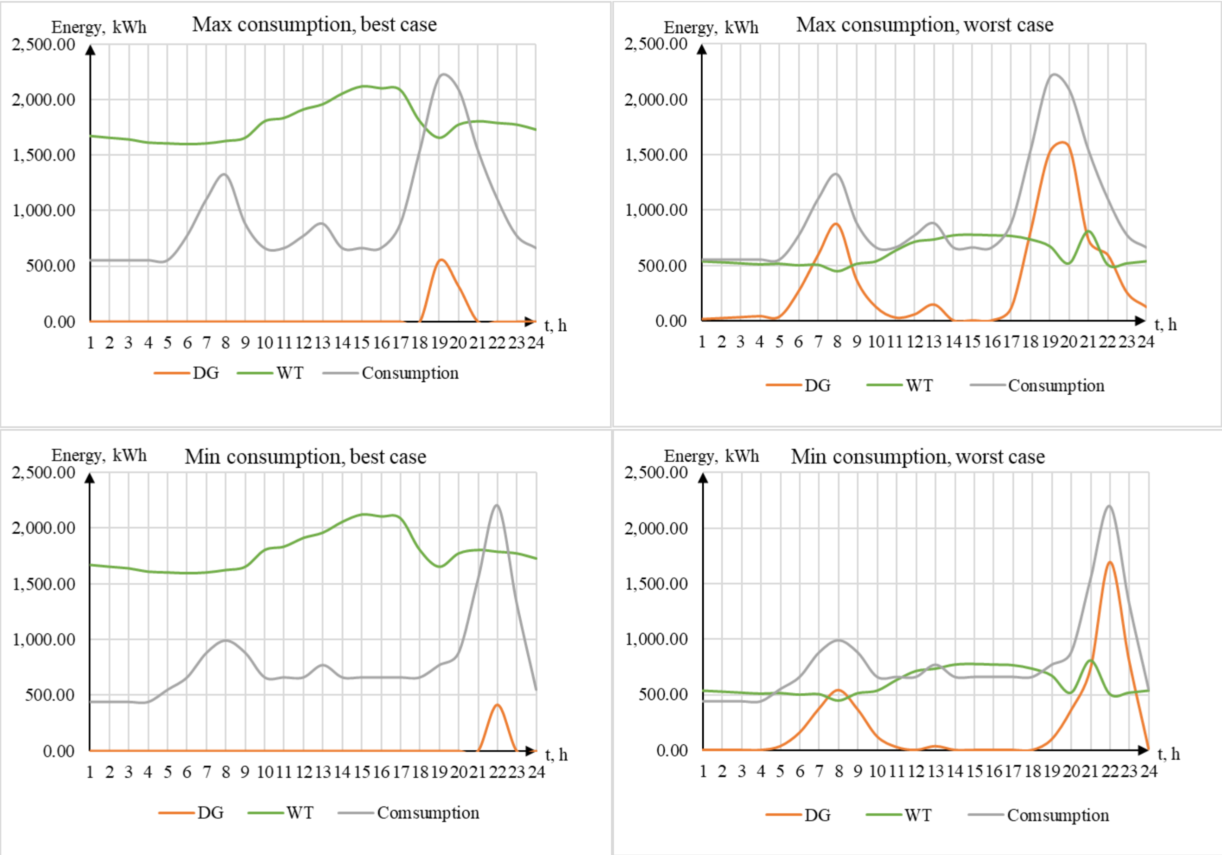

Figure 2.1 - Demand and supply diagram for Hummer H21.0-100KW

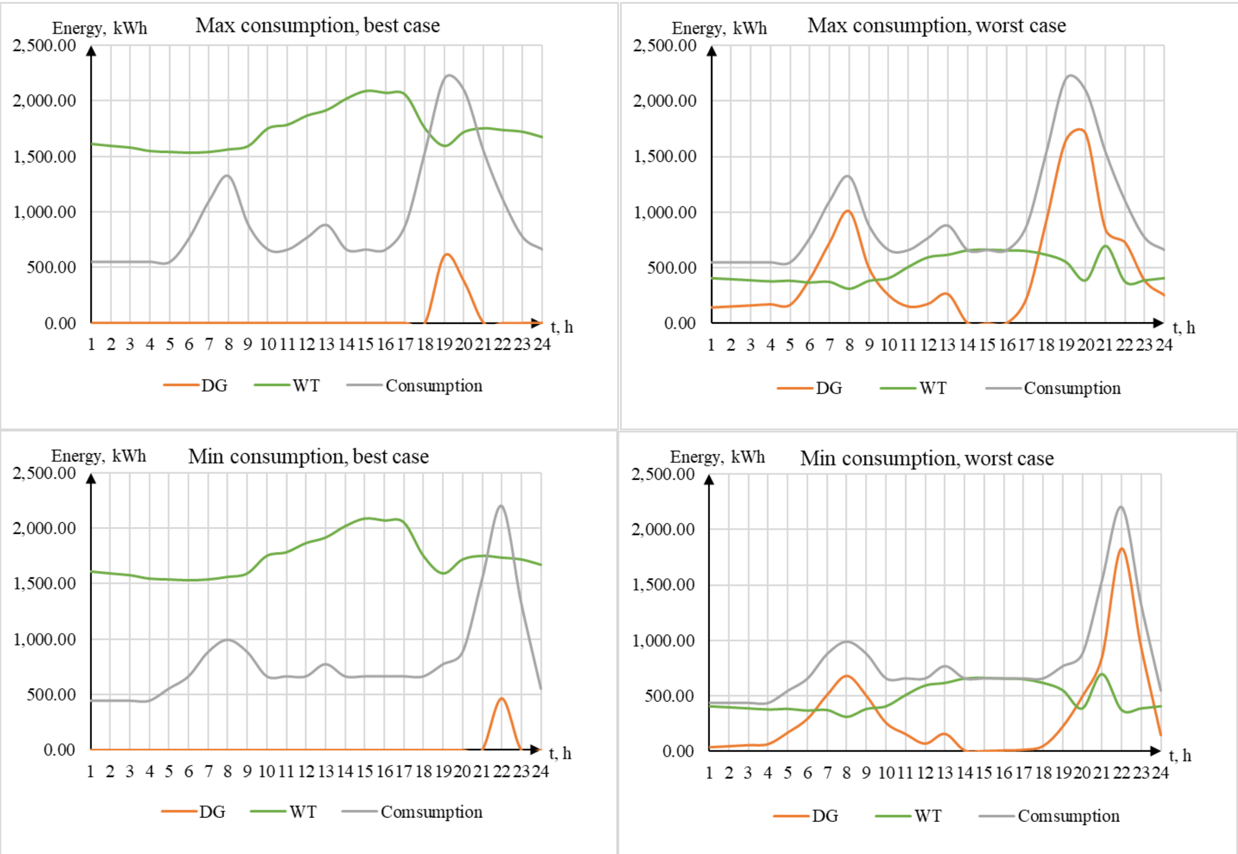

Figure 2.2 - Demand and supply diagram for Argolabe Turbec-100

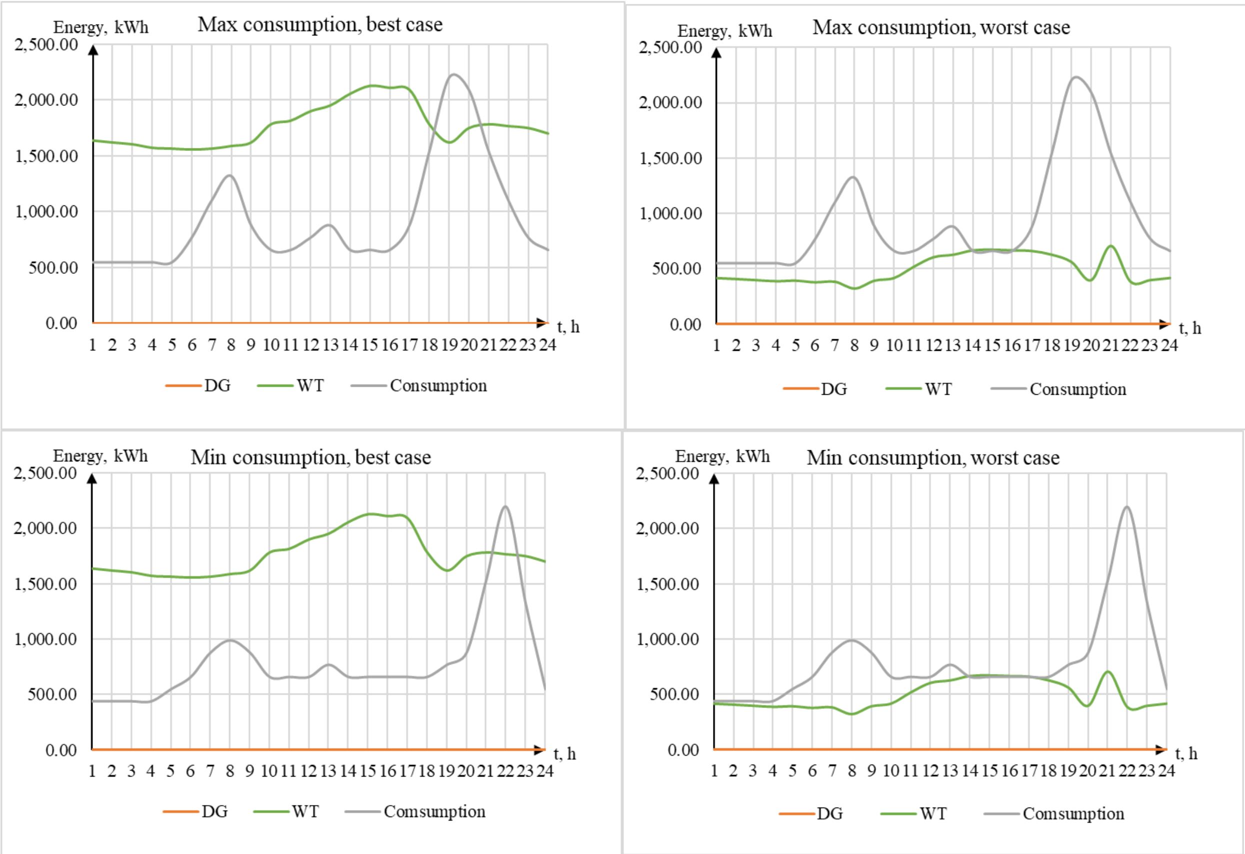

Figure 2.3 - Demand and supply diagram for AN Bonus 150/30

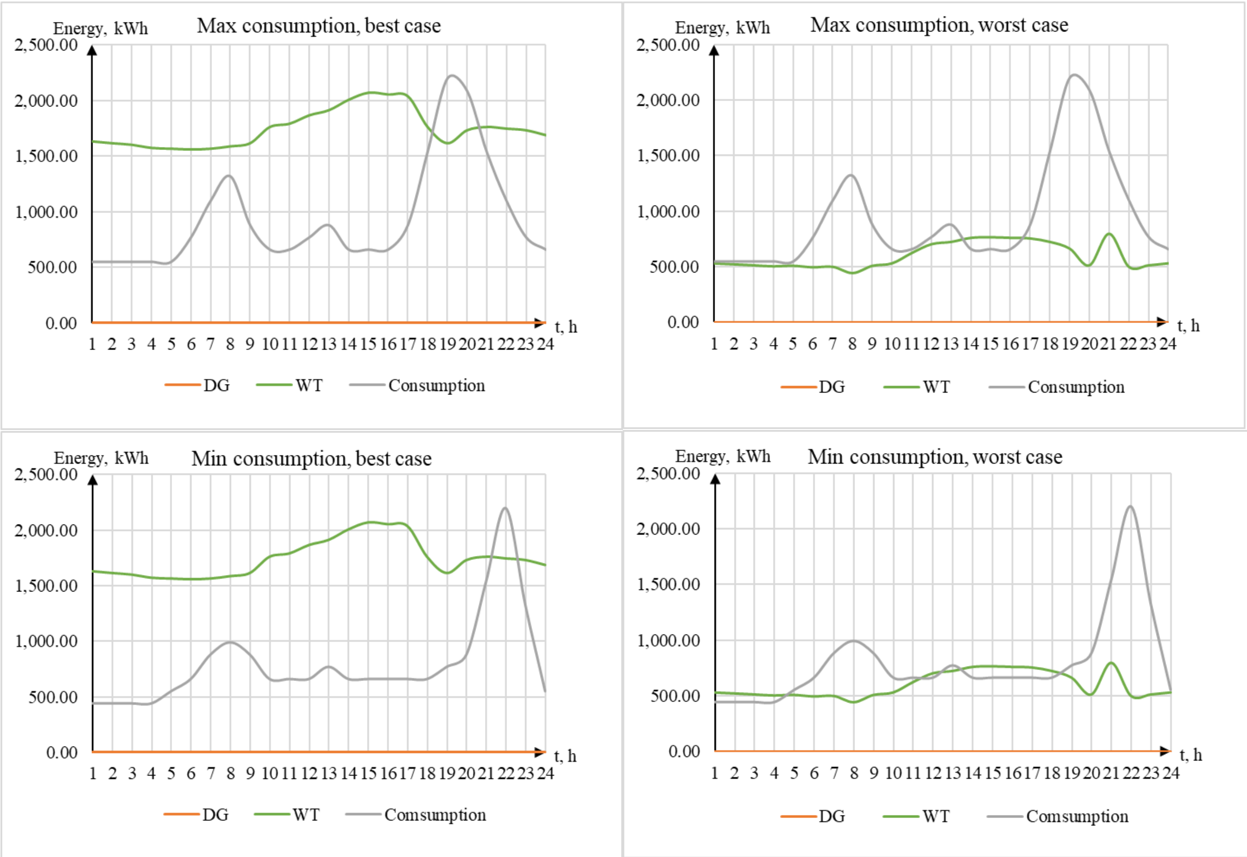

Figure 2.4 - Demand and supply diagram for Hummer H25.0-200KW

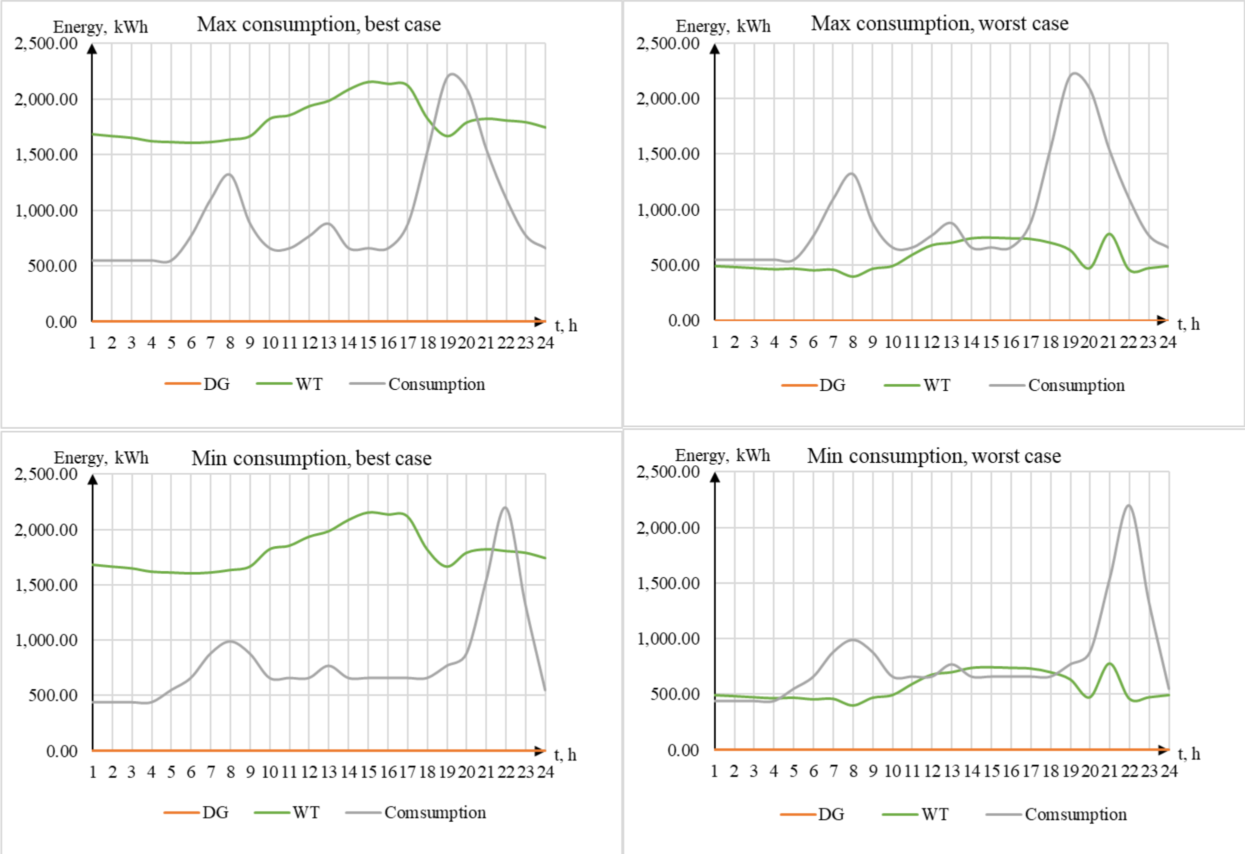

Figure 2.5 - Demand and supply diagram for Aeolia Windtech D2CF 200

Appendix 3

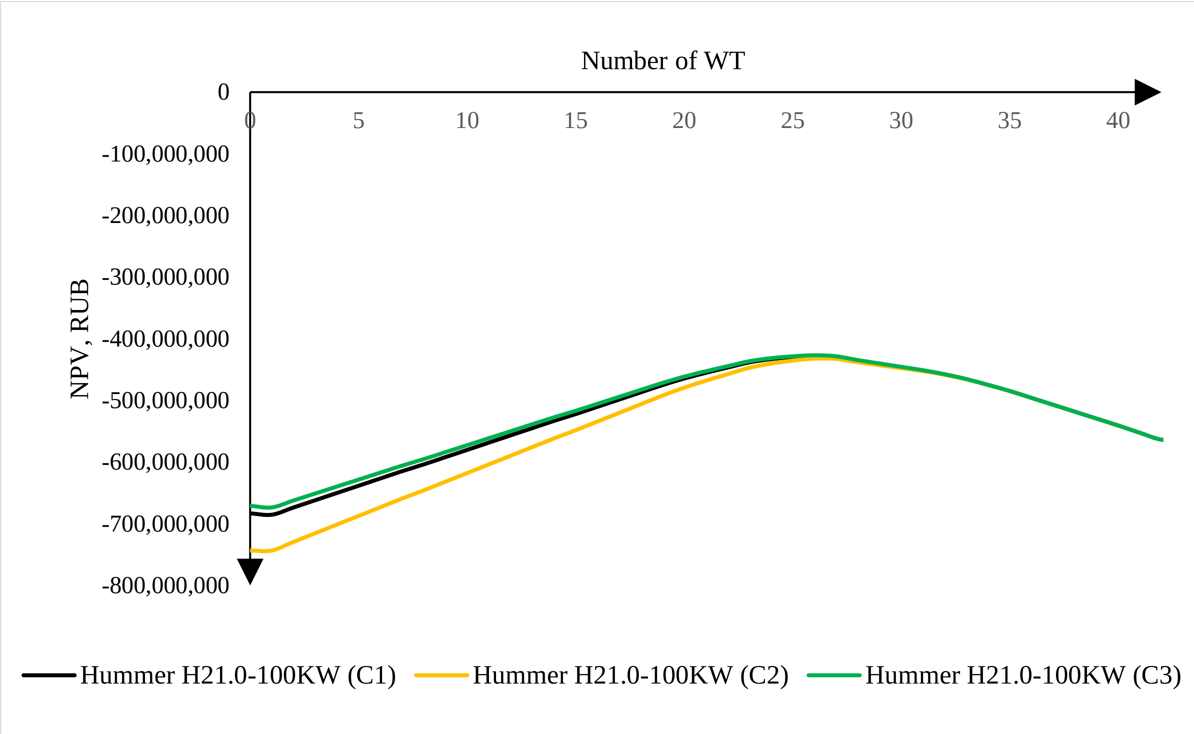

Figure 3.1 - Dependence of NPV on the number of WTs for Hummer H21.0-100KW

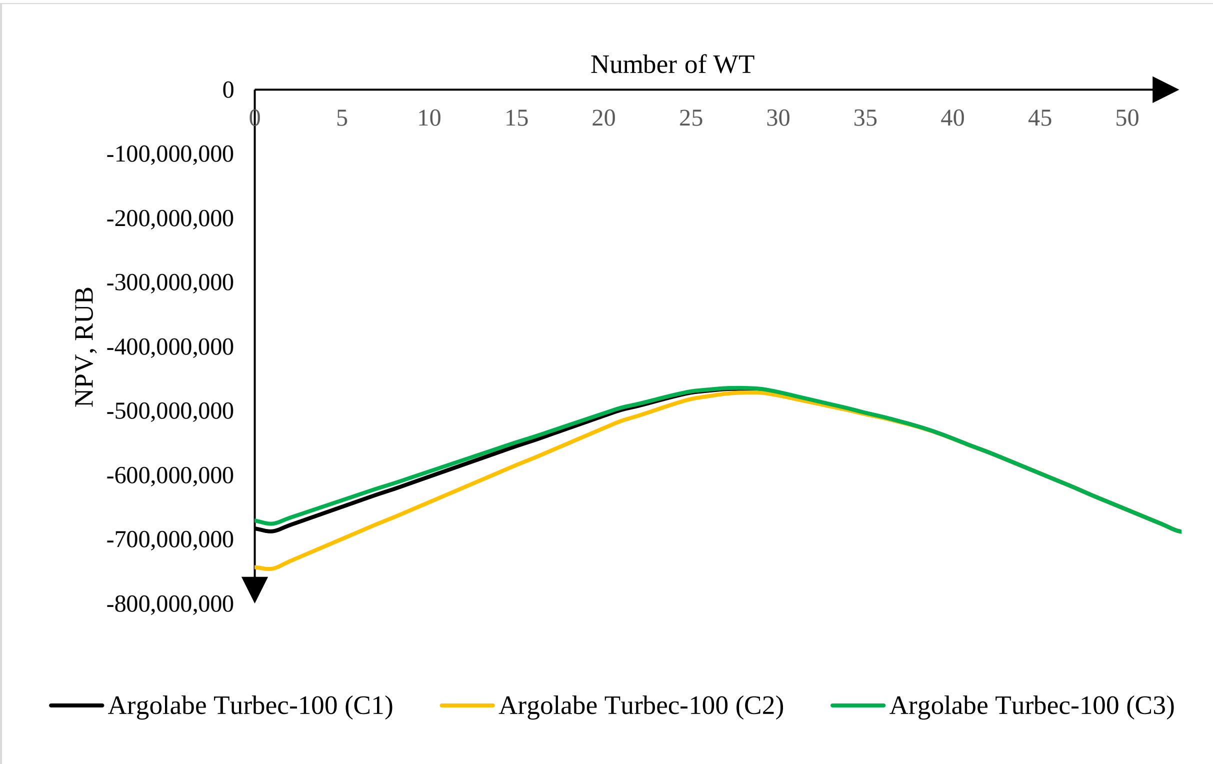

Figure 3.2 - Dependence of NPV on the number of WTs for Argolabe Turbec-100

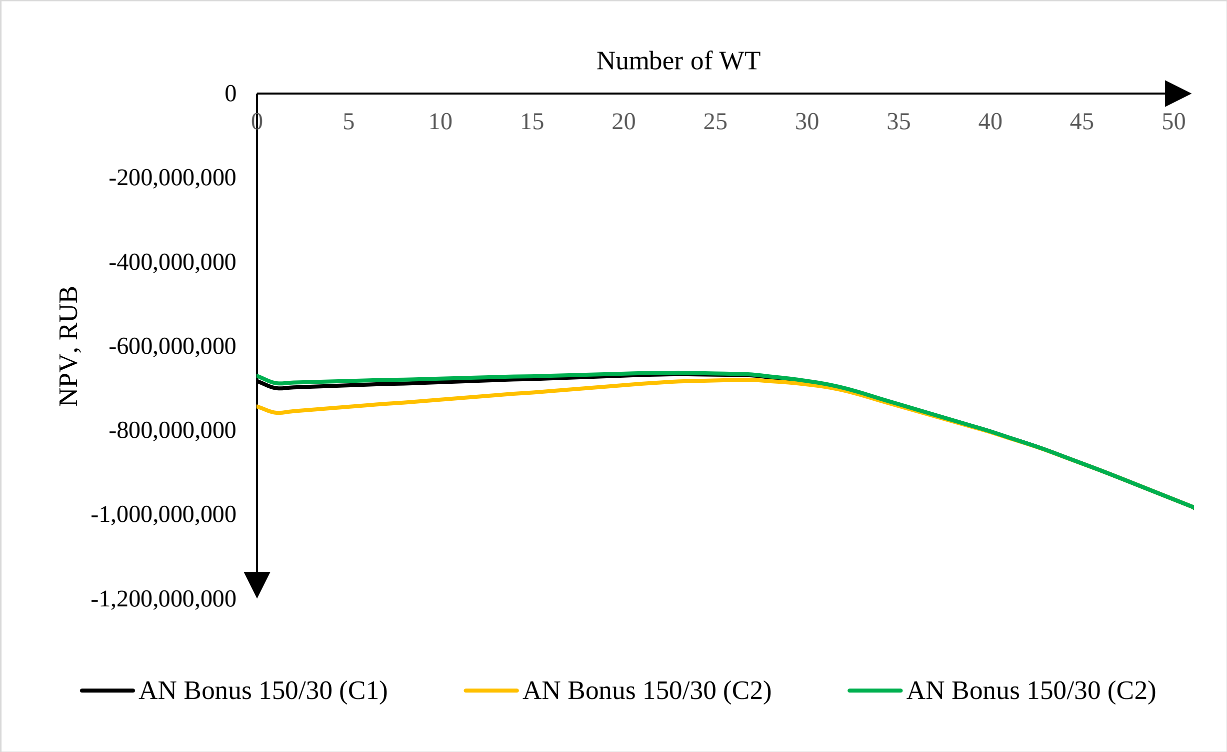

Figure 3.3 - Dependence of NPV on the number of WTs for AN Bonus 150/30

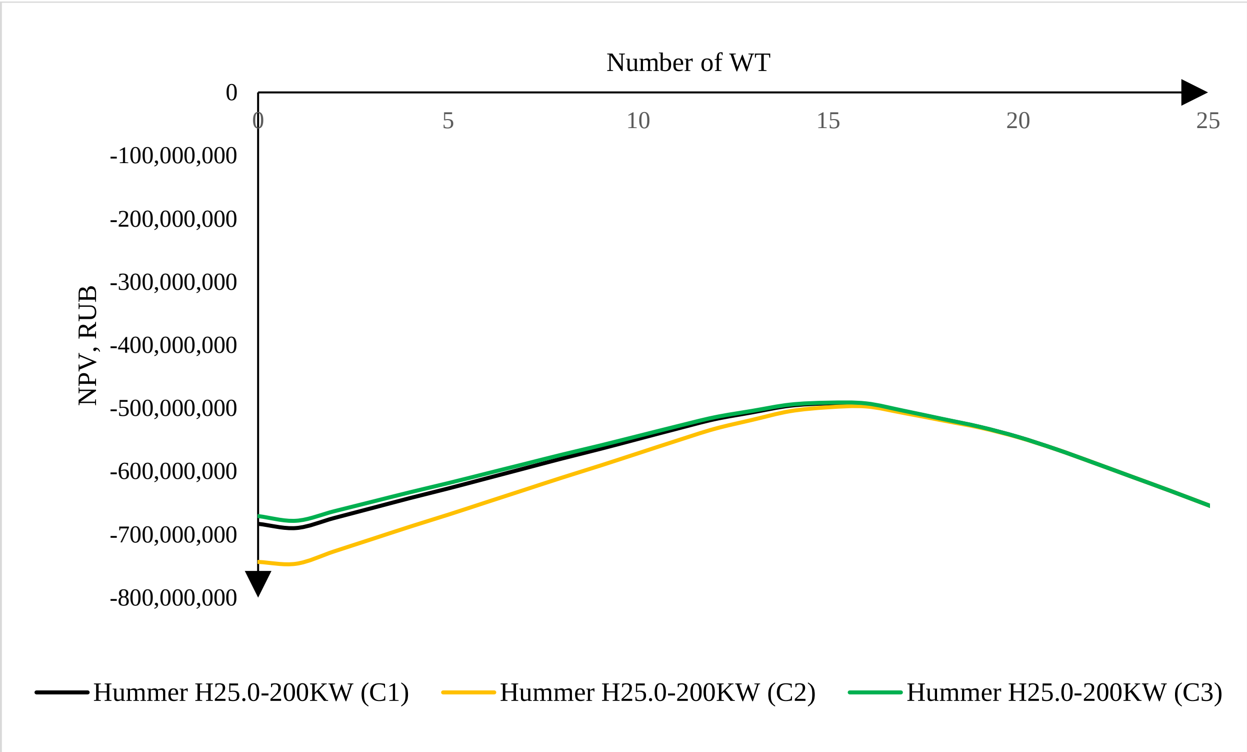

Figure 3.4 - Dependence of NPV on the number of WTs for Hummer H25.0-200KW

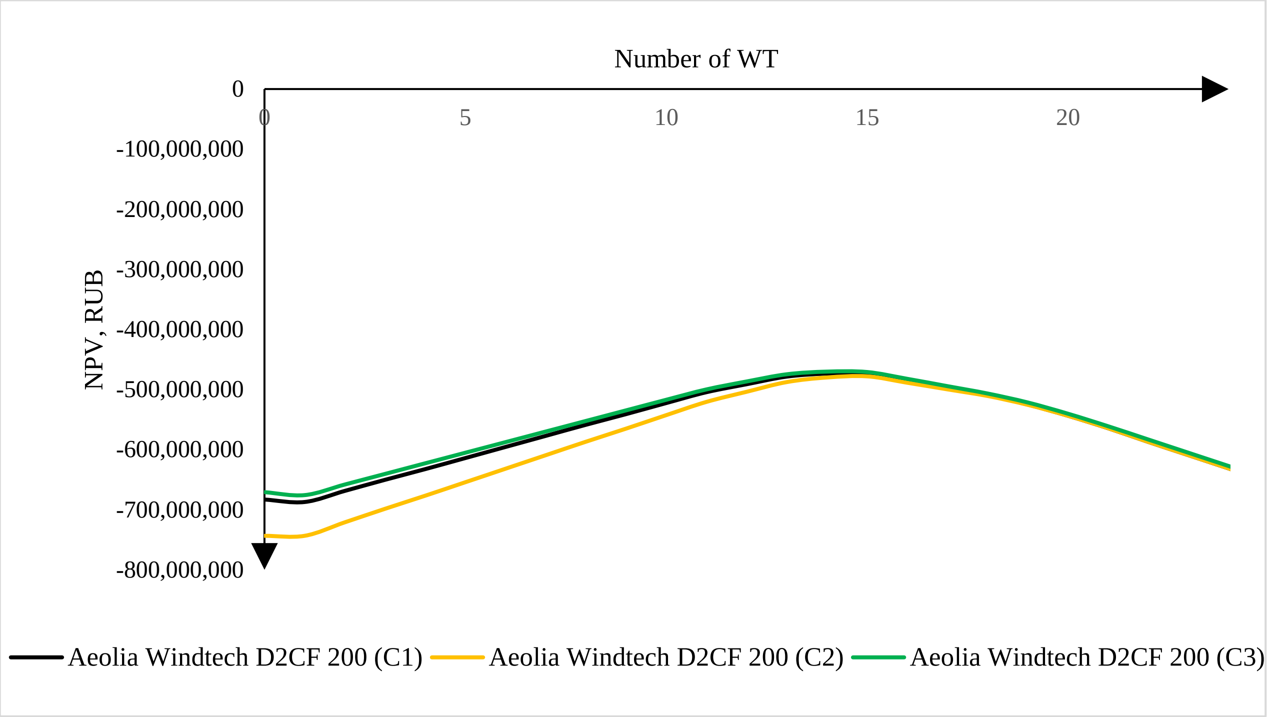

Figure 3.5 - Dependence of NPV on the number of WTs for Aeolia Windtech D2CF 200