Czech Technical University in Prague

Faculty of Electrical Engineering
Department of Economics, Management and Humanities

Residential building power supply with renewable energy sources

MASTER THESIS

Study program: Electrical Engineering, Power Engineering and Management
Branch of study/Specialization: Management of Power Engineering and Electrotechnics
Scientific supervisor: Ing. Bc. Blanka Kučerková

Anton Makarov

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MASTER‘S THESIS ASSIGNMENT

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II. Master’s thesis details

Master’s thesis title in English:

Residential Building Power Supply with Renewable Energy Sources

Master’s thesis title in Czech:

Residential Building Power Supply with Renewable Energy Sources

Guidelines:

- Describe environmental background of the chosen region
- Describe and compare proposed power supply systems
- Prepare mathematical simulation and financial model for project evaluation
- Provide technical and economic evaluation and sensitivity analysis
- Find optimal solution of the issue and make conclusion

Bibliography / sources:

1. Brealey, Myers, Allen – Principles of Corporate Finance, McGraw-Hill, 2016, 12th edition, ISBN:9781259253331
2. Sistemy elektrosnabzheniya s vetrovymi i solnechnymi elektrostanciyami: uchebnoe posobie/ B.V. Lukutin, I.O. Muravlev, I.A. Plotnikov – Tomsk: Izd-vo Tomskogo politekhnicheskogo universiteta, 2015.

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Date of master’s thesis assignment: **13.01.2020** Deadline for master's thesis submission: **05.01.2021**

Assignment valid until: **30.09.2021**

Ing. Bc. Blanka Kučerková Supervisor’s signature	Head of department’s signature	prof. Mgr. Petr Páta, Ph.D. Dean’s signature

III. Assignment receipt

The student acknowledges that the master’s thesis is an individual work. The student must produce his 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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Date of assignment receipt	Student’s signature

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".

January 2021 *Anton Makarov*

Abstract

Current research is focused on economic estimation of renewable energy efficiency in regions with low wind potential. The problem is that in some regions, such as Russian Federation, using of renewable energy sources are less than 1% and all produced electricity are generating by fossil fuels, because of specific environment. Because of this reason, there are few additional problems, such as exhaustibility of the resources, electricity price strongly dependent on resources price and environmental pollution.

The main purpose is to find an economically effective way to use renewable energy sources in specific regions. My thesis is based on example of residential building in Tomsk region, supplied with electricity using renewable energy.

In my diploma thesis I considered 4 different combination of electric supply and their estimated balance of energy consumption and generation by different power sources. In order to obtain the most relevant results, I analyze these scenarios with different type of financing and evaluated them from technical, economical and customer point of view.

Keywords

Renewable energy sources, alternative energy, wind generator, PV cells, gasoline generator, cottage power supply, wind potential, solar potential, energy balance, economic evaluation, sensitivity analysis, managerial decision making.

Contents

List of abbreviations

AC	Alternating Current
ATS	Automatic Transfer Switch
AU	Astronomical Unit
CSP	Concentrated Solar Power
DC	Direct Current
DCF	Discounted Cash Flow
HPP	Hydraulic Power Plant
IEA	International Energy Agency
IEPP	Industrial Enterprises Power Plant
IES	Integrated Energy System
IRENA	International Renewable Energy Agency
MPPT	Maximum Power Point Tracking
NASA	National Aeronautics and Space Administration
NPP	Nuclear Power Plant
NPV	Net Present Value
PV	Photovoltaic
RES	Renewable Energy Sources
RPM	Rotations Per Minute
SPP	Solar Power Plant
SHPP	Small Hydraulic Power Plant
TPP	Thermal Power Plant
UES	Unified Energy System
WPP	Wind Power Plant

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Introduction

Nowadays one of the most urgent issues is electric power supply. In our modern world dominates the use of exhaustible energy sources. They possess higher efficiency than renewable sources, however electric power consumption increases on daily basis. Problem of energy exhaustion is unavoidable and should be solved sooner or later, because humanity cannot abandon use electrical power. Therefore, exhaustion problem becomes more valuable. Especially this issue is relevant in the regions that unavailable to supply with power network. Because only option to supply with electrical power there is to use independent generators, however prices for the fuel are growing on daily basis, but renewable energy become more and more accessible.

The main purpose is to find an economically effective way to use renewable energy sources in specific regions. However, it should be noted that I approached this problem in such a way that I need to provide electricity to the consumer and I tried to do it as effective as possible. In other words, although I tried to set the most efficient appliances, I do not consider the issues of optimizing power consumption.

In my research I will design and analyze wind and solar power supply systems in the low wind regions on the Tomsk sample. Tomsk is a significant pattern with low wind potential and average number of sunny days no more than 150 per year. Experience of other countries shows that every year the use of renewable energy sources become more efficient, and the energy they generate become more accessible. Additionally, renewable energy sources allow us decrease level of environmental pollution and improve ecological situation due to the fact that replacement of thermal power plants with renewable will reduce amount of carbon dioxide that humanity produce.

My work consists of four main parts. The first one is analytic part, including review of current condition in the field of renewables, environmental analysis for creation of power supply systems, and analysis of current condition of the electric power industry in Russia. It includes estimation of solar and wind potential in Tomsk region, review of the electricity prices on the market, estimate and analyze all possible options house electrical supply. The second part is descriptive, which is about description of the consumer and equipment. There I have included typical equipment that customer will use in his house and equipment that will supply these house and detailed description of the equipment. The third part is a mathematical simulation and economic estimation. The last part of my work is about final decision making and a conclusion. These parts, that I provided here, are not the exact chapters, but it is the way, that I tried to follow.

1. Analysis of current conditions in the field of renewable energy sources

Renewable or "green" energy are produced from resources that are renewable, or inexhaustible, on a human scale. The basic principle of using renewable energy is to extract it from constantly occurring processes in the environment or renewable organic resources and provide it for technical use. Renewable energy is obtained from natural resources, such as sunlight, water flows, wind, tides, and geothermal heat, which are renewable. In other words, can be replenished naturally, as well as from biofuels: wood, vegetable oil, ethanol. [1]

1.1. The state of renewable energy all around the world

The development of renewable energy over the past 15-20 years has been going on according to a very optimistic scenario with a constant increase in installed capacity and share in the fuel and energy balance. The dynamics of the share of the use of various energy sources in the production of electricity is given in the table.

Table 1 – The dynamics of electricity production in the world due to various types of fuel in % of total production, based on data from [1]

Year	1990	1995	2000	2005	2010	2015
Coal	37.22%	37.45%	38.63%	39.84%	40.09%	39.15%
Oil	11.13%	9.27%	7.78%	6.18%	4.52%	4.00%
Natural gas	14.71%	15.16%	17.78%	20.16%	22.38%	22.85%
Nuclear	16.91%	17.49%	16.69%	15.06%	12.75%	10.53%
Hydro	18.42%	19.10%	17.37%	16.43%	16.33%	16.35%
Renewable	1.60%	1.52%	1.75%	2.33%	3.92%	7.11%
Electricity generation [GWh]	11900327	13329745	15518865	18377854	21616255	24400766

As you can see, in recent years there has been a positive growth trend in the use of renewable energy sources. The increase in the installed capacity of renewable energy plants is also characterized by a corresponding increase in investment in the renewable energy industry.

Let us represent the amount of electricity generated by different sources for the last period in the form of a diagram.

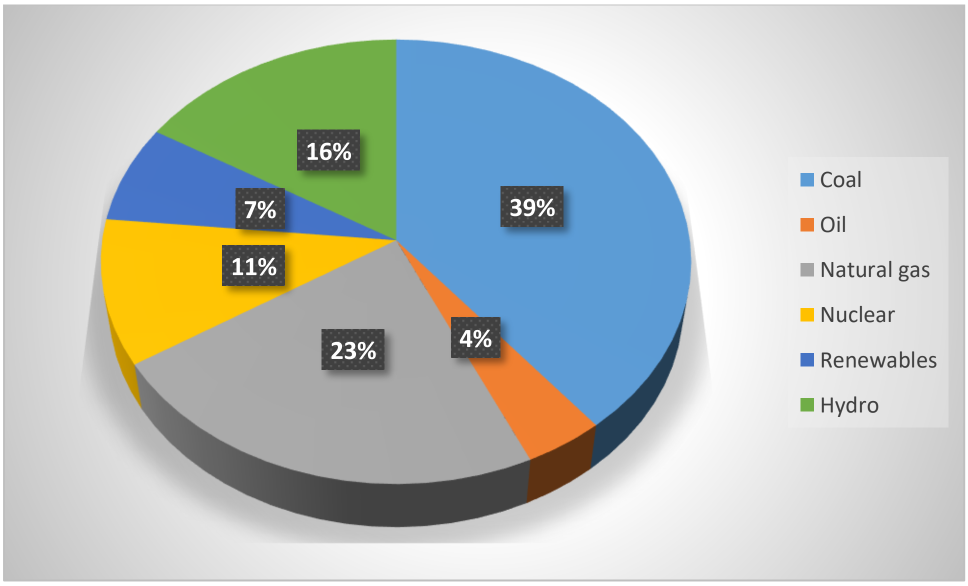

Figure 1. Electricity generated by different energy sources in the 2015 year [1]

Monitoring the development of renewable energy shows a significant annual increase in the installed capacity of power plants based on them. The total installed electric capacity is more than 2500 GW, which is over 20% of the total installed capacity of power plants in the world according to the source [2]

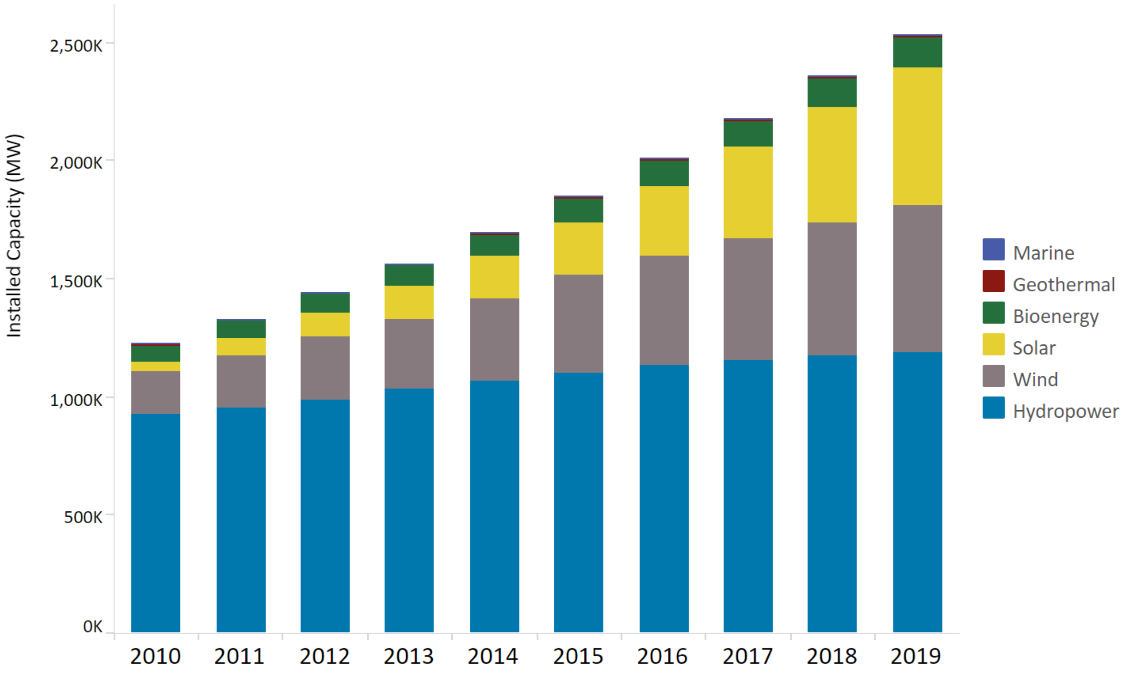

Figure 2. Worldwide installed capacity of Renewable energy sources from 2010 to 2019 years [3]

The main volume of renewable energy commissioned capacities in the world is formed by the commissioning of Small Hydraulics Power Plants, wind farms and solar power plants (Figure. 2). Moreover, usually in developed countries there are more SHPPs and solar power plants, and in the European Union - wind farms and, first of all, there are many of them in Germany and Spain. Among the developing countries, China is the leader, in which small hydropower is the most developed (although the "large" hydropower is in the lead in terms of input; in the lead, in which the small hydropower is most developed (although the "large" hydropower is in the lead in the world).

Renewable energy sources are expected to have the fastest growth in the electricity sector, providing nearly 30% of electricity demand in 2023 compared to 24% in 2017. The greatest influence will be exerted on the total amount of energy produced by solar photovoltaic energy, then wind energy and bioenergy. It is not expected such a rapid increase in the share of renewable thermal energy is possible since it is expected that a steady increase in the total demand for heat will be caused by continuous economic growth and population growth. [1]

1.2. The state of renewable energy in Russia

RES development in Russia is proceeding at a very modest pace. Our country is seriously lagging behind in terms of both input and conversion technologies for various types of renewable energy. The volumes of installed capacity are shown in the form of a diagram in the figure below.

It can be noted that in Russia, existing energy systems were presented that use all the main renewable energy sources. The problem is that their level of development did not meet either the needs of the state or the real possibilities for the full use of renewable energy sources. Despite their rather long application, all existing systems remained at the stage of research and development, design development, testing, or repair after testing.

However, in 2003, Russia adopted the "Energy Strategy of Russia for the Period until 2020" (approved by Decree of the Government of the Russian Federation of August 28, 2003 No. 1234-r), which focuses on "increasing per capita energy consumption and energy potential countries, and the development of environmentally friendly power plants with a combination of centralized and decentralized energy supply."

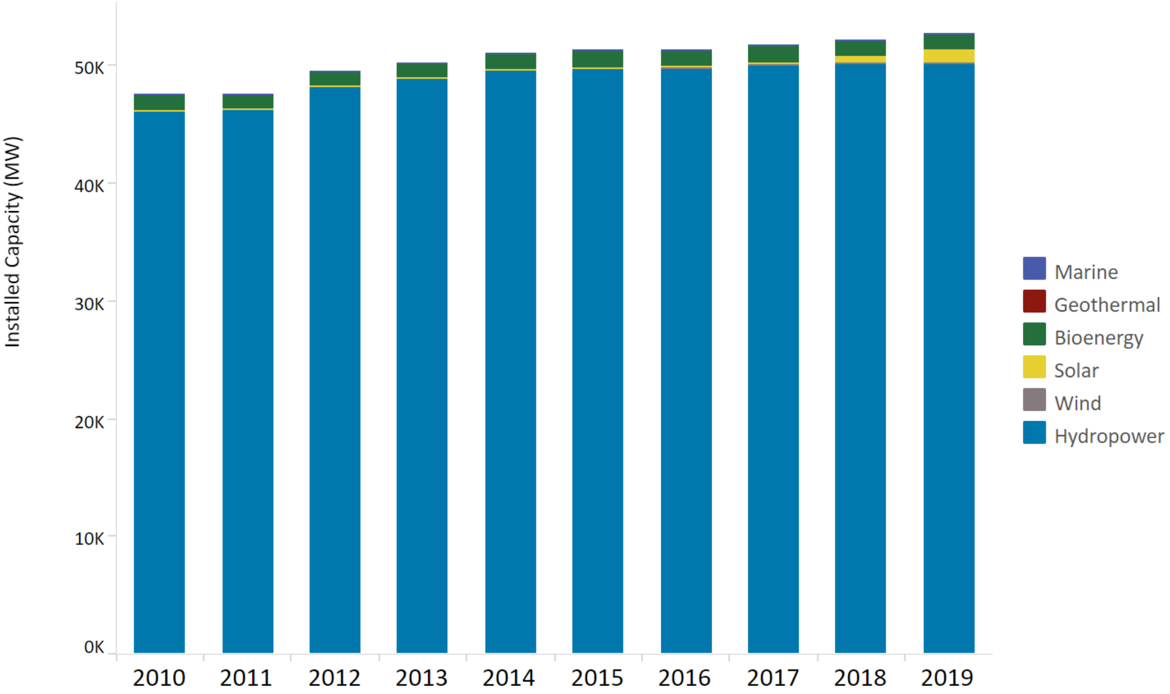

Figure 3. Installed capacity of Renewable energy sources in Russia from 2010 to 2019 years [3]

The result of this is an increase in the installed capacity of renewable energy sources, that you may see in figure 3.

Summary

All over the world, in recent years there has been an increase in installed capacity and generated electricity through renewable sources of energy and there is a partial replacement of fossil fuels. This reduces dependence on fossil energy resources and improves the environmental situation. However, it is not possible to completely abandon traditional energy in the nearest future due to a number of reasons, such as dependence on uncontrolled natural conditions, the necessity to maintain stability in the energy system, the inability to use renewable sources as backup sources, etc.

Statistics show that in Russia and in the rest of the world, with the exception of some countries, the following sequence in terms of installed capacity is, in decreasing order, respectively - Hydraulic power plants, Wind power plants, Solar power plants, and so on.

Russia on average lags behind many developed countries in the use of renewable sources. The reason is purely fuel energy inherited from the Soviet Union, with the exception of several large hydraulic power plants. In addition, the current government does not have a clear plan for the development of renewable energy. The installation of any renewable sources in Russia by the private sector for personal use does not provide for subsidies from the state, and there is also no possibility for individuals to sell electricity to the network.

All of the above factors negatively affect the motivation for the use of renewable energy sources in Russia by private individuals. Also, due to the low price of the electricity market, renewables are rarely seen as an alternative to traditional ones.

2. Environmental analysis for the creation of power supply systems

Tomsk Oblast is located in the southeast of the West Siberian Plain; it occupies an area of 316.9 thousand km^2. The territory under the jurisdiction of the municipality of Verticos rural settlement is 15.392 thousand ha. [4]

The climate in Tomsk region is sharply continental. Winter is harsh and long (average January temperature from -17 ° C to -21 ° C); summers are warm and short (average July temperature is + 17 ° C ... + 18 ° C). The growing season is 135-140 days. in the north, 150 days. on South.

Annual precipitation is 400-570 mm, of which 78-66% falls in liquid form, and the rest in solid form. The average height of the snow cover is 60-80 cm, snow is held in the north of 190-197, in the south - 176-182 days.

Seasonal permafrost spreads wide. The depth of soil freezing varies from 0.5-0.6 m in peat bogs to 3.5 m in sand, an average of 1.0-2.0 m. [4]

On average, in more than half of all days of the year, conditions are created in the city that facilitate the accumulation in the surface layer of exhaust gases from cars and harmful emissions from factory pipes.

The duration of stable snow cover is an average of 170 days. The average snow depth for winter is 60 cm. The severity of the climate in this period of the year is determined not only by low air temperature, but also by the combination of low temperature and significant wind speed, which leads to heat loss of people and rooms, creates a strong climate discomfort, which must be taken into account when heat engineering calculations. [5]

Gusty winds well ventilate the territory, but create additional dynamic loads on buildings and structures. The repeatability of significant wind speeds with negative temperatures reaches 28-35%, therefore, measures for wind protection of built-up areas are necessary. [6]

The discomfort of the environment is aggravated by snow tolerance - snow deposition can reach 350m^3 per 1 m running. lengths. The average number of days with snowstorms is 51, with snowdrifts - 26 days. Snow carried during snowstorms and snowdrifts endangers access roads, city streets, industrial sites and other facilities. Special snow protection measures are required, carried out in conjunction with wind protection, including a combination of appropriate building techniques and green spaces.

For most of the year, air in terms of humidity is characterized as moderately dry and moderately humid, which is favorable from the point of view of the human heat perception. The average annual rainfall is 535 mm. In some years, precipitation may be below normal, but the lack of precipitation is insignificant, not more than 10%. About a quarter of the days in a year is kept uncomfortable relative humidity - 80% or more. [6]

The number of days with a thunderstorm (average 27, maximum 42) is significant, which determines the need for lightning protection. [6]

The number of days with fogs, as well as hail, is on average small. [6]

To improve the model in further calculations, I analyzed the data for the last 5 years from the nearest weather station provided in the public domain [7]. The results of this analysis are shown in the table.

Table 2 – Results of temperature analysis in Bogashevo, based on data from [7]

Temperature, °C			
Month	max	min	average
January	3	-40	-16,855
February	7	-44	-12,737
March	10	-29	-4,770
April	28	-14	3,920
May	29	-7	9,107
June	32	0	17,794
July	32	3	18,351
August	30	2	15,841
September	28	-4	9,445
October	22	-15	1,704
November	10	-35	-10,389
December	2	-42	-12,522

This is very important for further calculations of power consumption, since they can vary significantly depending on the temperature.

2.1. Wind potential analysis

When solving the problems of evaluating the wind energy potential, its contribution to the energy supply system of a particular or other object and the ecology of the region, there is a need for a large amount of information over the long-term conditions. Wind is the most volatile and unstable meteorological element.

The presence of various obstacles on the surface (topography, vegetation, water spaces, man-made structures) has a very strong effect on the speed and direction of the wind. The influence of these obstacles is characterized by the roughness parameter of the underlying surface. The roughness of the underlying surface exerts influence not only on the surface of the earth, but also on sufficiently high altitudes. This feature makes it necessary to use information about the wind recorded in various points only taking into account the uniformity of the territory. If the location of the points and the weather stations under consideration is not different, then these weather stations can be considered as suitable. Data from meteorological stations can be applied to points located at a distance of up to 50 kilometers. [5] Under conditions of open terrain, the indications of two stations close to each other may differ depending on the location of the weather vane at the station, its degree of protection by trees and buildings located in the station area.

Over time, the conditions around the stations are also subject to changes and they must be taken into account when analyzing the wind regime and the degree of protection of the weather vane [8].

In order to obtain reliable data on the average wind speeds of the territory, it is necessary to use significant volumes of measurements for a fairly long time.

The average annual wind speed is defined as the arithmetic mean value obtained as a result of speed measurements at regular intervals over a given period. [8]

Average monthly and annual wind speeds over long periods of time are the main and initial data for compiling characteristics of the general level of wind intensity. According to the characteristics, it is possible to preliminarily judge about the prospects of placing wind energy equipment in the required area. When compiling the characteristics, it is necessary to remember that the wind speeds strongly depend on the surface roughness and that the data of weather stations may change over time with the change in the surrounding territory. This should be taken into account when comparing the average wind speeds and bring them to equal conditions [8].

In order to obtain reliable data on the average wind speeds of the territory, it is necessary to use significant measurement volumes for a sufficiently long time.

In our case, we can use the data from the meteorological database [7]. Due to the functionality of this service, we can use a pre-calculated average value for the period from 1.01.2015 to 23.11.2019. Take the data on the wind speed at the Tomsk airport, located in the village of Bogashovo.

To calculate wind speeds, observations from weather stations provided by site rp5.ru will be used.

The average wind speed is determined as the mean value obtained as a result of multiple measurements of wind speeds over equal time intervals for a given time interval (day, month, year), is calculated by the formula [8]:

$$V_{av} = \frac{1}{n}\sum_{i=1}^{n} V_i, \qquad (1)$$

where V_{av} – average wind speed, [m/s];

n is the number of time periods;

V_i - wind speed in a certain period of time, [m/s];

The calculated data is summarized in table 1.

Table 3 – Average monthly and annual wind speed, based on data from [7]

Year	2015	2016	2017	2018	2019	Average
	Wind speed, m/s					
January	0,67	2,21	4,60	4,27	4,47	3,25
February	4,42	3,33	4,83	2,94	4,35	3,97
March	4,18	3,75	4,03	4,55	4,40	4,18
April	3,90	3,09	4,95	4,94	4,38	4,25
May	3,54	3,52	4,82	4,13	4,38	4,08
June	2,99	2,90	3,05	3,63	3,20	3,15
July	3,05	2,98	2,34	3,03	2,90	2,86
August	3,66	2,74	2,54	2,71	2,69	2,87
September	3,04	2,56	3,25	3,45	3,82	3,22
October	4,65	2,64	3,58	5,00	4,57	4,09
November	3,73	3,76	4,12	5,25	4,80	4,33
December	5,16	4,71	3,97	3,28	-	4,28

For clarity, I present the data obtained on the figure 4.

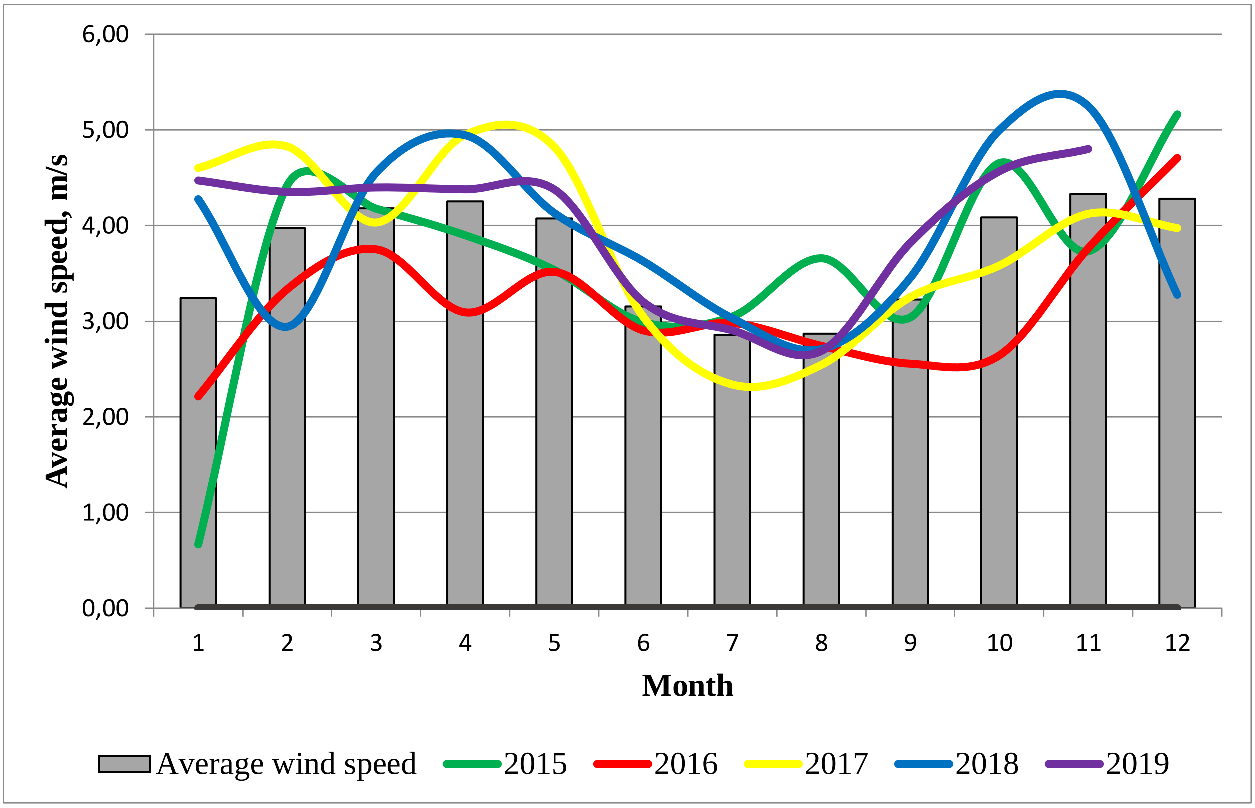

Figure 4. Average monthly and annual wind speed from 2015 to 2019 years

According to the calculations, the average wind speed at an altitude of 10-12 meters above the earth's surface, averaged over a 10-minute period, is V_{av} = 3,71 m / s.

For a numerical estimation of the dispersion of wind speeds from the average value, the coefficient of variation of average speeds is used, which is determined by the following expression [8]:

$$C_v = \frac{S_v}{V_{av}} \qquad (2)$$

where S_v is the standard deviation of the current wind speed from the average value.

Thus, from [8] S_v for the selected period, according to calculations, is 2,33 m/s. Following the formula (2), the coefficient of variation of average speeds will be

$$C_v = \frac{S_v}{V_{av}} = \frac{2,33}{3,71} = 0,63$$

It is known that the wind speed increases with distance from the underlying surface and the air flow becomes more stable. The degree of increase in wind speed with height is highly dependent on the roughness of the underlying surface. Approximately the wind speed at a height h can be estimated by the formula [8]:

$$V_H = V_M \cdot (\frac{h}{h_M})^{\alpha}, \qquad (3)$$

Where V_H – wind speed on the height H, [m/s]
V_M – wind speed on the height of the mast, [m/s]
h_M – height of the mast, [m]
α - coefficient related to the average wind speed at the height of the mast

Table 4 – Dependence of α on wind speed V_M [8]

V_M, [m/s]	0…3	3,5…4	4,5…5	5,5	6…11,5	12…12,5	13…14
α	0,2	0,18	0,16	0,15	0,14	0,35	0,13

I take a height equal to H = 20m. Then, according to formula (3), the average wind speed at a height of H are calculated in Table 5.

Table 5 – Recalculated wind speed at the height of 20m

Month	1	2	3	4	5	6	7	8	9	10	11	12
Average wind speed, [m/s]	3,25	3,97	4,18	4,25	4,08	3,15	2,86	2,87	3,22	4,09	4,33	4,28
Wind speed at a height of 20m, [m/s]	3,83	4,68	4,93	5,01	4,81	3,71	3,37	3,38	3,80	4,82	5,11	5,05

This is important information, but a deeper analysis will be used to further calculate electricity generation. Analysis of the average wind speed allows us to understand at what level the output will keep on average, however, using it to calculate the output will not give us the necessary accuracy due to the non-linear dependence of the generation on the wind speed.

For more accurate calculations of electricity generation, I will use wind repetition for 5 years. The measurement interval at the weather station is one hour, and I took it for an interval with a constant wind speed.

Table 6 – Wind repetition in Bogashevo for 5 years, with 1 hour interval between measurements, based on data from [7]

	Wind speed [m/s]							
Month	0 – 3	3	4	5	6	7	8	9 – 17
January	1231	459	469	412	407	326	227	189
February	1012	485	542	457	361	260	131	136
March	1187	547	482	422	356	281	196	249
April	878	718	596	492	363	204	163	186
May	959	792	703	493	316	198	115	144
June	1570	754	559	310	177	109	63	58
July	2015	644	448	275	180	71	57	30
August	1886	774	518	285	145	57	36	19
September	1432	826	592	339	212	107	50	42
October	1128	677	595	426	348	238	161	147
November	923	636	566	485	364	234	173	219
December	1036	539	501	522	455	288	205	174

Note: In reality, the values of electricity generation may differ from those that will be obtained in further calculations, since in real life we work with continuous data, but we will accept this as an assumption.

In addition to calculations, it is necessary to depict a wind rose for the study area in order to know the prevailing wind direction.

Wind rose - is a graphical representation of the repeatability of wind directions. It is of great practical importance when using large-capacity wind turbines, where instead of slip rings, a power cable laid in a cable channel is used. In the process of operation, the gondola of such a wind turbine rotates around its axis, thereby unwinding the cable. The wind rose allows you to set the duration of the interservice period when maintenance personnel need to unwind and lay the cable.

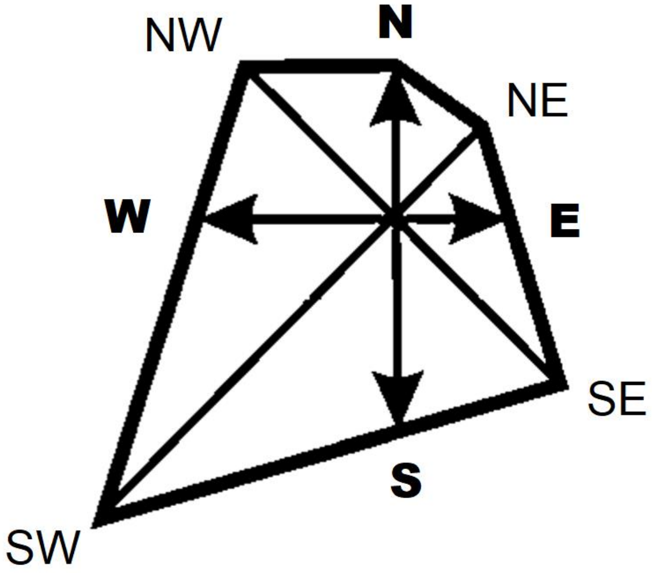

Figure 5. Wind rose for the Tomsk region. [7]

Correct accounting of wind directions allows you to most effectively locate wind turbines on the ground.

Analyzing wind repeatability, it must be remembered that from an energy point of view, it is much more important to know the energy characteristic (maximum possible output) of the wind in the selected directions than in which direction the wind prevails.

2.2. Solar insolation analysis

Since ancient times, main source of energy for our planet was the Sun. Solar energy produces the energy of wind, water, heat, biomass, as well as the use of rough and hard coal, oil and natural gas, but this is indirect energy and accumulated over thousands of years and millions of years. The energy of the Sun can be used directly as a source of electricity and heat.

“Insolation - is the quantity of potentially useful solar radiation, which falls on an illuminated surface. Solar insolation varies greatly from one point of the earth's surface to another. To calculate insolation of an area, several factors should be taken into account: influence of seasons, for instance, in winter light level is lower and daylight hours are shorter; characteristics of illuminated terrain (some relief features may prevent illumination); local weather conditions (frequent cloudy weather, fogs and rains), etc.” [9]

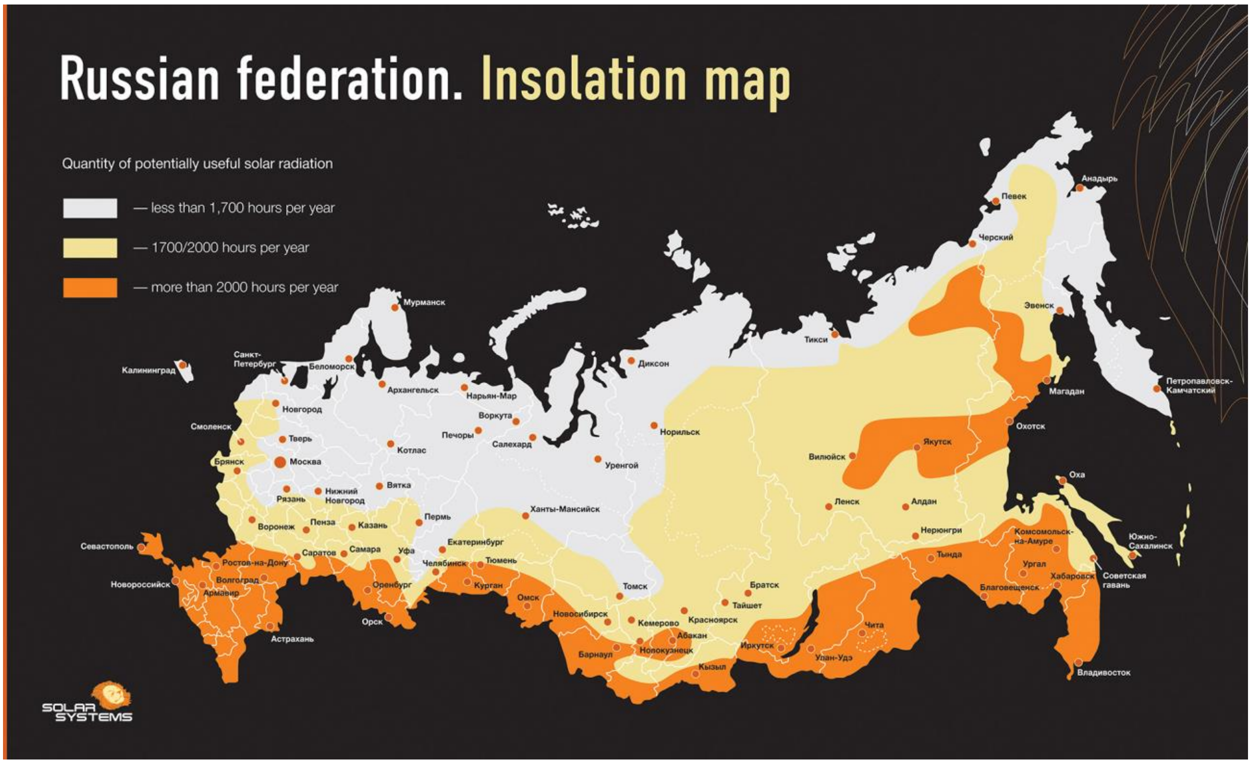

Figure 6. Russian Federation insolation map. [9]

Solar insolation is characterized by a wide spectral range - from radio waves to gamma radiation. At a distance of 1 AU from the Sun, the density of its radiation flux is 1360 W / m^2.

Also often is used definition of the solar constant on the surface of the Earth, which is equal to the value of insolation on the surface, located at the sea level and oriented on the Sun. [10]

It is convenient to define a surface solar constant—that is, a value of insolation on a surface that, at sea level, faces the vertical sun on a clear day. This "constant" has the convenient value of about 1000W / m^2 or "one sun." At other than vertical, owing to the larger air mass through which the rays have to pass, the insolation is correspondingly smaller. [11]

In order to assess the renewable energy potential of solar energy, it is necessary to determine the energy potential of solar insolation in a given region. The assessment is based on the data of the National Aeronautics and Space Administration (NASA). NASA data is used in the processed form in the RETScreen software. The data provided below is valid for facility located at coordinates latitude 56,5102, longitude 84,9546.

To determine the solar radiation incident on an oblique the investigated flat area in cloudy conditions, I use the expression [8]:

$$Q_{sl} = Q_{dir} + Q_{dif} \cdot [1 - (a + bn) \cdot n], \tag{4}$$

Where, Q_{dir} – direct solar energy incident on a sloped surface, [W/m^2],

Q_{dif} – diffused solar energy incident on a sloped surface, [W/m^2],

a – coefficient depending on the environment (land or sea) and the latitude of the place, a = 0,383 for Tomsk [relative units], according to [8];

b – coefficient, which in this case can be considered constant and equal to 0,38 [relative units], according to [8];

n – relative cloudiness (0 for cloudless weather, 1 for fully cloud weather) [relative units];

$$Q_{dir} = Q_{ort} \cdot \cos\theta, \tag{5}$$

Where, Q_{ort} – direct solar energy incident on a surface orthogonal to beams of light, [W/m^2],

θ – direct sunglight incidence angle [degrees], figure 8.

$$Q_{ort} = \frac{Q_0 \cdot sin\,\alpha}{sin\,\alpha + c}, \tag{6}$$

Where, Q_0 – surface solar constant [W/m^2], Q_0 = 1000 W/m^2, according to [11],

sin α – the angle between the vertical axis and the incident beams of light [relative units], figure 8

c – degree of transparency of the atmosphere [relative units], c = 0,32 [8]

$$Q_{dif} = Q_{dif\,hor} \cdot [0{,}55 + 0{,}434 \cdot cos\,\theta + 0{,}313(cos\,\theta)^2], \tag{7}$$

Where, $Q_{dif\,hor}$ – diffused solar energy incident on a horizontal surface, [W/m^2],

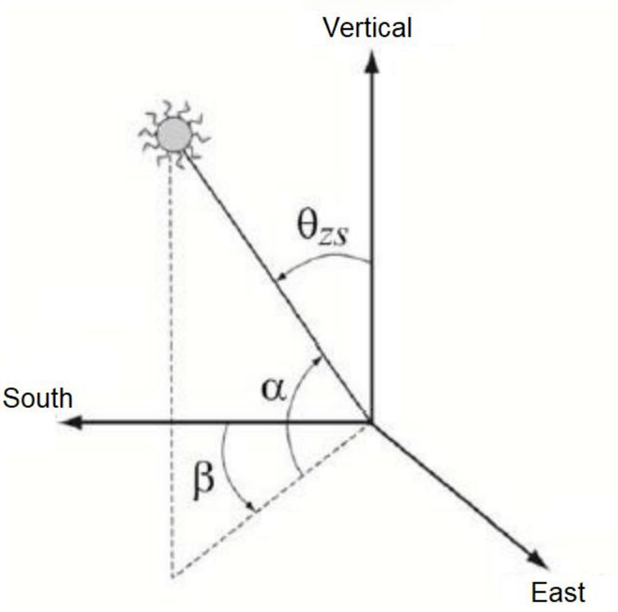

Figure 7. The coordinates of the Sun relative to a geographically oriented coordinate system [8].

$$Q_{ort} = \frac{1 \cdot sin(35°)}{sin(35°) + 0{,}32} = 0{,}642\ [\mathrm{kW/m^2}],$$
$$Q_{dir} = 0{,}642 \cdot cos\,45° = 0{,}4539\ [\mathrm{kW/m^2}],$$
$$Q_{dif} = 0{,}69 \cdot [0{,}55 + 0{,}434 \cdot cos(45°) + 0{,}313(cos\,45°)^2] = 0{,}6992\ [\mathrm{kW/m^2}],$$
$$Q_{sl} = 0{,}4539 + 0{,}6992 \cdot [1 - (0{,}383 + 0{,}38 \cdot 0) \cdot 0] = 1{,}1531\ [\mathrm{kW/m^2}]$$

Other months are provided in the table below. Data in table 4, column 2 provided by NASA database in software RETScreen, next columns are calculated by formulas above.

Table 7 – Values of solar radiation in Tomsk. Based on data from RETScreen software.

Month	Daily average solar radiation, horizontal, [kWh/m^2/day]	Daily average solar radiation, sloped, [kWh/m^2/day]	Monthly solar radiation, horizontal, [kWh/m^2/ month]	Monthly solar radiation, sloped, [kWh/m^2/ month]
December	0,46	0,92	14,26	28,52
January	0,69	1,15	21,39	35,75
February	1,59	2,07	44,52	57,82
Average value per winter season	0,91	1,38	26,72	40,70
March	2,94	3,43	91,14	106,43
April	4,29	4,80	128,7	144,04
May	5,48	6,01	169,88	186,22
Average value per spring season	4,24	4,75	129,91	145,56
June	5,79	6,32	173,7	189,64
July	5,8	6,33	179,8	196,28
August	4,55	5,06	141,05	157,01
Average value per summer season	5,38	5,91	164,85	180,98
September	2,83	3,32	84,9	99,65
October	1,58	2,06	48,98	63,71
November	0,83	1,29	24,9	38,85
Average value per autumn season	1,75	2,22	52,93	67,40

As you can see in the table 7, the maximum values of solar energy correspond to the spring and summer season. In order to plot the values of solar energy, it is necessary to know daylight duration, which is provided in table 8.

Table 8 – The average monthly daylight duration based on data from [12]

Month	Sunrise	Sunset	Daylength
December	9:29	16:48	7:19
January	9:54	16:52	6:58
February	9:17	17:50	8:33
Average per winter season	9:33	17:10	7:36
March	8:13	18:52	10:39
April	6:51	19:58	13:07
May	5:35	21:00	15:25
Average per spring season	6:53	19:56	13:03
June	4:39	21:57	17:18
July	4:34	22:12	17:38
August	5:21	21:30	16:09
Average per summer season	4:51	21:53	17:01
September	6:22	20:16	13:54
October	7:22	18:56	11:34
November	8:28	17:38	9:10
Average per autumn season	7:24	18:56	11:32

It is necessary to build sinusoidal plot, in the range of angles from 0 º to180 º (sunrise = 0 º, sunset = 180 º), so for each hour of solar activity I have to calculate the angle, in accordance with the number of hours of the day. To calculate the power of the proposed photovoltaic installation (PMT), I use the formula:

$$P_{PV} = \eta \cdot \lambda \cdot S, \text{ [kW]} \tag{8}$$

Where η – efficiency of PV installation [relative units], let assume $\eta = 0{,}15$;
λ – solar radiation, [kW/m^2];
S – area of solar panel, [m^2], let assume $S = 1m^2$;

Average winter daylength is 7 hours 36 minutes, when divided into equal intervals, I obtain that every minute the angle of the sun changes by 0,3939 degrees. The same way I can calculate generated power for each season. Let us build the tables and provide them in appendices.

According to the data in appendices 1 - 4, I build seasonal plots of the generated active power, figure 9.

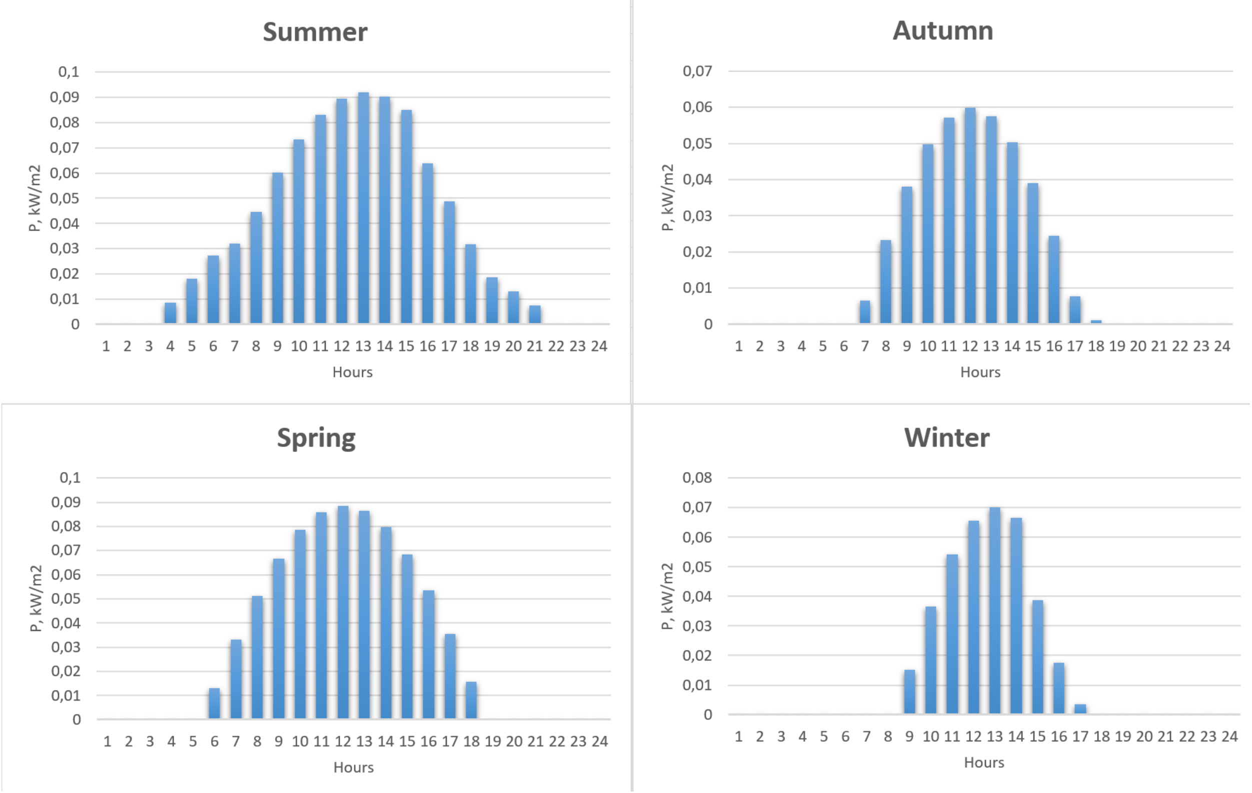

Figure 8. Seasonal plots of the generated active power

2.3. Other renewable sources analysis

Hydropower is the most used form of renewable energy in Russia, which has large potential. As for 2018 operated in Russia 102 hydroelectric power plants and pumped storage power plants (with a capacity of more than 10 MW) with a total capacity of 51.7 GW (including hydropower plants with a total capacity of 48,506.3 MW operated as part of the Unified Energy System of Russia)). Hydropower accounts for about 20% of the installed capacity of the Russian electric power industry and 17-18% of electricity generation in Russia [13].

Although hydropower is widespread in Russia and climatic condition suit to build hydropower plant, but the main problem that it does not seem possible to construct whole power plant in order to supply single house. Thus, I will not consider this option in the future.

3. Description of the consumer

3.1. Formulation of the problem

Bogashevo - the village where the considered cottage is located. It is inaccessible to the central power supply from the electrical network. This is one of the main reasons why land and houses here can cost up to 40% cheaper than similar ones in villages with access to the electric network. I chose this particular village for consideration for a number of reasons. Firstly, the price of land and houses. Thus, I do not need to optimize consumption to the minimum possible and I can consider it as a house with similar electrical appliances that could be in a cottage powered by an electric network, because of saving on land and cottage cost. Secondly, this village is located in an area with low wind and solar potential, which is the main issue of my work. And the last, but not least, is a personal intention to buy a cottage in this village. It is necessary to note that here I tried to include not only the most necessary electrical appliances, but also some elements of luxury, since this cottage is not considered as a refuge, but as a permanent residence, with slight excesses.

In order to define exact structural scheme, I have to first describe the consumer. Let assume that I supply cottage house with total area 150 m^2. My cottage will consist of: Kitchen, Living room, 2 Bedrooms, Children’s room and 2 Bathrooms. There are few appliances that possess not so clear electricity consumption needs an additional investigation.

3.2. Lighting

This part needs additional investigation because each room has its own area and its own requirements to the lighting.
Let us build table with required lighting according to sanitary standards of daylighting and artificial lighting [14].

Table 9 – Lighting nominal power calculation

Room	Area [m^2]	Lighting requirements [lx]	Required light flux [lm]	Installed bulbs light flux [lm]	Nominal power [W]
Kitchen	18	150	2700	4x880	4x10
Living room	48	150	7200	6x1350	6x15
Bedroom 1	20	150	3000	4x880	4x10
Bedroom 2	20	150	3000	4x880	4x10
Children's room	22	200	4400	4x1100	4x12
Bathroom 1	14	100	1400	2x880	2x10
Bathroom 2	8	100	800	1x880	1x10
Total					228

3.3. Heating system

Although heating is not a part of research, it is necessary to mention it since it is possible to heat a house with electricity. However, in order to heat such big house in such harsh climate I would need to increase electricity consumption for too much, which contradicts the main idea of this project. So, this part needs additional investigation because it is necessary not only for electric supply problem, but also for general house description.

According to the standard [15] allowable temperature values for residential buildings are in the range of +18° C - 25° C depending on the type of room. In living rooms, the temperature should not be lower than +18° C, and in the bathroom - not lower than plus 25 °C.

Although there is no electric network in the village, near the village there is a woodworking plant, where I can order firewood with low shipping price. Because of this reason we can install a wood-burning boiler without problems. Also, I make this decision due to raw of advantages:

- Low cost
- Operational and environmental safety
- Small sizes
- Quick installation
- Noiselessness

Figure 9. Wood-burning boiler [16]

3.4. Electricity consumption

Also, I have to design table with installed electrical appliances and their nominal power in order to find consumed power. To do that I use common appliances for such area.

Table 10 – Appliances and their nominal powers installed in the cottage

Room	Area, [m^2]	Installed electrical appliances	Nominal power, [kW]
Kitchen	18	Electric stove	8
		Fridge	0,5
		Dishwasher	2,2
		Lighting	0,04
		Microwave	1
		Ventilation	0,2
		Kettler	1,5
		1 Socket x 16 A; 4 Sockets x 6 A	0,6
Living room	48	TV	0,3
		Lighting	0,09
		5 Sockets x 6 A	0,5
Bedroom 1	20	Lighting	0,04
		Computer	0,3
		2 Sockets x 6 A	0,2
Bedroom 2	20	Lighting	0,04
		Computer	0,3
		2 Sockets x 6 A	0,2
Children's room	22	Computer	0,4
		Stereo system	0,2
		Lighting	0,048
		2 Sockets x 6 A	0,2
Bathroom 1	14	Ventilation	0,15
		Lighting	0,02
		2 Sockets x 6 A	0,2
Bathroom 2	8	Washing machine	2,2
		Ventilation	0,15
		Lighting	0,01
		1 Sockets x 6 A	0,1
Other	-	Wood-burning boiler additional equipment	0,15
		Water supply system	1,1
Total	150	-	20,938

Now, when I defined total nominal power, I should define daily consumption for the whole year. It is necessary because I cover all month's load.

Table 11 – Monthly consumption for the whole year

Month	Consumption [kWh]
January	761,95
February	691,53
March	742,92
April	700,95
May	674,28
June	652,53
July	674,28
August	674,28
September	673,95
October	724,32
November	731,37
December	755,75

Detailed table with all type of appliances consumption are provided in appendix 6.

Difference between months are not significant because there are almost no seasonal. Also, during winter months, I spend more for heating, but it is not significant because I use wood-burning boiler for heating my house.

During some hours the power supply system will be overloaded and underloaded sometimes. This fact means that I need to consider variant with integrated battery storage system or backup power supply system, in order to fully cover loads with energy.

4. Analysis of the possible configurations of hybrid power supply

Since the nearest electric power line is at a distance of about 30 km, the variant of electric supply from grid is excluded, due to its high cost and landscape features.

So thus, there are several configurations of hybrid power supply with renewable energy source. Most of them are a combination of renewable energy source and gasoline generator. The gasoline generator provides consumers with energy when there is lack of energy from RES (for example the wind is weak for wind power plant or at night for photovoltaic power plant). Also, the configurations include storage battery. It keeps energy in case when the power plant generates more power than consumer needs.

4.1. Stand-alone wind generator

Wind generator is an installation that uses wind power to produce electrical energy. Usually, wind generators are made of tower and blades.

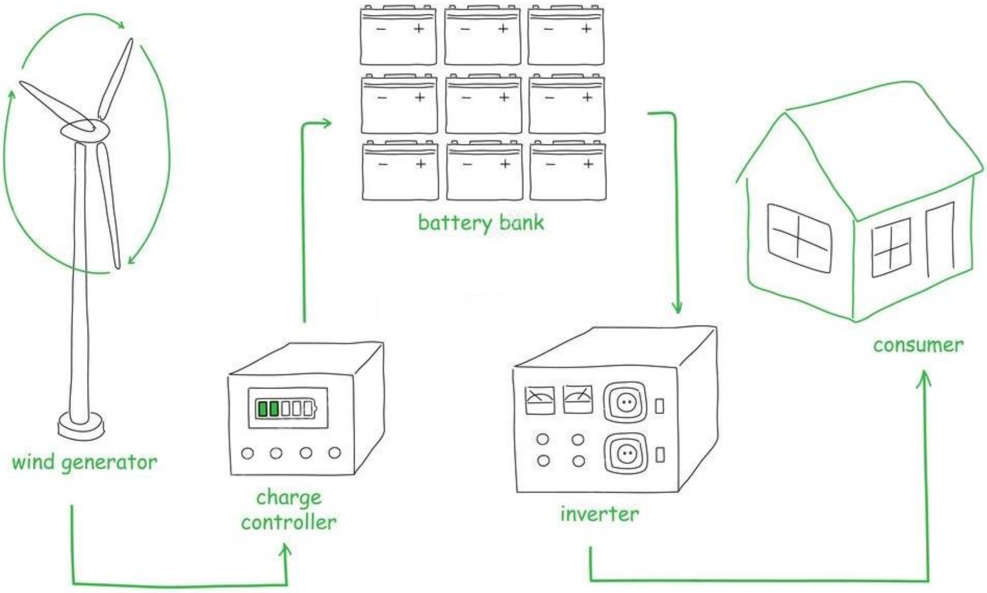

Figure 10. Stand-alone wind generator [17]

Due to the climate characteristics of Western Siberia, and in particular the Tomsk Region, it will be advisable to consider low-speed wind generators. Low-speed generator is considered to be powered by wind if the blades rotate along the vertical axis. Achieving low speed contributes to a high number of wings.

In order to operation of the rotor of a vertical windmill, the effect of magnetic levitation is used, which allows it to actually soar in the air. The use of rare earth magnets allows us to compensate the force of gravity, and special automated systems hold the mechanism at the desired position. This approach makes it possible to start spinning the rotor with very low wind gusts (from 0,17 m / s). Reducing the number of mechanical parts significantly increases the reliability and durability of the entire structure, and also positively affects acoustic comfort (noise level up to 20 dB). [17]

Vertical type wind turbines require almost no maintenance. In comparison with the classic horizontal generator, which will require maintenance every six months, this is a significant advantage.

The requirements for installing a vertical wind turbine do not contain statements on noise insulation or the minimum distance to residential buildings. Silent operation is achieved through the use of the effect of magnetic levitation, which allows to nullify almost all vibrations and achieve a noise load of less than 20 dB. The tower of the windmill can even be installed on the roof of the house, as the generator is almost silent.

One of the main disadvantages of a vertical wind turbine is its low efficiency in comparison with a horizontal wind generator. Efficiency is in the range 15-25%, but it is lower than horizontal wind turbines, which efficiency is 25-35%. [17]

The vertical wind generator is a rather complicated design, which negatively affects the weight, and this, in turn, makes it difficult to lift the device to a great height. Because of this, problems arise when it is catching the wind, since strong wind gusts are most often observed at high altitudes.

4.2. Hybrid wind and solar power supply

This type of generation is a hybrid system of accumulator inverter type, operating in the complex as on renewable natural energy resources, which for mankind are wind and solar radiation energy.

Combined power systems that use wind and solar energy at the same time have several advantages over stand-alone wind or solar installations.

For conditions, for example, in Russia, and especially in its middle lane, wind speed in summer is relatively small, but there is a lot of sun and long daylight hours. While in winter, on the contrary, there are a lot of strong winds and less sunlight. Since the peak of electricity generation in wind and solar systems occurs at different times of the day and year, such a combined system, accordingly, produces more energy.

Such a hybrid electrical installation for generating electricity is capable of ensuring the stability of its supply to the network of small cottage villages, country houses and a small private business.

The main element in the system is a wind generator that produces electrical energy and charges batteries. To avoid the dependence of the system on the absence or availability of energy resources and to ensure its greatest efficiency and stability, we supplemented the system with photovoltaic modules that generate solar energy and charge its batteries.

This hybrid installation is able to function without an electrical network. In the absence of sun and wind, the system will supply energy from the batteries.

The system should have several controllers - for PV modules, and for a wind generator - electrical devices for monitoring and controlling the battery charge, and inverters - for providing 220 V AC for consumers of electric energy from direct current batteries.

MPPT charge controller for PV modules increases by more than 30% the energy flow from PV modules to the battery, and performs the tasks of 2 devices: battery charge control and power amplifier of PV modules. [18]

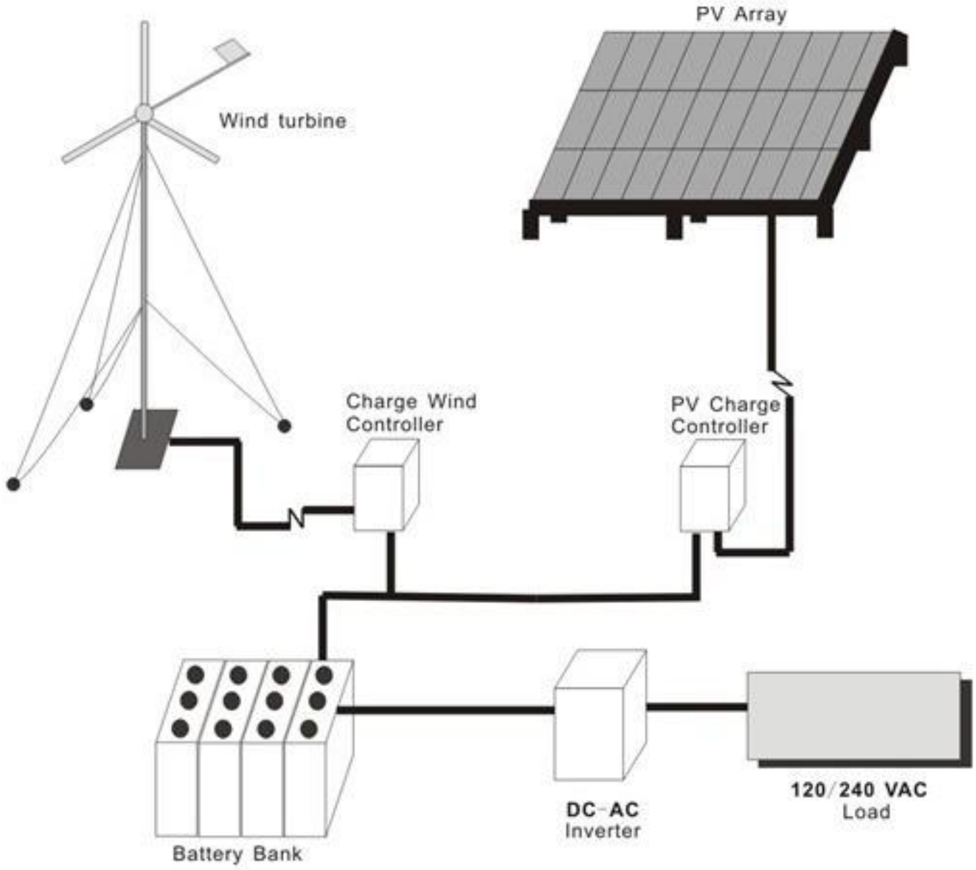

Figure 11. Wind and solar hybrid power supply system [19]

4.3. Wind, solar and gasoline generator

This is also hybrid type of power supply, working almost the same way as previous one, but at the time when there is no wind, sun and batteries are empty, gasoline generator starts to operate. Such time calls “Deficit time”, when power I need to consume are higher, than power the system can produce, without gasoline generator. Period of time, when wind turbine and PV arrays can cover all the consumption, calls “Normal time”. In this scheme specialized ATS controller is used, that monitors under / over voltage, under / over frequency and voltage unbalance and forward a start command on gasoline generator, if it is necessary.

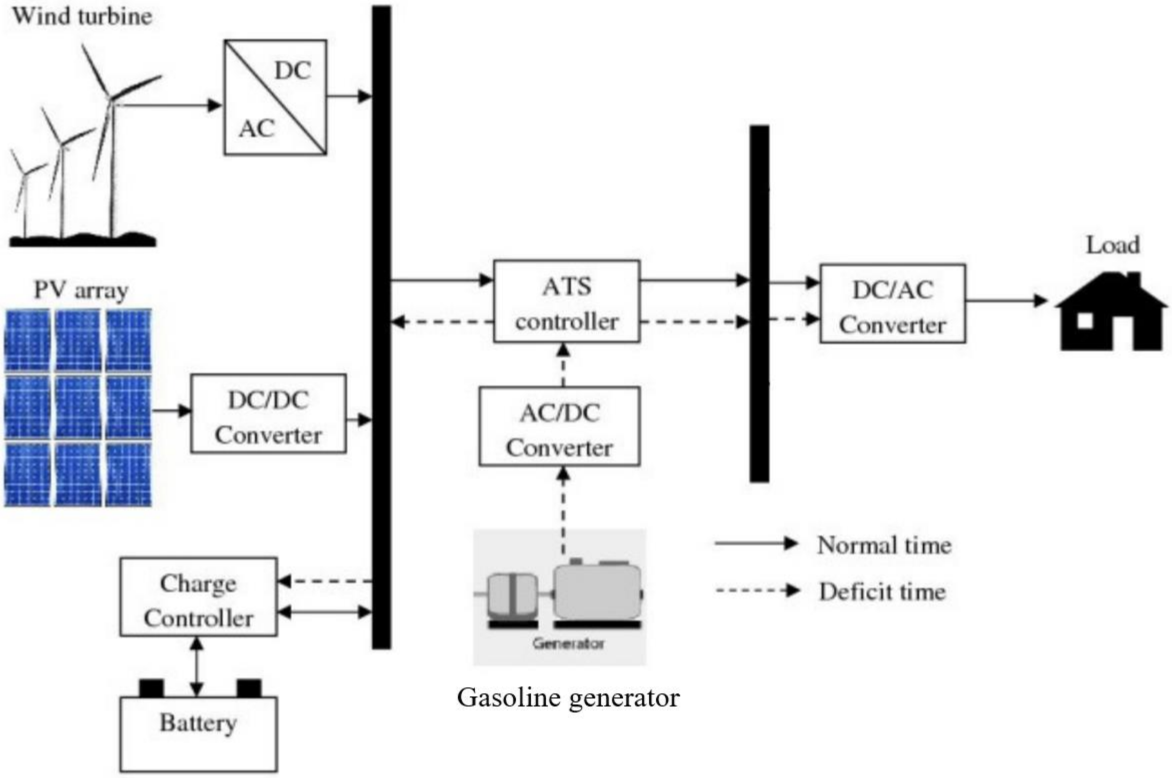

Figure 12. PV, wind and gasoline hybrid power supply system [20]

Due to the load is residential house, with permanently working appliances (not all of them, but part), it is very important to have backup generator, because in sharply continental climate zone often occurs windless and cloudy weather and batteries could not cover this period. It is obvious, that for this purpose the best option is third system, since it is the most reliable one, but for completeness it is necessary to consider all these options in simulation.

5. Mathematical simulation

The effectiveness of the projected object directly depends on the correct choice of equipment. Features of the facility location impose additional requirements for the operation of equipment. Harsh climatic conditions, a large amount of precipitation, and a significant temperature difference make the use of conventional equipment ineffective and impossible. Thus, before make simulations, I have to select suitable equipment, which can operate in such severe weather.

5.1. Wind generator

First of all, I choose wind generator. Due to the low wind speed, the best solution would be to use “Condor Air” 10 kW wind generator. The low starting speed of wind of 2,5 m/s and the low nominal speed of wind of 8 m/s, the most fully corresponds to the wind potential in the considered region.

Condor Air is a high-tech horizontal type wind generator developed by the “Energy Decision” company and adapted to work in Russian climatic conditions. Operational temperature range: from -40 to +50 degrees in the normal version and up to -55 in the version for low temperatures. The price of the wind generator includes a **charge controller** and a **mast**. [21]

Short description of the generator is provided in table below; full description is in the Appendix 7.

Table 12 – Short description of the wind generator [21].

Wind wheel diameter	7,5 m
Blade height	3,5 m
Nominal RPM	35-40
Output voltage	170-240 V
Nominal power	10 kW
Maximum power	11,2 kW
Nominal wind speed	9 m/s
Operational wind speed	3 – 20 m/s
Generator type	Three phase permanent-magnet generator
Generator frequency	0 - 50 Hz
Output current	Alternating
Nominal current	100 A
Maximum current	110 A
Cost	770 000 RUB

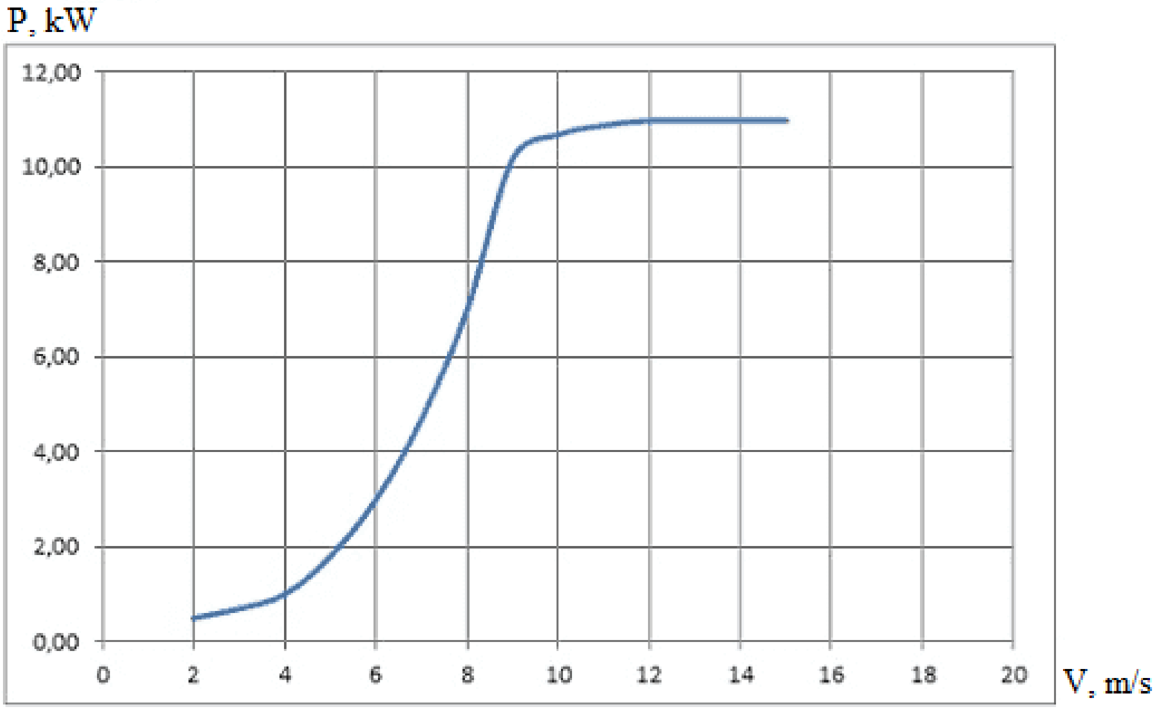

Figure 13. Dependence of active power on wind speed [5]

$$P = \xi \cdot \pi \cdot R^2 \cdot 0{,}5 \cdot V^3 \cdot \rho \cdot \eta_{rg} \cdot \eta_{gen} \qquad (9)$$

Where ξ – wind energy using coefficient,
R – rotor radius, [m]
V – wind speed, [m/s]
ρ – air density, [kg/m^3]
η_{rg} – reduction gear efficiency
η_{gen} – generator efficiency

Let's calculate the amount of energy generated by a single wind generator over a period of months to a month, using formula 12 [8].

Table 13 – Amount of generated energy per month for the whole year

Month	W, [kWh/month]
January	1620,94
February	1315,04
March	1638,02
April	1466,74
May	1310,84
June	778,24
July	623,22
August	572,32
September	774,68
October	1378,38
November	1557,46
December	1610,98
Total	14646,86

I present the obtained results as a histogram to visualize them.

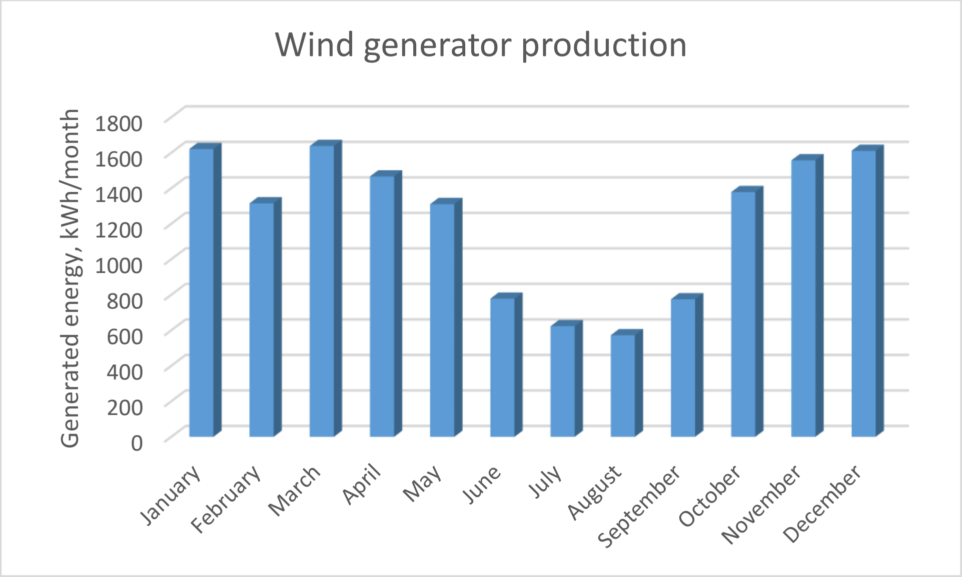

Figure 14. Amount of generated energy per month for the whole year

Let’s calculate the balance of generated and consumed energy for the whole year using formula (10) in order to determine deficiency of energy in system.

$$\Delta W = W_g - W_c, \tag{10}$$

Where, W_g – Generated energy, [kWh/month]
W_c – Consumed energy [kWh/month]

Table 14 – Balance of generated and consumed energy for the whole year

Month	W_g, [kWh/month]	W_c, [kWh/month]	ΔW, [kWh/month]
January	1620,94	761,95	858,99
February	1315,04	691,53	623,51
March	1638,02	742,92	895,1
April	1466,74	700,95	765,79
May	1310,84	674,28	636,56
June	778,24	652,53	125,71
July	623,22	674,28	-51,06
August	572,32	674,28	-101,96
September	774,68	673,95	100,73
October	1378,38	724,32	654,06
November	1557,46	731,37	826,09
December	1610,98	755,75	855,23
Total	14646,86	8458,11	6188,75

* Details about consumed power provided in appendix 6.

Let's build the graph to visualize the deficiency of energy in system.

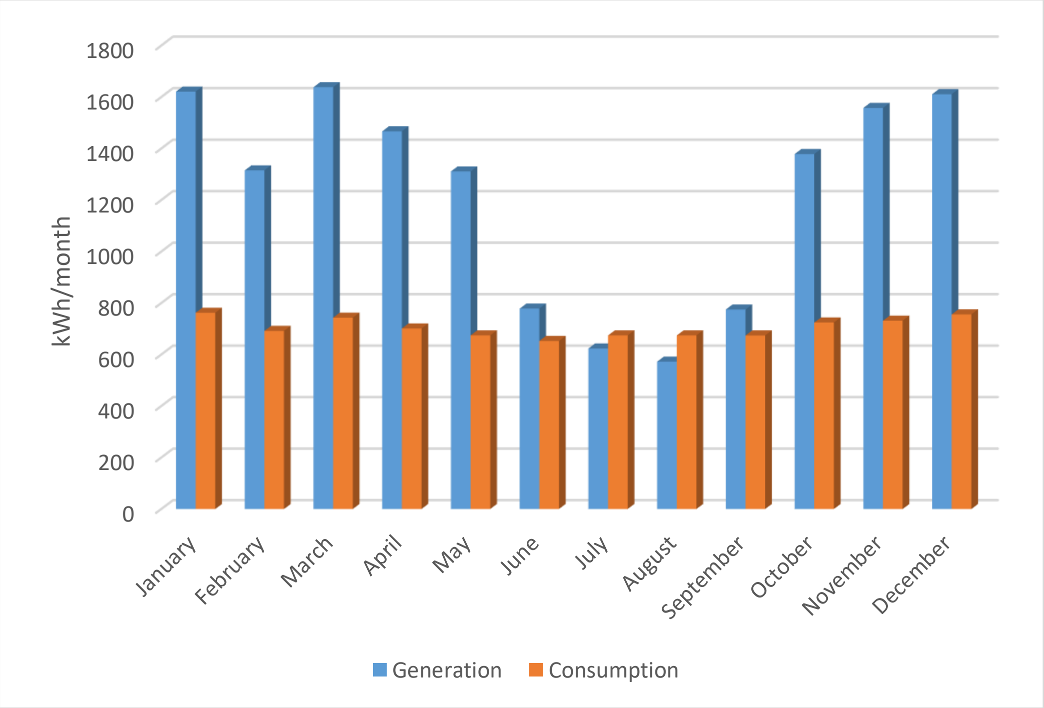

Figure 15. Balance of the energy per month for the whole year

As you may see from the figure 15, not all months' loads are covered by wind generator. There is deficiency of energy in summer months June and July. Thus, this energy is not enough to satisfy our needs and I have to install additional source of energy. Since deficiency is not too high it is not reasonable to install more than 1 wind generator and I decided to consider it only as combination with other sources of energy.

5.2. Solar modules

As PV modules, I choose “Exmork FSM-300M”. Main characteristics are provided in table below.

Table 15 – Solar module “Exmork FSM-300M” main characteristics [22]

Electrical parameters	
Maximum power, W	300
Nominal voltage, V	24 V
On-load voltage, V	36
Off-load voltage, V	43,15
On-load current, V	8,33
Short circuit current, A	9,14
Maximum off-load voltage of PV array, V	1000
Efficiency, %	17,4
Cost	21 385 RUB

Also, PV charge controllers are included. The full specification provided in appendix 8.

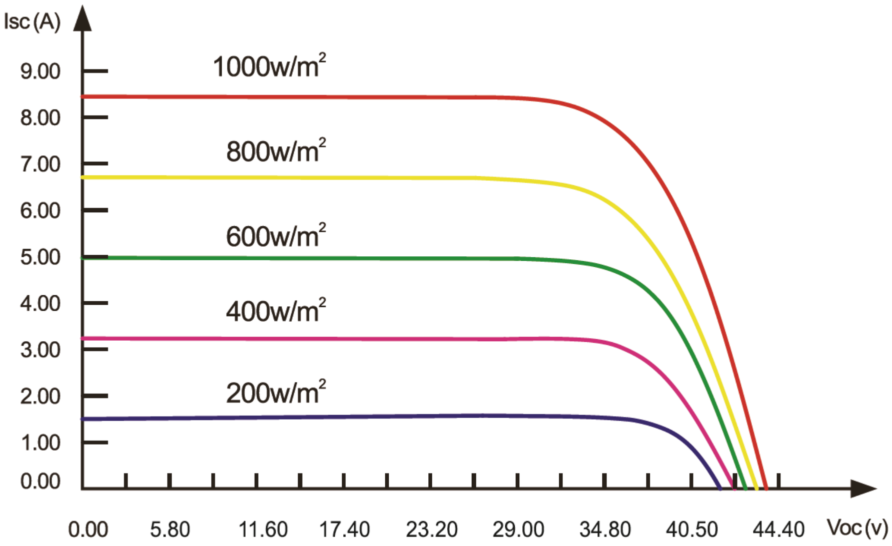

Figure 16. Current and voltage dependences on the intensity of solar radiation

Now I calculate amount of energy generated by one solar module during one year month by month using methodic from [8]

Solar module with nominal power P_{SM} generates such amount of energy:

$$\mathrm{W}_{SM} = \frac{P_{SM} \cdot \lambda}{1000} \ [\mathrm{k}Wh]; \tag{11}$$

where, λ - insolation during the chosen period, [kWh/m^2];

Example of calculations for January:

$$\mathrm{W_{SM}} = \frac{300 \cdot 28{,}52}{1000} = 8{,}556 \ [\mathrm{kWh}]$$

Table 16 – Amount of energy generated by solar module “Exmork FSM-300M”

Month	Energy generated by 1 solar module, $W_{1SM}, [kWh]$	Energy consumptions, $W_C, [kWh]$	Necessary quantity of solar modules, N_{SM}
January	8,556	761,95	90
February	10,725	691,53	65
March	17,346	742,92	43
April	31,929	700,95	22
May	43,212	674,28	16
June	55,866	652,53	12
July	56,892	674,28	12
August	58,884	674,28	12
September	47,103	673,95	15
October	29,895	724,32	25
November	19,113	731,37	39
December	11,655	755,75	65
Total	391,176	8458,11	-

As you can note from the table 16, in order to cover energy consumptions, we need to install at least 90 solar modules, that is too costly and ineffective, due to big difference between months. Furthermore, all we need is to cover deficiency. Obviously, the highest deficiency of energy is in winter season and to avoid it, same as with wind generators, I will combine solar modules with other energy sources.

Two solutions are possible to cover the current energy deficit. First is to install additional gasoline generator, the second is to install wind generators. Let us begin from second alternative, since we already choose and describe the equipment. From the previous calculation, you can note that to cover all the load I have to install **10 kW wind generator** and ~**5 solar cells**. However, to reliability I decided to increase number of solar cells to **20**, because this equipment too dependent from uncontrolled conditions.

Table 17 – Amount of energy generated by hybrid wind-solar power plant

Month	Energy consumption, [kWh]	Energy generated by 20 solar modules, [kWh]	Energy generated by 10kW wind generators, [kWh]	Total energy generated, [kWh]
January	761,95	171,12	1620,94	1792,06
February	691,53	214,5	1315,04	1529,54
March	742,92	346,92	1638,02	1984,94
April	700,95	638,58	1466,74	2105,32
May	674,28	864,24	1310,84	2175,08
June	652,53	1117,32	778,24	1895,56
July	674,28	1137,84	623,22	1761,06
August	674,28	1177,68	572,32	1750
September	673,95	942,06	774,68	1716,74
October	724,32	597,9	1378,38	1976,28
November	731,37	382,26	1557,46	1939,72
December	755,75	233,1	1610,98	1844,08
Total	8458,11	7823,52	14646,86	22470,38

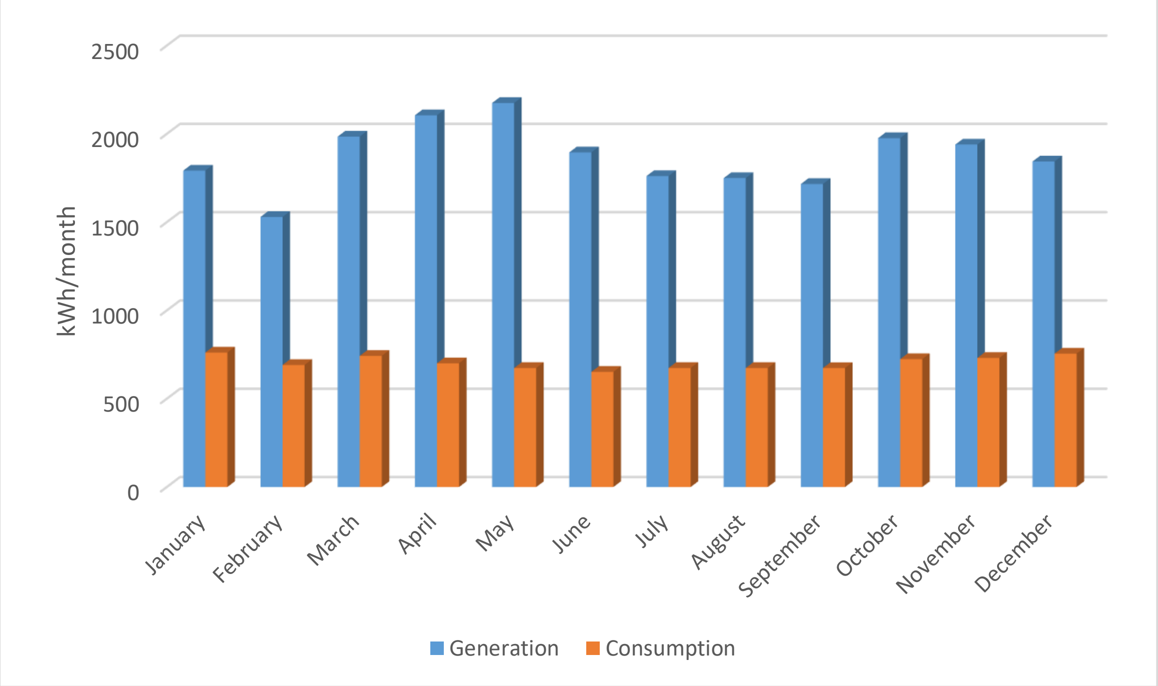

Figure 17. Wind-solar power plant monthly energy balance for the whole year

5.3. Gasoline generator

As gasoline generator I choose "EUROPOWER EP20000TE". Brief description of main characteristics is provided in table below.

Table 18 – "EUROPOWER EP20000TE" generator main characteristics [23]

Nominal power, kW	16
Frequency, Hz	50
Dimensions l x w x h	100 x 64 x 72cm
Maximum apparent power, kVA	20
Nominal voltage, V	380/220
Cost	599 990 RUB

The cost also includes ATS controller and AC/DC converter. The full specification is provided in the appendix 9.

Table 19 – approximate calculation of annual gasoline consumption for different structures of power plant

Month	Gasoline consumption, l/h		
	Stand-alone GG	1 WT + GG	20 PV + GG
January	445	0	345
February	404	0	279
March	434	0	231
April	409	0	37
May	394	0	0
June	381	0	0
July	394	30	0
August	394	60	0
September	394	0	0
October	423	0	74
November	427	0	204
December	441	0	305
Total	4940	90	1475

* 1 WT + GG – Combination of 10 kW "Condor Air" wind generator + Gasoline generator "EUROPOWER EP20000TE"

* 20 PV + GG – Combination of 20 x 0.3 kW "Exmork FSM-300M" solar cells + Gasoline generator "EUROPOWER EP20000TE

5.4. Inverter

The next device I have to install is inverter. Inverter is a device which converts DC voltage to AC voltage. The form of voltage can be sinusoidal, close to sinusoidal or pulsed. Inverters are used as stand-alone devices and as a part of uninterruptible power supply systems.

As inverter I choose “**GoodWe DT series 25 kW inverter**”. Brief description of main characteristics is provided in table below.

“GoodWe smart DT series inverter is typically designed for the home solar systems, covering 4kW/5kW/6kW. By adopting cutting-edge technology of photovoltaic field, it provides three phase AC output, making home system connection well balanced, safer and more convenient. The integrated two MPPTs allow two-array inputs from different roof orientations. And the combination of both RS485 and Wi-Fi communication makes the system well interactive and extremely easy to monitor.” [24]

Table 20 – Brief description of main characteristics of the inverter [24]

Input Data(DC)	
Max. DC Power	32.5 kW
Max. DC Voltage	1000 V
Nominal DC Voltage	620 V
Min. DC Voltage to Start Feed In	250 V
Output Data (AC)	
Max. AC Power	25 kW
Nominal AC Power	25 kW
Nominal AC Voltage	400 V
Max. AC Current	37 A
Frequency	50, 60 Hz
Cost	300 000 RUB

The full specification is provided in the appendix 10.

5.5. Batteries

The battery is a consumable item in an autonomous or backup power system. The better you pick up the battery for your system, the longer it will work and the less will ultimately be the cost of electricity generated by your system.

The main parameter of any battery is its capacity. Depending on which system it will be used in, it is necessary to choose the required face value. In our case, batteries are going to use as backup for the main power sources. It means, that battery will be discharged quite rarely (in case of fault of the main source of electricity). I will consider the required capacity based on a 100% discharge cycle. I will design backup system for 1 day of normal house operating.

To supply house with energy during the whole this day we need to 4,75 kA*h capacity. I will install “**Delta DTM 12250 L (12V / 250Ah)**” in the amount of 20 batteries. Description of technical characteristics is provided in table below.

Table 21 – Technical characteristics of battery “**Delta DTM 12250 L (12V / 250Ah)**” [25]

Technical characteristics:	
Voltage, V	12
Capacity, Ah	250
Length, mm	520
Width, mm	269
Heigth, mm	222
Height with terminal, mm	225
Weigth, kg	71.2
Lifetime, age	10
Cost	47 191 RUB

Summary

After calculation of energy balance, I decided to consider a few additional hybrid combinations of power plant structure and complement them. I provide all the considered structures below:

- 10 kW “Condor Air” wind generator + 20x0.3kW “Exmork FSM-300M” solar cells
- 10 kW “Condor Air” wind generator + Gasoline generator “EUROPOWER EP20000TE”
- 20x0.3kW “Exmork FSM-300M” solar cells + Gasoline generator “EUROPOWER EP20000TE”
- Stand-alone Gasoline generator “EUROPOWER EP20000TE”

All other equipment is the same for all these options.

6. Economic comparison of possible option of electric supply

To make the final decision, it is very important to assess the not only technical, but also economic component of the project. In this chapter I will evaluate all the structures of electric supply from previous chapter with different types of financing. In particular I will consider financing with own funds and with bank loan.

It is necessary to note, that all considered power supply structures do not have any opportunity to sell electricity, since they are off-grid. Also, I do not consider selling equipment and other sources of revenues. Hence, it will be “expenses-only” project. Also, since net cash flow always will be negative, it is not necessary to calculate depreciation, because I will not pay any taxes. For such projects it is impossible to calculate IRR or Payback period, thus, to evaluate the structures, I will use the NPV investment decision criteria, calculated by formula from [26]:

$$NPV = \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t} - INV, \tag{12}$$

where CF_t – net cash flow during t-period;

r – discount rate;

t – number of time period;

T – project lifetime;

INV – initial investments.

Table 22 – Assets’ prices and lifetimes

	Cost [RUB]	Lifetime [years]
Wind generator	770 000	20
PV Cell	21 385	20
Gasoline generator	599 990	20
Inverter	300 000	20
Battery	47 191	10
Delievery	40 000	-
Maintenance	80 000	-
Installation	Depends on the scenario	-
Other	250 000	-
Gasoline fuel (1 liter)	42,4	-

* All the prices provided in the table have shown per unit of the equipment or product

* Maintenance will be held every year

* Other – all the expenses, that was not included in previous paragraphs, including wiring, gearboxes, project expenses

As you can note from table 21, lifetime of batteries twice lower than other equipment, thus, I have to buy new batteries after 10th year.

Table 23 – Scenarios description

	Wind generators number	PV Cells number	Fuel consumption	Batteries number	Bank loan	Investment cost, RUB
Scenario 1	1	20	-	20	No	2 731 520
Scenario 2	1	20	-	20	Yes	0
Scenario 3	1	-	90	20	No	2 903 810
Scenario 4	1	-	90	20	Yes	0
Scenario 5	-	20	1475	20	No	2 561 510
Scenario 6	-	20	1475	20	Yes	0
Scenario 7	-	-	4940	20	No	2 133 810
Scenario 8	-	-	4940	20	Yes	0

* Scenarios without fuel consumption do not include gasoline generator

In order to calculate annuity payment for bank loan I will use formula [26]:

$$PMT = PVAF \cdot PV = \frac{1-(1+r)^{-T}}{r} \cdot PV, \tag{13}$$

where PMT – annual loan payment,
PVAF – Present Value Annuity Factor,
PV – present value,
r – interest rate,
T – number of periods

Economic characteristics

Inflation rate – a quantitative measure of the rate at which the average price level of a basket of selected goods and services in an economy increases over some period of time. It is the rise in the general level of prices where a unit of currency effectively buys less than it did in prior periods [27]. To estimate level of inflation I used Geometric average value.

Table 24 – Inflation data [28]

Year	Inflation, %	Geometric average value, %
2019	3	6,689
2018	4,3	
2017	2,5	
2016	5,4	
2015	12,9	
2014	11,36	
2013	6,45	
2012	6,58	
2011	6,1	
2010	8,78	

So, as inflation rate, I will use average value for last 10 years.

Inflation rate = 6,689 %

"Cost escalation can be defined as changes in the cost or price of specific goods or services in a given economy over a period. This is similar to the concepts of inflation and deflation except that escalation is specific to an item or class of items (not as general in nature), it is often not primarily driven by changes in the money supply, and it tends to be less sustained. While escalation includes general inflation related to the money supply, it is also driven by changes in technology, practices, and particularly supply-demand imbalances that are specific to a good or service in a given economy." [26]

Table 25 – Gasoline price growth data [29]

Year	Gasoline price growth, %	Average value, %
2017	6,58	7,732
2016	6,10	
2015	6,83	
2014	5,23	
2013	7,75	
2012	5,97	
2011	6,77	
2010	12,56	
2009	12,06	

Gasoline escalation = 7,732 %

Batteries escalation should be less than inflation due to obsolescence of this technology, but not zero, I assume

Batteries escalation = 2 %

Escalation for maintenance I assume to be equal to average inflation rate.

Maintenance escalation = 6,689 %

The interest rate is the amount a lender charges for the use of assets expressed as a percentage of the principal. The interest rate is typically noted on an annual basis known as the annual percentage rate. The assets borrowed could include cash, consumer goods, or large assets such as a vehicle or building. [30]

According to database [31] long term loans interest rates are from 8 to 19%. So, let us assume

Interest rate = 11 %

Discount rate is used in discounted cash flow analysis. DCF is a commonly followed valuation method used to estimate the value of an investment based on its expected future cash flows. Based on the concept of time value of money, the DCF analysis helps assess the viability of a project or an investment by calculating the present value of expected future cash flows using a discount rate. [32]

Also, I assume a discount rate to be a risk-free asset. It is can be taken at the level of governmental bonds [33]

Discount rate = 8 %

Table 26 – Obtained results

	NPV, RUB
Scenario 1	-4 586 893
Scenario 2	-5 223 119
Scenario 3	-4 828 208
Scenario 4	-5 504 563
Scenario 5	-5 548 130
Scenario 6	-6 144 757
Scenario 7	-7 777 905
Scenario 8	-8 274 912

As you can see from the table, the best scenario according to economic evaluation is first, but I will not rush to conclusions as this is not the only factor important for me. In order to make a final decision, I have to take into account cost of initial investment and technical parameters.

The full tables with calculations provided in appendices 11, 12 and 13.

Sensitivity analysis

Sensitivity analysis of an investment project (sensitivity analysis) is an assessment of the impact of changes in the initial parameters of an investment project (investment costs, cash inflows, discount rate, operating expenses, etc.) on its final characteristics, which are usually used as IRR or NPV.

To analyze the sensitivity of an investment project, the main thing is to assess the degree of influence of each (or a combination of) changes from the initial parameters in order to provide for the worst development of the situation in the investment project. [34]

In this part I will analyze sensitivity of all the scenarios to discount rate, interest rate, fuel escalation and fuel price in order to evaluate how input parameters affect the project.

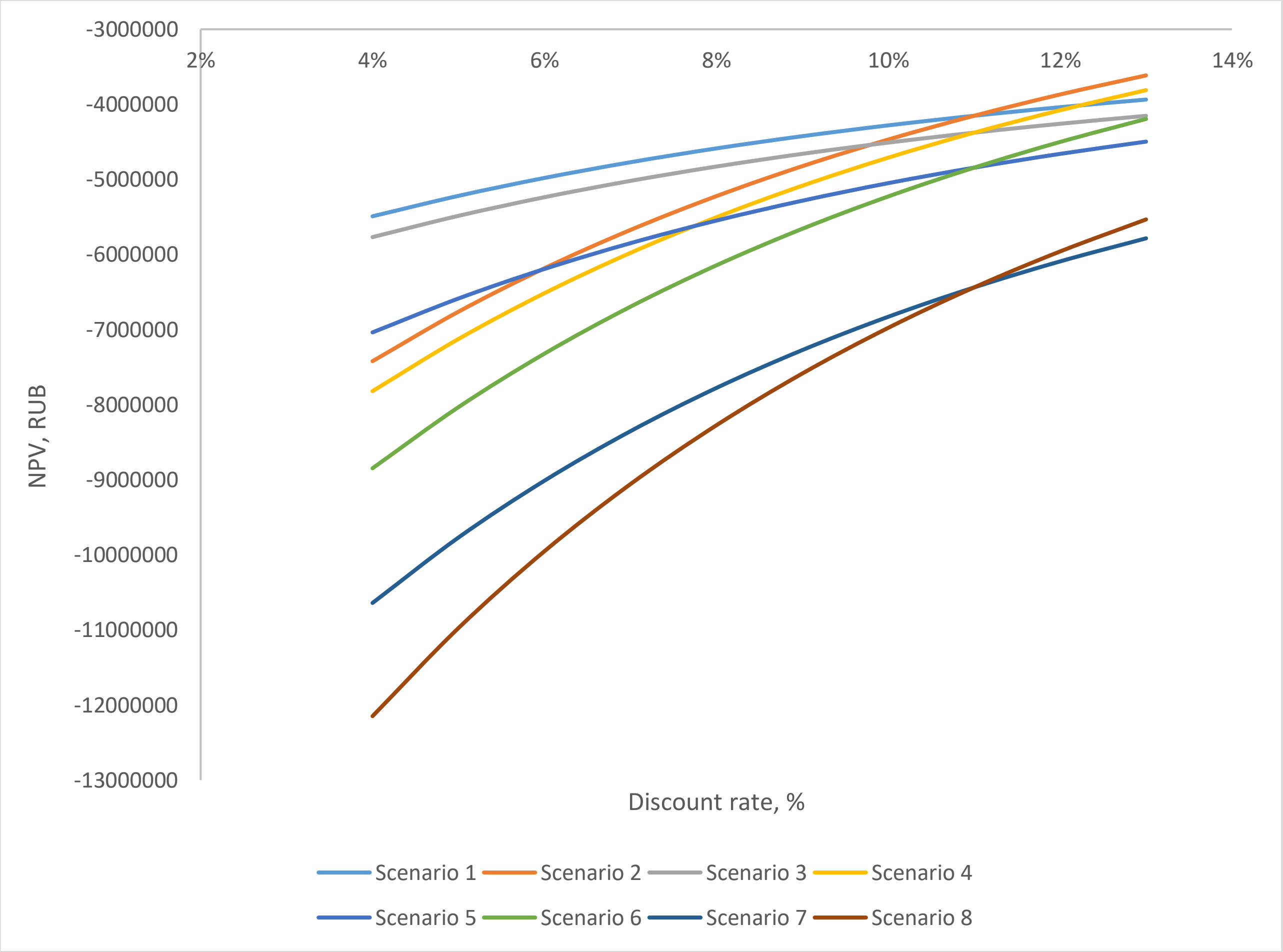

Figure 18. Sensitivity of NPV to discount rate

As you can see from the figure 18, the higher discount rate, the higher will be NPV for these scenarios. It can be explained by type of the projects, due to there are no cash inflows, increase of discounting leads to increase of NPV.

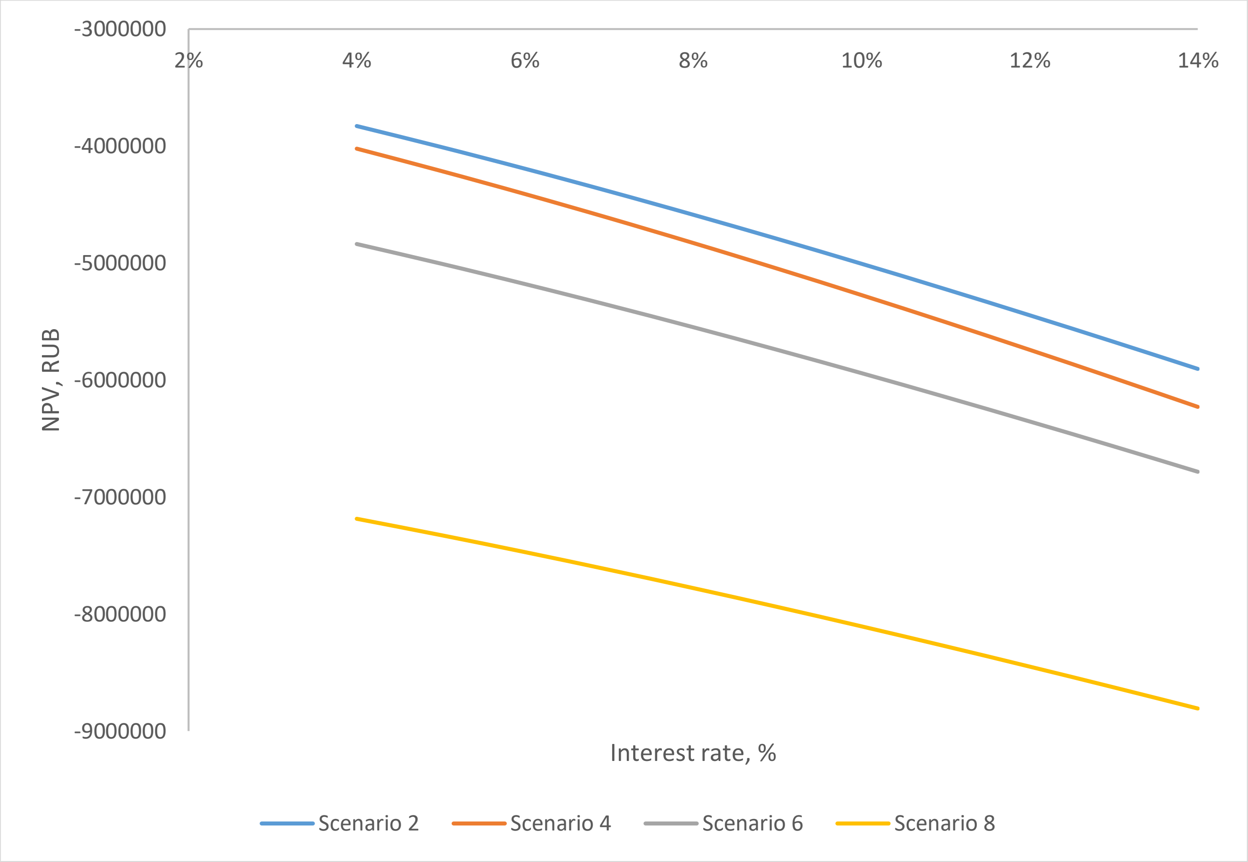

Figure 19. Sensitivity of NPV to interest rate

On this figure I have shown only these scenarios, which include bank loan. As you can see here, the higher loan amount of the scenario, the more sensitive NPV will be to interest rate. In any case, scenario 6 has the best NPV comparing with other scenarios, financed by bank loan.

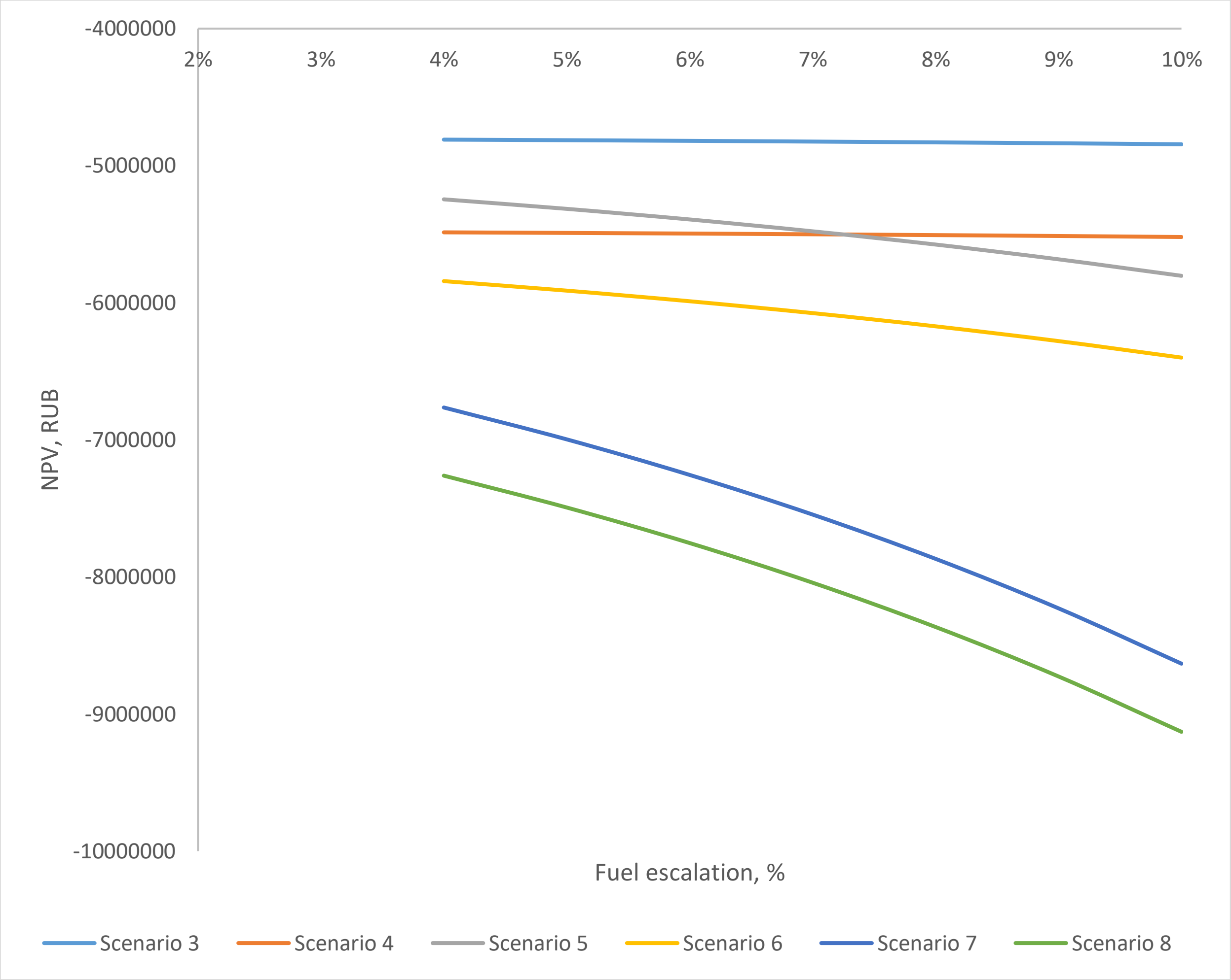

Figure 20. Sensitivity of NPV to gasoline escalation

I include to this figure only scenarios, including gasoline generator. As you can see, dependence for same project, but with different initial financing are same. However, it is necessary to note, projects with higher consumption of fuel more sensitive to fuel escalation.

7. Final decision making

Now, as rational decision maker, I should make the most suitable decision for me. Almost everything is ready for a final decision, however, to make a decision, it is only necessary to introduce criteria for evaluation and evaluate each scenario according to the entered criteria so that the solution is the most suitable for me.

Among the criteria, one should take into account not only the NPV of each scenario, but also other aspects, such as Investment cost and Reliability, etc. The final list of criteria will be given in the table below, with explanations.

Table 27 – Scenarios evaluation according to specified criteria

	Reliability [C1]	Convenience [C2]	NPV [C3]	Investment cost [C4]	Fuel dependence [C5]
Type	max	max	max	min	min
Scale	ordinal [1 to 4]	ordinal [1 to 4]	interval	interval	ordinal [0 to 2]
Scenario 1	1,000	1,000	-1,147	1,366	0,000
Scenario 2	1,000	1,000	-1,306	0,000	0,000
Scenario 3	4,000	3,000	-1,207	1,452	1,000
Scenario 4	4,000	3,000	-1,376	0,000	1,000
Scenario 5	2,000	2,000	-1,387	1,281	2,000
Scenario 6	2,000	2,000	-1,536	0,000	2,000
Scenario 7	3,000	4,000	-1,944	1,067	3,000
Scenario 8	3,000	4,000	-2,069	0,000	3,000
Weight	0,200	0,100	0,300	0,200	0,200

Here I would like to clarify that from customer point of view, the value of the initial investment has almost the same value as NPV. Since we are talking about large amounts of money, an individual may simply not have that kind of money. As for the other scales, they are intuitively arranged and displays what interests me more among these scenarios.

There are two types of scale – ordinal and inverval. An ordinal scale is one where the order matters but not the difference between values. An interval scale is one where there is order and the difference between two values is meaningful. [35]

In order to find the optimal solution, I use Global Criterion Method. [36] According to this method, I have to recalculate values from initial scale, to relative scale. In order to do that I should use formulas (14) for “min” and (15) for “max”:

$$f = \frac{f_W - f_i}{f_W - f_B} \tag{14}$$

$$f = \frac{f_i - f_W}{f_B - f_W}, \quad (15)$$

Where f_W – the worst scenario rating of the criteria,

f_B – the best scenario rating of the criteria,

f_i – current scenario rating of the criteria,

f – relative rating of the criteria

Table 28 – Results of calculation according to global criterion method

	Reliability [C1]	Convenience [C2]	NPV [C3]	Investment cost [C4]	Fuel dependence [C5]	$\sum w_i f_i$
Scenario 1	0,000	0,000	1,000	0,059	1,000	0,512
Scenario 2	0,000	0,000	0,827	1,000	1,000	0,648
Scenario 3	1,000	0,667	0,935	0,000	0,667	0,680
Scenario 4	1,000	0,667	0,751	1,000	0,667	0,825
Scenario 5	0,333	0,333	0,739	0,118	0,333	0,412
Scenario 6	0,333	0,333	0,578	1,000	0,333	0,540
Scenario 7	0,667	1,000	0,135	0,265	0,000	0,327
Scenario 8	0,667	1,000	0,000	1,000	0,000	0,433

According to global criterion methodic, the obtained value the better solution will be.

So, as you can see, from the table 28, the best solution will be “Scenario 4”. This scenario includes hybrid power supply, financing by bank loan. More precisely, there will be installed Gasoline generator and Wind generator.

It is necessary to note, although scenario 3 has close value to scenario 4, obtained scenario is more suitable decision. Since the value of initial investment is significant factor, especially from customer point view, although as a result I choose scenario with lower NPV. Between these two scenarios this criterion is decisive.

Conclusion

The main goal of my work was to provide electricity to a house inaccessible to the central power supply system. The objectives of this work were the design of various power supply options and the choice of the optimal one. Also, my goals were to reduce environmental impact factors and to calculate the economic efficiency of the cottage's electricity supply using renewable energy sources.

The main result of this work is a developed algorithm for the optimal design of a decentralized power supply system. The created model takes into account a very wide range of factors, trying to assess the main possible risks and problems associated with the problem of building a power supply system. However, this complexity is close to real situations when the designer is faced not only with technical obstacles when creating a new generating unit.

I looked at four different scenarios with different financing options. wind generator and 20 solar panels; wind generator and gasoline generator; 20 solar panels and gasoline generator; stand-alone gasoline generator. Among these options, from my point of view, it was necessary to choose an option that is reliable enough, but at the same time the most economically profitable, with minimal dependence on the price of fuel.

The result of the presented algorithm is a project ready for implementation, with economic indicators calculated for it and an analysis of possible risks, such as changes in fuel prices, changes in interest rates on loans, etc. The resulting project consists of one wind generator “Condor Air” 10 kW and gasoline generator “EUROPOWER EP20000TE” 16 kW. From the decision-making part, I would note that the most suitable financing option for me is a bank loan. The decisive factor for me, from a consumer point of view, was the value of the initial investment cost.

It should be noted that all the work I have done is based on statistical data, such as wind speeds, solar radiation, electricity consumption. All these data will be well suited for the average cottage, in weather conditions that do not deviate from the norm. However, if against the weather anomalies there is an energy source independent of the weather conditions, as well as rechargeable batteries, in order to store energy, then no one is safe from force majeure situations, such as the financial and economic crisis, the epidemic, the sledges against the state, which is very strongly affects inflation, component prices, interest rates, gasoline prices, etc.

The last, but not least factor is the subsidization of alternative energy by the government. Unfortunately, currently in Russia there are no such subsidies and there are no prerequisites for them to appear. It only remains to hope for an improvement in the situation regarding alternative energy, because for many people this will be the decisive factor.

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Appendices

Appendix 1 – Winter solar radiation values for 1 m^2 based on data from [14]

Time	Sun angle, φ, deg	λ, kW/m^2	P, kW/m^2
9:00 – 9:33	0	0	0
9:33 – 10:00	10,6346	0,1005	0,0151
10:00 – 11:00	34,2670	0,2444	0,0367
11:00 – 12:00	57,8993	0,3612	0,0542
12:00 – 13:00	81,5317	0,4381	0,0657
13:00 – 14:00	105,1641	0,4666	0,0700
14:00 – 15:00	128,7965	0,4434	0,0665
15:00 – 16:00	152,4289	0,2581	0,0387
16:00 – 17:00	176,0613	0,1164	0,0175
17:00 – 17:10	180	0,0234	0,0035
17:10 – 18:00	0	0	0
Total			0,3678

Appendix 2 – Spring solar radiation values for 1 m^2 based on data from [14]

Time	Sun angle, φ, deg	λ, kW/m^2	P, kW/m^2
6:00-6:53	0	0	0
6:53-7:00	1,6092	0,0875	0,0131
7:00-8:00	15,4023	0,2209	0,0331
8:00-9:00	29,1954	0,3422	0,0513
9:00-10:00	42,9885	0,4448	0,0667
10:00 - 11:00	56,7816	0,5230	0,0785
11:00 - 12:00	70,5747	0,5725	0,0859
12:00 - 13:00	84,3678	0,5908	0,0886
13:00 - 14:00	98,1609	0,5766	0,0865
14:00 - 15:00	111,9540	0,5309	0,0796
15:00 - 16:00	125,7471	0,4561	0,0684
16:00 - 17:00	139,5402	0,3563	0,0534
17:00-18:00	153,3333	0,2370	0,0356
18:00-19:00	167,1264	0,1047	0,0157
19:00-19:56	180	0	0
Total			0,7565

Appendix 3 – Summer solar radiation values for 1 m^2 based on data from [14]

Time	Sun angle, φ, deg	λ, kW/m^2	P, kW/m^2
4:00-4:51	0,0000	0,0000	0,0000
4:51 - 5:00	1,5851	0,0571	0,0086
5:00 - 6:00	12,1526	0,1213	0,0182
6:00 - 7:00	22,7202	0,1815	0,0272
7:00-8:00	33,2877	0,2142	0,0321
8:00-9:00	43,8552	0,2981	0,0447
9:00-10:00	54,4227	0,4020	0,0603
10:00 - 11:00	64,9902	0,4886	0,0733
11:00 - 12:00	75,5577	0,5543	0,0831
12:00 - 13:00	86,1252	0,5963	0,0894
13:00 - 14:00	96,6928	0,6127	0,0919
14:00 - 15:00	107,2603	0,6029	0,0904
15:00 - 16:00	117,8278	0,5672	0,0851
16:00 - 17:00	128,3953	0,4256	0,0638
17:00-18:00	138,9628	0,3257	0,0489
18:00-19:00	149,5303	0,2118	0,0318
19:00 - 20:00	160,0978	0,1240	0,0186
20:00 - 21:00	170,6654	0,0880	0,0132
21:00 - 21:53	180,0000	0,0500	0,0075
Total			0,8882

Appendix 4 – Autumn solar radiation values for 1 m^2 based on data from [14]

Time	Sun angle, φ, deg	λ, kW/m^2	P, kW/m^2
7:00-7:24	0,0000	0,0000	0,0000
7:24-8:00	9,3642	0,0443	0,0066
8:00-9:00	24,9711	0,1553	0,0233
9:00-10:00	40,5780	0,2543	0,0381
10:00 - 11:00	56,1850	0,3315	0,0497
11:00 - 12:00	71,7919	0,3811	0,0572
12:00 - 13:00	87,3988	0,3988	0,0598
13:00 - 14:00	103,0058	0,3832	0,0575
14:00 - 15:00	118,6127	0,3356	0,0503
15:00 - 16:00	134,2197	0,2599	0,0390
16:00 - 17:00	149,8266	0,1625	0,0244
17:00-18:00	165,4335	0,0516	0,0077
18:00-18:56	180,0000	0,0070	0,0011
Total			0,4148

Appendix 5 – Hour coefficient for winter and summer season [19]

Hour	Season	
	Winter	Summer
1	0,25	0,15
2	0,25	0,15
3	0,25	0,15
4	0,25	0,15
5	0,25	0,175
6	0,35	0,21
7	0,50	0,28
8	0,60	0,31
9	0,40	0,28
10	0,30	0,21
11	0,35	0,21
12	0,40	0,21
13	0,30	0,24
14	0,30	0,21
15	0,30	0,21
16	0,30	0,21
17	0,40	0,21
18	0,70	0,21
19	1,00	0,25
20	0,95	0,28
21	0,70	0,5
22	0,50	0,7
23	0,35	0,42
24	0,30	0,18

Appendix 6 – Detailed appliances electricity consumption

Consumer type	ominal pow	Consumption [kWh]											
	P_{nom}	January	February	March	April	May	June	July	August	September	October	November	December
Electric stove	8	238,7	217,525	238,7	231	238,7	231	238,7	238,7	231	238,7	231	238,7
Fridge	0,5	6,2	5,65	6,2	6	6,2	6	6,2	6,2	6	6,2	6	6,2
Dishwasher	2,2	17,05	15,5375	17,05	16,5	17,05	16,5	17,05	17,05	16,5	17,05	16,5	17,05
Lighting	0,228	21,204	19,323	17,67	17,1	14,136	13,68	14,136	14,136	17,1	17,67	20,52	21,204
Microwave	1	18,6	16,95	18,6	18	18,6	18	18,6	18,6	18	18,6	18	18,6
Kettler	1,5	21,7	19,775	21,7	21	18,6	18	18,6	18,6	21	21,7	21	21,7
TV	0,3	24,18	22,035	24,18	23,4	24,18	23,4	24,18	24,18	23,4	24,18	23,4	24,18
Computers	1	130,2	118,65	130,2	126	130,2	126	130,2	130,2	126	130,2	126	130,2
Stereo system	0,2	6,2	5,65	6,2	6	6,2	6	6,2	6,2	6	6,2	6	6,2
Washing machine	2,2	68,2	62,15	68,2	66	68,2	66	68,2	68,2	66	68,2	66	68,2
Boiler additional equipment	0,15	108,5	96,05	93	72	31	30	31	31	45	74,4	99	102,3
Water supply system	1,1	53,17043	48,453694	53,170425	51,45525	53,17043	51,45525	53,17043	53,17043	51,45525	53,17043	51,45525	53,17043
Ventilation system	0,5	32,55	29,6625	32,55	31,5	32,55	31,5	32,55	32,55	31,5	32,55	31,5	32,55
Socket network	2	15,5	14,125	15,5	15	15,5	15	15,5	15,5	15	15,5	15	15,5
Total	20,878	761,9544	691,53669	742,92043	700,95525	674,2864	652,5353	674,2864	674,2864	673,9553	724,3204	731,37525	755,7544

Appendix 7 – Wind generator “Condor Air” 10 kW [21]

Wind wheel diameter	7,5 m
Blade height	3,5 m
Nominal RPM	35-40
Output voltage	170-240 V
Nominal power	10 kW
Maximum power	11,2 kW
Starting wind speed	2,5 m/sec
Nominal wind speed	9 m/sec
Operational wind speed	3 - 20 m/sec
Hurricane protection	Automatic
Automatic wind orientation	Yes
Tower height	20 m
Weight without tower	1730 kg
Blades quantity	3
Wind energy utilization	>0,42
Generator type	Three phase permanent-magnet generator
Generator frequency	0 - 50 Hz
Output current	Alternating
Nominal current	50 A
Maximum current	60 A
Inverter type	Optional
Recommended Battery Quantity	20/40
Recommended Battery Capacity	150/200 A*hour
Conversion system efficiency	>0,85
Noise level	45 dB
Wind speed limit	35 m/sec
Basic equipment	
Tower	1 unit
Generator	1 unit
Rotor	1 unit
Blades	Set
Fasteners	Set
Controller	1 unit
Technical certificate	1 unit
Cost	770 000 RUB
Lifetime	20 years

Appendix 8 – Solar module “Exmork FSM-300M” technical specification [22]

Electrical parameters	
Maximum power, W	300
On-load voltage, V	36
Off-load voltage, V	43,15
On-load current, V	8,33
Short circuit current, A	9,14
Maximum off-load voltage of PV array, V	1000
Efficiency, %	17,4
Operational parameters	
Sizes (LxWxH), mm	1956x992x45
Weight, kg	23
Quantity of elements	72 (12x6)
Solar cells	Grade A, monocrystal
Cell size, mm	156x156
Type of cable connectors	MC4
Shell protection	Anodized aluminum frame, tempered anti-reflective glass
Operating and storage temperature, ° C	-40 +80 ℃
Protection level	IP 65
Cost	21 385 RUB
Lifetime	20 years

Appendix 9 – Gasoline generator “EUROPOWER EP20000TE” technical specification [23]

Generator	
kVA max.	20
kVA cont.	18
kVA @ 1~230V	6
kVA @ 3~400V	18
kW max.	16
Amps cont. @ 1~230V	26A
Amps cont. @ 3~400V	26A
Dimensions l x w x h	100 x 64 x 72cm
Weight incl. oil (+ coolant if water-cooled), excl. fuel	213kg
Weight incl. oil (+ coolant if water-cooled) + fuel	244kg
Engine	
Brand/Type	B&S Vanguard 543477 1142 J1-14051512
HP max.	28
kW max.	21
rpm	3000
Cylinder	2
Fuel	Gasoline
EU Emission norm	Stage V
Cooling	Air-cooled
Displacement	895cm3
Consumption @75% load	7 litres/hour
Tank	41 litres
Autonomy @75% load	5.9 hours
Noise level	79 dB(A)@7m
Alternator	
Brand/Type	Sincro GT2MAS ˜ with brushes
Nominal voltage	3~400V and 1~230V
Frequency	50Hz
Protection degree	IP23
Lifetime	20 years

Appendix 10 – Inverter “**GoodWe DT series 25 kW” technical specification [24]**

Input Data(DC)	
Max. DC Power	32.5 kW
Max. DC Voltage	1000 V
Nominal DC Voltage	620 V
Min. DC Voltage to Start Feed In	250 V
Max. DC Current	27 A
MPP(T) Voltage Range	260~850 V
No of MPP Trackers	2
DC Inputs	6
Output Data (AC)	
Max. AC Power	25 kW
Nominal AC Power	25 kW
Nominal AC Voltage	400 V
Max. AC Current	37 A
Frequency	50, 60 Hz
Power Factor (cosθ)	1
Distortion (THD)	< 1.5 %
No of feed-in phases	3
Max. Efficiency	98.40%
Euro Efficiency	98.10%
General Data	
Dimensions (H/W/D)	650x516x203 mm
Weight	40 kg
Power Consumption at Night	< 1 W
Noise Level	< 45 dB(A)
Operating Temperature	-25 ~ +60 ℃
Transformer	Transformerless
Humidity	0-100 %
Cooling	Fan
Max. Altitude	4000 m
Interface	RS 485, WLAN
Display	LCD, LED
Protection Features	
Protection Features	Anti Island Protection(ENS), Overvoltage Protection, Overcurrent Protection, Residual Current Device (RCD), Reverse Polarity Protection
Lifetime	20 years

Appendix 11 – NPV Calculations for Scenarios 1 – 4

Scenario 1																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Wind generator	770000																					
PV Cells	427700																					
Inverter	300000																					
Batteries	943820										1150511,313											
Delivery	40000																					
Other	250000																					
Maintenance		80000	85351,2	91060,34177	97151,36803	103649,823	110582,9597	117979,8539	125871,5263	134291,0727	143273,8025	152857,3872	163082,0178	173990,574	185628,8035	198045,5142	211292,7786	225426,1526	240504,9079	256592,2812	273755,7389	
CF	-2731520	-80000	-85351,2	-91060,34177	-97151,368	-103649,823	-110582,96	-117979,8539	-125871,5263	-134291,0727	-1293785,116	-152857,3872	-163082,0178	-173990,574	-185628,8035	-198045,5142	-211292,7786	-225426,1526	-240504,9079	-256592,2812	-273755,739	NPV
DCF	-2731520	-74074,0741	-73174,89712	-72286,63517	-71409,1557	-70542,32793	-69686,0225	-68840,11157	-68004,4691	-67178,97041	-599272,8407	-65557,91329	-64762,11307	-63975,97297	-63199,37574	-62432,20554	-61674,34794	-60925,68988	-60186,1197	-59455,52708	-58733,803	-4586892,573

Scenario 2																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Loan payment		343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	343 012,36 ₽	
Maintenance		80000	85351,2	91060,34177	97151,36803	103649,823	110582,9597	117979,8539	125871,5263	134291,0727	143273,8025	152857,3872	163082,0178	173990,574	185628,8035	198045,5142	211292,7786	225426,1526	240504,9079	256592,2812	273755,7389	
Batteries											1150511,313											
CF		-423012,364	-428363,5636	-434072,7054	-440163,732	-446662,1867	-453595,323	-460992,2175	-468883,8899	-477303,4363	-1636797,48	-495869,7508	-506094,3815	-517002,9376	-528641,1671	-541057,8778	-554305,1422	-568438,5162	-583517,2716	-599604,6448	-616768,103	NPV
DCF		-391678,114	-367252,7123	-344580,9085	-323533,483	-303990,779	-285841,996	-268984,5312	-253323,3762	-238770,551	-758153,9339	-212670,0366	-200977,0421	-190100,9072	-179981,7223	-170564,0079	-161796,3871	-153631,2817	-146024,6307	-138935,6298	-132326,491	-5223118,521

Scenario 3																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Wind gen	770000																					
Gasoline g	599990																					
Inverter	300000																					
Batteries	943820										1150511											
Delivery	40000																					
Other	250000																					
Maintenance		80000	85351,2	91060,34	97151,37	103649,8	110583	117979,9	125871,5	134291,1	143273,8	152857,4	163082	173990,6	185628,8	198045,5	211292,8	225426,2	240504,9	256592,3	273755,7	
Fuel		3816	4197,6	4617,36	5079,096	5587,006	6145,706	6760,277	7436,304	8179,935	8997,928	9897,721	10887,49	11976,24	13173,87	14491,25	15940,38	17534,42	19287,86	21216,64	23338,31	
CF	-2903810	-83816	-89548,8	-95677,7	-102230	-109237	-116729	-124740	-133308	-142471	-1302783	-162755	-173970	-185967	-198803	-212537	-227233	-242961	-259793	-277809	-297094	NPV
DCF	-2903810	-77607,4074	-76773,7	-75952	-75142,4	-74344,8	-73558,9	-72784,7	-72022,1	-71271	-603441	-69802,9	-69085,7	-68379,6	-67684,6	-67000,5	-66327,2	-65664,7	-65012,9	-64371,7	-63741	-4843778,151

Scenario 4																						
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Loan payment		364 647,79 ₽	364647,8	364647,8	364647,8	364647,8	364647,8	364647,8	364647,8	364647,8	364647,8	364647,8	364647,8	364647,8	364647,8	364647,8	364647,8	364647,8	364647,8	364647,8	364647,8	
Maintenance		80000	85351,2	91060,34	97151,37	103649,8	110583	117979,9	125871,5	134291,1	143273,8	152857,4	163082	173990,6	185628,8	198045,5	211292,8	225426,2	240504,9	256592,3	273755,7	
Fuel		3816	4197,6	4617,36	5079,096	5587,006	6145,706	6760,277	7436,304	8179,935	8997,928	9897,721	10887,49	11976,24	13173,87	14491,25	15940,38	17534,42	19287,86	21216,64	23338,31	
Batteries											1150511											
CF		-448463,79	-454197	-460325	-466878	-473885	-481376	-489388	-497956	-507119	-1667431	-527403	-538617	-550615	-563450	-577185	-591881	-607608	-624441	-642457	-661742	NPV
DCF		-415244,25	-389400	-365421	-343169	-322518	-303349	-285553	-269030	-253686	-772343	-226194	-213892	-202460	-191833	-181953	-172764	-164218	-156266	-148865	-141976	-5520133,907

Appendix 12 – NPV Calculations for Scenarios 5 – 8

Scenario 5

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Gasoline g	599990																					
PV Cells	427700																					
Inverter	300000																					
Batteries	943820										1150511											
Delivery	40000																					
Other	250000																					
Maintenance		80000	85351,2	91060,34	97151,37	103649,8	110583	117979,9	125871,5	134291,1	143273,8	152857,4	163082	173990,6	185628,8	198045,5	211292,8	225426,2	240504,9	256592,3	273755,739	
Fuel		62540	68794	75673,4	83240,74	91564,81	100721,3	110793,4	121872,8	134060	147466	162212,7	178433,9	196277,3	215905	237495,5	261245,1	287369,6	316106,6	347717,2	382488,952	
CF	-2561510	-142540	-154145	-166734	-180392	-195215	-211304	-228773	-247744	-268351	-1441251	-315070	-341516	-370268	-401534	-435541	-472538	-512796	-556611	-604310	-656244,691	NPV
DCF	-2561510	-131981,481	-132155	-132359	-132594	-132860	-133158	-133487	-133849	-134242	-667578	-135128	-135621	-136147	-136707	-137301	-137929	-138593	-139291	-140026	-140796,122	-5803310,114

Scenario 6

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Loan payment		321663,2496	321663,2	321663,2	321663,2	321663,2	321663,2	321663,2	321663,2	321663,2	321663,2	321663,2	321663,2	321663,2	321663,2	321663,2	321663,2	321663,2	321663,2	321663,2	321663,25	
Maintenance		80000	85351,2	91060,34	97151,37	103649,8	110583	117979,9	125871,5	134291,1	143273,8	152857,4	163082	173990,6	185628,8	198045,5	211292,8	225426,2	240504,9	256592,3	273755,739	
Fuel		62540	68794	75673,4	83240,74	91564,81	100721,3	110793,4	121872,8	134060	147466	162212,7	178433,9	196277,3	215905	237495,5	261245,1	287369,6	316106,6	347717,2	382488,952	
Batteries											1150511											
CF		-464203,25	-475808	-488397	-502055	-516878	-532968	-550437	-569408	-590014	-1762914	-636733	-663179	-691931	-723197	-757204	-794201	-834459	-878275	-925973	-977907,94	NPV
DCF		-429817,824	-407929	-387705	-369026	-351778	-335860	-321174	-307633	-295154	-816570	-273084	-263358	-254422	-246220	-238702	-231820	-225528	-219787	-214559	-209808,396	-6399937,314

Scenario 7

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Gasoline g	599990																					
Inverter	300000																					
Batteries	943820										1150511,3											
Delivery	40000																					
Other	250000																					
Maintenance		80000	85351,2	91060,34177	97151,37	103649,8	110583	117979,9	125871,5	134291,1	143273,8	152857,4	163082	173990,6	185628,8	198045,5	211292,8	225426,2	240504,9	256592,3	273755,7	
Fuel		209456	230401,6	253441,76	278785,9	306664,5	337331	371064,1	408170,5	448987,5	493886,29	543274,9	597602,4	657362,7	723098,9	795408,8	874949,7	962444,7	1058689	1164558	1281014	
CF	-2133810	-289456	-315752,8	-344502,1018	-375937	-410314	-447914	-489044	-534042	-583279	-1787671	-696132	-760684	-831353	-908728	-993454	-1086242	-1187871	-1299194	-1421150	-1554770	NPV
DCF	-2133810	-268014,815	-270707,133	-273476,8755	-276325	-279253	-282262	-285352	-288526	-291785	-828037,8	-298559	-302078	-305687	-309386	-313178	-317064	-321045	-325122	-329298	-333573	-8632539,897

Scenario 8

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Loan payment		267954,5497	267954,5497	267954,5497	267954,5	267954,5	267954,5	267954,5	267954,5	267954,5	267954,55	267954,5	267954,5	267954,5	267954,5	267954,5	267954,5	267954,5	267954,5	267954,5	267954,5	
Maintenance		80000	85351,2	91060,34177	97151,37	103649,8	110583	117979,9	125871,5	134291,1	143273,8	152857,4	163082	173990,6	185628,8	198045,5	211292,8	225426,2	240504,9	256592,3	273755,7	
Fuel		209456	230401,6	253441,76	278785,9	306664,5	337331	371064,1	408170,5	448987,5	493886,29	543274,9	597602,4	657362,7	723098,9	795408,8	874949,7	962444,7	1058689	1164558	1281014	
Batteries											1150511,3											
CF		-557410,55	-583707,35	-612456,6515	-643892	-678269	-715868	-756998	-801997	-851233	-2055626	-964087	-1028639	-1099308	-1176682	-1261409	-1354197	-1455825	-1567149	-1689105	-1822724	NPV
DCF		-516120,879	-500434,971	-486187,8362	-473280	-461618	-451119	-441701	-433294	-425829	-952152,6	-413480	-408487	-404213	-400614	-397649	-395277	-393464	-392177	-391386	-391062	-9129547,165