CZECH TECHNICAL UNIVERSITY IN PRAGUE
Faculty of Electrical Engineering
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Assessment of effectiveness the use of solar panels

Master thesis

Study program: Electric Power Generation and Transportation
Field of study: Economics and management of power engineering

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Prague 2016

České vysoké učení technické v Praze
Fakulta elektrotechnická

Katedra ekonomiky, manažerství a humanitních věd

ZADÁNÍ DIPLOMOVÉ PRÁCE

Student: Bulgakov Aleksandr

Studijní program: Elektrotechnika, energetika a management
Obor: Ekonomika a řízení energetiky

Název tématu: Assessment of effectiveness the use of solar panels

Pokyny pro vypracování:

- Review of the solar energy market in Russia
- Method used for economic evaluation.
- Preparation of methodology for calculation of PV installation effectiveness
- Implementation of proposed methodology for given location

Seznam odborné literatury:

Power System Economics-Designing Markets for Electricity - S. Stoft - Wiley
Handbook on Energy Economics - J. Evans, L. Hunt - Edward Edgar

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Platnost zadání: do konce letního semestru akademického roku 2016/2017

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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

This paper presents a model for the economic evaluation of electrical energy production from photovoltaic systems. The economic evaluation model takes into account all the operational incomes as well as all the expenses for the implementation, operation and maintenance of the photovoltaic system. The model uses financial criteria and is applied for the economic evaluation of an off-grid photovoltaic station located in decentralized area of the settlement Stepanovka.

KEYWORDS

Photovoltaic plants, decentralized power supply, electricity production, cash flows, net present value, sensitivity analysis

CONTENTS

ABBREVIATIONS

AC – Alternative current

DC – Direct current

PV – Photovoltaic

SPVP – Solar photovoltaic plants

RE – Renewable energy

CAPM – Capital asset pricing model

WACC – Weight average cost of capital

NPV – Net present value

CF – Cash flow

EAT – Earning after tax

EBT – Earning before tax

INTRODUCTION

Solar energy is abundantly available and environmentally clean. Today the solar technologies use the sun to provide heat, electricity, light, etc. for domestic household consumers and manufacturers. Future resources such as natural gas, coal and petroleum are being depleted, and combined with the environmental harmful process of using these energy sources, it has become a necessity to invest in renewable energy resources which in the future would lead to obtaining energy without degrading the environment. The energy potential of the sun is huge, but receiving solar energy is a problem now because of the limited efficiency of the array cells. Most solar panels are around 10-15% efficient. Currently the best-achieved sunlight conversion rate is around 21.5 % [1] and it shows that there is still enormous room for improvement.

In addition, solar power system play a crucial role in regions without central power supply (Decentralized energy supply). Decentralized energy supply is one of the most important problems of modern power engineering. More than 65% [2] of the territory of Russia fall into the category of decentralized energy supply – that is a consumer supply of electricity from a source unconnected to a power system. Power supplementation of such regions would help in at least two ways: formation of quality of life of the population and also creation of suitable conditions for business, as the question of ensuring access and quality is very important. One of the solutions to this problem is the supply by a solar power system. [2]

This work is devoted to research in the area of optimal design of a solar power system. The goal of the thesis is the assessment of efficiency of the use of solar panels by domestic household consumer.

For achieving this goal it was required to solve the following problems:

- The problem of decentralized electricity supplies and possible ways to solve it;
- Governmental or regional support for renewable sector of energy;
- To develop methods for assessment of effectiveness of the use of solar panels and choosing equipment for solar power systems;
- Implementation of proposed methods for given location.

1. Review of the solar energy market in Russia.

1.1 Technical information about PV technology.

A PV system consists of one or more PV modules. One PV-module consists of about 36-72 photovoltaic solar cells.

A solar cell is a solid-state electrical device (p-n junction) that converts the energy of light directly into electricity (DC) using the photovoltaic effect. The process of conversion first requires a material that absorbs the solar energy (photon), and then raises an electron to a higher energy state, and then the flow of this high-energy electron to an external circuit. [1]

A p-n junction: It is formed by joining p-type (high concentration of hole or deficiency of electron) and n-type (high concentration of electron) semiconductor material. Due to this joining, excess electrons from n-type try to diffuse with the holes of p-type whereas excess hole from p-type try to diffuse with the electrons of n-type. Movement of electrons to the p-type side exposes positive ion cores in the n-type side, while movement of holes to the n-type side exposes negative ion cores in the p-type side, resulting in an electron field at the junction and forming the depletion region. [3]

The are three basic types of construction of PV panels:

Monocrystalline silicon PV panels:

These are made using cells sliced from a single cylindrical crystal of silicon. This is the most efficient photovoltaic technology, typically converting around 15% of the sun's energy into electricity. The manufacturing process required to produce monocrystalline silicon is complicated, resulting in slightly higher costs than other technologies.[3]

Polycrystalline silicon PV panels:

Also known as multicrystalline cells, polycrystalline silicon cells are made from cells cut from an ingot of melted and recrystallized silicon. The ingots are then saw-cut into very thin wafers and assembled into complete cells. They are generally cheaper to produce than monocrystalline cells, due to the simpler manufacturing process, but they tend to be slightly less efficient, with average efficiencies of around 12%.[3]

Amorphous silicon PV panels:

Amorphous silicon cells are made by depositing silicon in a thin homogenous layer onto a substrate rather than creating a rigid crystal structure. As amorphous silicon absorbs light more effectively than crystalline silicon, the cells can be thinner - hence its alternative name of 'thin film' PV. Amorphous silicon can be deposited on a wide range of substrates, both rigid and flexible, which makes it ideal for curved surfaces or bonding directly onto roofing materials. This technology is, however, less efficient than crystalline silicon, with typical efficiencies of around 6%, but it tends to be easier and cheaper to produce.[3]

Other thin film PV panels:

A number of other materials such as cadmium telluride (CdTe) and copper indium diselenide are now being used for PV modules. The attraction of these technologies is that they can be manufactured by relatively inexpensive industrial processes, certainly in comparison to crystalline silicon technologies, yet they typically offer higher module efficiencies than amorphous silicon. Most offer a slightly lower efficiency: copper indium diselenide is typically 10-13% efficient and CdTe around 8 or 9%. A disadvantage is the use of highly toxic metals such as Cadmium and the need for both carefully controlled manufacturing and end-of-life disposal.[3]

1.2 Current status of solar power system in Russia:

The major source of energy in Russia is the thermal power station they produce 68% of the total installed electricity of the total energy mix, where gas contributes to this figure approximately by two thirds and the rest for coal, the hydro power plant produce 21% and nuclear power plant produce 11% energy. The renewable energy sources such as solar or wind power account for less than 1% of the total electricity production. The diagram are present in the Figure 1

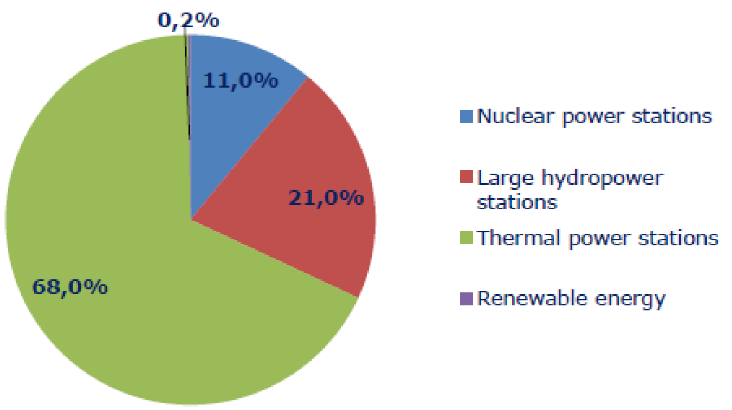

Figure 1 – Structure of the installed power generating capacity. [4]

This structure various for different zones of Russia, such as Far East, Siberia and European part. In each of these areas, use the different energy resources. As show in Figure 2, in the European part of the Russia prevails gas while in the rest of Russia coal is the main fuel for power generation.

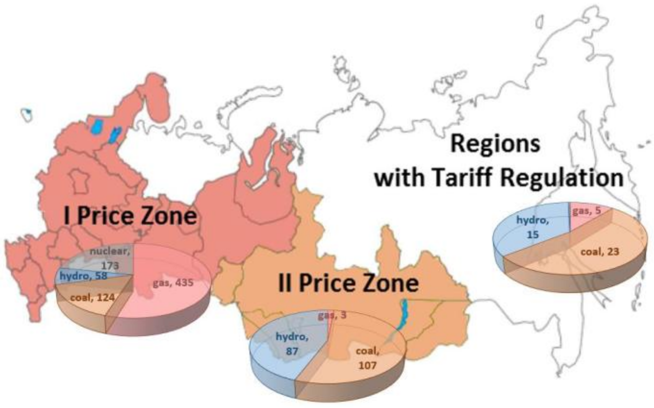

Figure 2 – Power production on Russia by zone. [4]

Whereby, the territory of Russia is divided into two price zones. In the first zone, the price of electricity depends on the change in gas prices, and the second zone where coal price determines electricity prices. Equilibrium pricing is realized in the power market within these two zones. In the rest of Russia electricity tariffs are regulated.

The whole power market consists of the wholesale market (95% of electricity production in the country) and retail markets. Participation in the wholesale market is obligatory for generators with installed capacity more than 25 MW. Power plants with capacity between 5 and 25 MW may choose whether participate in wholesale or retail market. Industrial electricity consumers and utility providers are other participants of the wholesale market. Retail markets are established to bring electricity traded in the wholesale market to end-users. Retail markets participants are consumers, utility providers, power providers, small generators, and distribution companies.[4]

On the territory of Russia a number of geographical zones and climatic regions, offers an abundance of renewable energy sources. Solar energy in Russia is not particularly in demand, despite its huge potential. Currently share of solar energy in the total energy system of Russia is only 0,001%. [5] The Department of energy of Russia agreed to 2020 to increase it to 0,9%. According to preliminary forecasts of the major regions that will host the alternative energy sources should be the southern regions of Russia as well as in the region not connected to the centralized power grid. Table 1 below outlines the projected annual installation by renewable energy technology.

Table –1 Annual objectives for renewable power generation capacity installation.

Type of facility	2015	2016	2017	2018	2019	2020	Total
Wind power, MW	200	600	700	1000	1500	2000	6150
PV, MW	170	220	250	290	460	510	2000
Biomass, MW	50	50	80	100	120	160	580
Biogas, MW	15	25	40	60	80	100	330
Total, MV	675	1178	1333	1744	2558	3198	11031

1.3 Perspectives and problems of development Solar Power System

Solar energy is one of the promising directions of renewable energy. To convert it into useful energy the fuel is free and will never be subject to the ups and downs of energy markets. There are three main directions the use of solar energy: direct conversion of solar energy into electricity, the conversion of solar energy in the heat and the conversion of the solar energy into electrical energy on thermodynamic cycle (solar thermodynamic station).[6]

The photovoltaic energetics will be development, both worldwide and in Russia, largely due to the following qualities:

- The photovoltaics is a clean energy source.
- Raw material base photovoltaic energetics (silicon) is practically inexhaustible, the content of silicon in the earth’s crust exceeds the reserves of uranium per 100 thousand time.
- Photovoltaic cells are of a particularly high operational quality: lifetime (20-30 years)
- Photovoltaic energetics is independent of the constant increase in prices of electricity.

In Russia, there are a huge number of areas suitable for solar power plants, mostly located on the south and southeast of the country. The promising areas of use of our solar potential and other renewable energy sources shown in Figure 3.

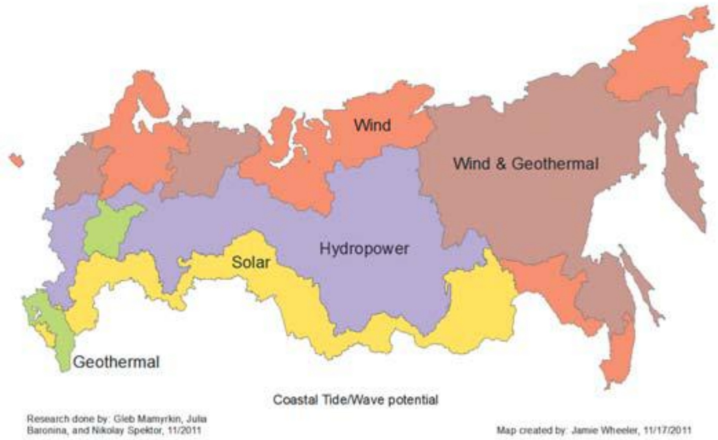

Figure 3 – The potential of renewable energy sources in Russia. [7]

Solar panel can be used in the following areas:

- in industry (aircraft industry, automobile construction, etc.),
- in agriculture,
- in households,
- at solar power plants,
- in autonomous lighting systems,
- in space industry.

Today Russia possesses advanced technologies of transforming solar energy into electricity. There are several companies that have developed and are improving technologies of photovoltaic converters how to silicon-based and with multiple-junction structure. There is a number of developments for the use of concentrating systems for solar power plants.[6]

Development of solar energy in Russia is due to several factors:

1) Climatic conditions: this factor influences the selection of a solar plant technology that is most suitable for a certain region. [8]

2) State support: legal economic incentives of solar energy exerts a decisive influence on its development. The following types of state support are applied with success in some European countries: reduced tariff for solar power plants, subsidies for construction of solar power plants, different tax benefits, reimbursement of a part of expenses related to credits for the purchase of solar power plants. [8]

3) Costs of SPVP: today solar power plants are the most expensive technologies of producing electric energy. However, solar energy becomes commercially viable, as the cost of 1 kWh of generated electric energy decreases. The demand for SPVP depends on the reduction of the cost of 1W of installed capacity of SPVP. The cost reduction is due to the increase of efficiency factor, the reduction of technological expenses and the reduction of the production cost-efficiency (the influence of competition). [8]

4) Environmental standards: the solar energy market can be positively influenced by strict environmental standards (restrictions and fines). [8]

5) Problems of technological connection: delays of implementation of requests of technological connection to the centralized system of electricity supply are an incentive to transfer to alternative energy sources, including SPVP. These delays are because of the lack of capacities and the ineffective type of technological connection by network companies or the lack of financing of technological connection from the tariff. [8]

6) Initiatives of local authorities: regional and municipal authorities can implement their own programs of solar energy development or, more widely, renewable/non-conventional energy sources. [8]

7) Development of domestic production: the Russian production of SPVP can exert a positive influence on the development of the Russian consumption of solar energy. Firstly, domestic production increases the knowledge of the population of solar technologies and their popularity. Secondly, the cost of SPVP for end consumers is reduced, since there is less intermediate links in the distributor chain and the transport component is smaller. [8]

1.4 Describe of the problem the consumer without central power supply.

Due to the constant growth of world's population, the problem of electrification will always exist. Today over 1.6 billion people have no access to electricity and more than 2 billion people rely on wood and dung for fuel consumption. Access to electricity constitutes the basis for a minimum standard of living. It is fundamental to social economic development and improve their quality of life. Due to the remoteness of most villages, the majority of settlements does not connected to the central power grid. The lack of economic opportunities leads to large scale migration. [9]

In the area of decentralized energy supply Russia currently has a population of about 10 million people. The areas of decentralized electricity supply are located in the far East, Siberia, Altai, Volga and other regions of Russia. In these areas electricity used in housing community, on livestock farms, in homes. Most of energy consumed for domestic needs of the population, for the production of low-grade heat. [2]

More than 50% of the territory of Tomsk region with a population of 30 million people not covered by the central grid. In the territory of such settlements, there are about 80, they are characterized by low population density and weak industrial exploitation of these areas.

The electricity supply in decentralized area is supplied from local diesel power plant, the total number of which is 123 unit, and the total installed capacity is 35-45 MW.[2]

Low technical and economic indicators of the majority of diesel power station, high diesel prices and high transport tariffs result in high cost of production of electricity by diesel power plant. Fuel component in the tariff of electricity by diesel power plants more than 7 times higher than the cost of 1 kWh of electricity from power plant.

The high cost of electricity from diesel power plants entails lower specific power consumption in decentralized area. If in areas to central grid figure is 4400 kWh per person per year in decentralized areas 1900 kWh. [11]

The aging of equipment of diesel power plants and rising fuel prices exacerbate the situation, which can cause a further decline in production and lower quality of power supply to consumers. Mass non-payments for poor quality power supply and increase of subsidies from the regional budgets of Tomsk region on compensation of expenses on the organization of power supply from diesel power plant.

All this determines the need to finding ways to reduce the cost of the electrical energy in remote settlements of Tomsk region, with the simultaneous upgrading of equipment the power-generating sources. [11]

The objects of decentralized power supply are a large variety in terms of installed capacity, the power modes, requirements for quality of power, etc., therefore it is rather difficult to classify. The most common decentralized power system received to provide electrical energy the following groups of consumers: [10]

- Individual consumers small capacity from one to tens kW, such as: cottage, weather stations, cell towers, farms, etc.
- Group non-industrial consumers with installed capacity from ten to hundreds kW, such as: large residential buildings and neighborhood, the various areas of the social sphere, village, settlements, etc.
- Industrial enterprises with an installed capacity of hundreds to thousand kW, mainly the enterprises of the oil and gas industry.

A characteristic feature of decentralized consumer is abruptly variable electrical load curve during the day and the year. As an example, Fig. 4 show the daily load curve the consumption of small autonomous location as Fig. 5 annual load curve. [10]

To secure a stable energy supply in such conditions necessary a simple, reliable, cost-effective power source that has an opportunity for a wide range of installed capacity.

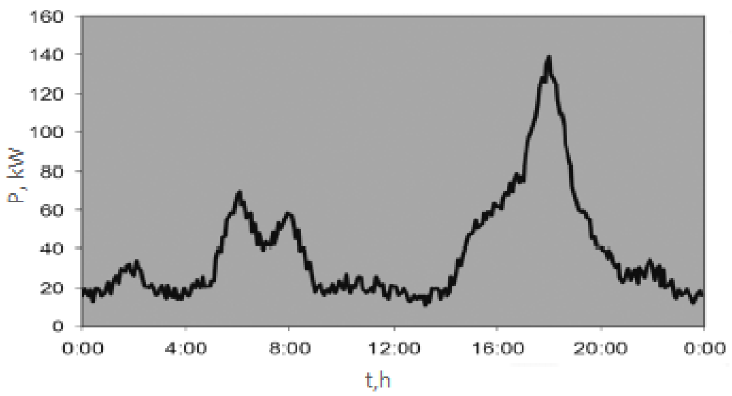

Figure 4 – Daily load curve. [10]

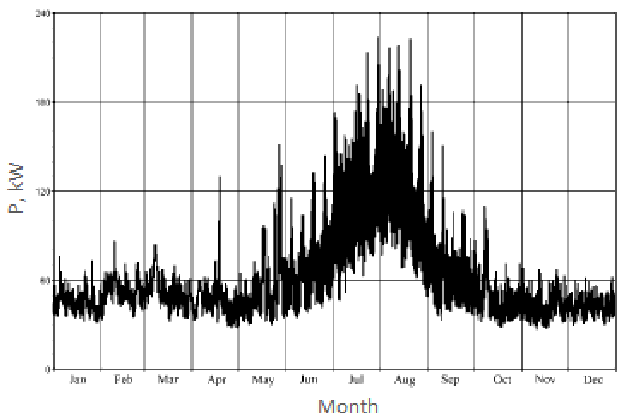

Figure 5 – Annual load curve. [10]

1.5 Governmental or regional support

The energy sector is one of the main elements of the Russian economy. At all times it is energy development was given paramount importance. This approach has allowed industry to operate with minimal financial losses. It should be noted that any economic industry cannot simply stand still, to improve results and further work requires a constant inflow of capital. Therefore, investment in the energy sector of Russia are today a necessity. [12]

Just like other sectors of the economy, the renewable energy sector faces major barriers to investment, including lack of transparency; competition from subsidized conventional energy sources; and a weak financial industry. The lack of a specific national RE strategy, of adequate legislation and regulatory framework further constrains the development of renewable energy markets. Improving the overall investment climate, by continuing the economic, financial, legal, regulatory and fiscal reforms, is therefore vital. It is also important to maintain and extend the reforms to the energy sector and to eliminate subsidies for conventional energy sources. [13]

In addition to broad economic reforms, Russian policy makers could also introduce specific measures to enhance the development of renewable energy. This will not necessarily require substantial financial support because there are practical low-cost and often competitive measures that would stimulate investment in renewable energy technologies and could lead to considerable economic returns. In the short term, Russian policy makers could concentrate on measures that would enhance the use of RE systems that already have competitive advantages in specific applications. As Russian businesses become experienced with installation and maintenance on a large scale, new markets for these technologies will open up, creating even more competitive opportunities. [13]

Each renewable energy technology will require specific measures to facilitate its market deployment, but a number of general actions are suggested here that could enable the development of a market for RE technologies.

The typical pattern that countries have followed to develop a renewable energy market is to implement a strategy in three main steps: adopt a renewable energy strategy (identify goals); adopt relevant laws (set up the market structure); and specify implementation mechanisms (establish market rules). It is possible, however, to introduce some actions of each next step before the full implementation of the preceding one. [13]

Russia has made the first important steps toward the recognition of the importance of renewable energy sources. The Federal program “Energy Efficient Economy in 2002-2005 and up to 2010” adopted in November 2001 contains a section “Effective Energy Supply of Regions, including Northern Territories, on the basis of Non-traditional Renewable Energy Sources and Local Fuels”. The national energy strategy, adopted by the Russian government in May 2003, states the strategic goals of the development of renewable energy and local fuels (wood and peat) are to: [13]

- reduce use of non-renewable energy sources

- reduce negative environmental impact of the energy sector
- stabilize energy supply in decentralized and isolated regions
- reduce the expense of fuel transported over long distances

National goals can be quantified in the form of Renewable Energy Targets that set a minimum percentage of energy or electricity supply in a given country (or region) from renewables. For example, the European Union's Renewable Energy Directive16 sets the target to achieve 22.1% of electricity produced from renewable energy and 12% of renewables in gross national energy consumption by 2010. The Russian energy strategy does not articulate official targets for renewable energy development, but it states that it is possible to put into operation 1000 MW of power generation capacity and 1200 MW of heat capacity based on renewables by 2010, if the necessary government support is ensured. It is not precise, however, about how the government will support renewables. Building on experience in other countries, Russia could also establish national renewable energy targets and outline a strategy (or an action plan) to achieve these targets. Conversely, Russia could eschew a national target and focus on setting real energy prices and then establishing a set of incentives and other market mechanisms to encourage renewables' contribution to the goals. [13]

The new Russian energy strategy underlines the necessity of adopting a federal law on renewables. Indeed, a national renewable energy law would translate a national strategy into a structure of roles and authorities. The next step in the RE strategy implementation would be bringing into practice the national strategy on the territorial, regional and local levels. This will require adequate regulatory and institutional rules authorized under the national renewable energy policy. Regulations and provisions can either enforce the mechanisms outlined in the national law, or introduce specific regional/local initiatives in accordance with the national strategy.[13]

National policies as well as regulations can be of a different nature depending on their purpose: to create a legal and institutional framework for renewable energy project implementation, to help the RE industry, or to stimulate or assist consumers of RE systems. Some regional and local activities can be aimed at direct support of concrete renewable energy projects. This report suggests, based on international experience, a number of policies and measures that could contribute toward building a market for renewable energy technologies: e.g. renewable energy portfolio standards, broad information dissemination, fiscal incentives (reduced VAT, accelerated depreciation, investment tax credits, etc.), direct project support and others. [13]

2. Techno-economic evaluation method

2.1 General information

A techno-economic model is developed. The model consists of two main components, one with technical information and energy balance data and one with information concerning the economic parameters. In this paper, a model is proposed in order to evaluate if the investments in PV plants are profitable or not. The methodology offers the possibility for the evaluation of all types of PV plants, more analytically, this methodology deals with three main types of PV systems:

- Off-grid PV systems.
- Grid connected PV systems.
- Concentrated PV systems.

In this section, the basic information's for each type of a PV plant are given. Finally, the economic evaluation method is presented.

There are two basic methods for using solar energy to create electricity; concentrated solar power and photovoltaic panels with grid connection and off-grid connection. Concentrated solar power systems (Figure 6) use mirrors and lenses to reflect sunlight onto a small area, where it is converted to heat that powers a steam turbine. This type of solar station is gaining popularity as costs decrease, and applications are very practical for developing countries. The other more popular type of solar energy system is the photovoltaic panel (Figure 7), which has been used for large power plants. The electrical power created by photovoltaic systems had increased tenfold within the last ten years, and photovoltaic panels are now a legitimate option for renewable power generation. The dramatic rise in popularity is due to the increasing efficiency of the photovoltaic cells and decreasing system cost. Photovoltaic panels can be used to create small amounts of power for residences and small business buildings, or they can form massive arrays that can provide power to entire towns. Photovoltaic cells use crystalline silicon to convert sunlight to direct current power, which is converted to alternating current power with an inverter. The main variable controlling the amount of electricity a solar energy system can produce is the amount of sunlight that reaches it. This differs depending on the season, geographic location, and weather. Climates closer to the equator and with more sunny days will produce more power and will be more profitable. However, solar energy systems are proving their worth as they increase in popularity throughout the world. [19]

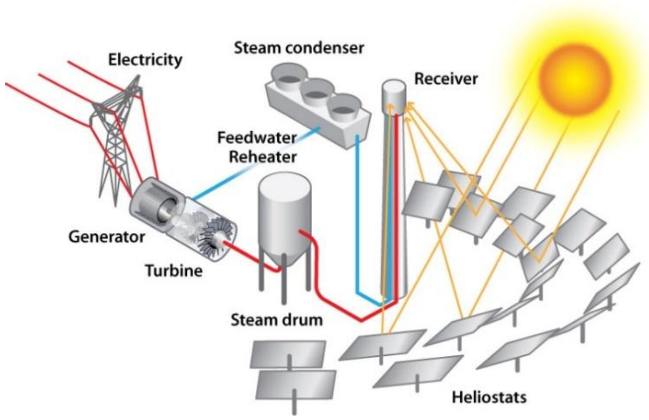

Figure 6 – Concentrated solar power systems. [19]

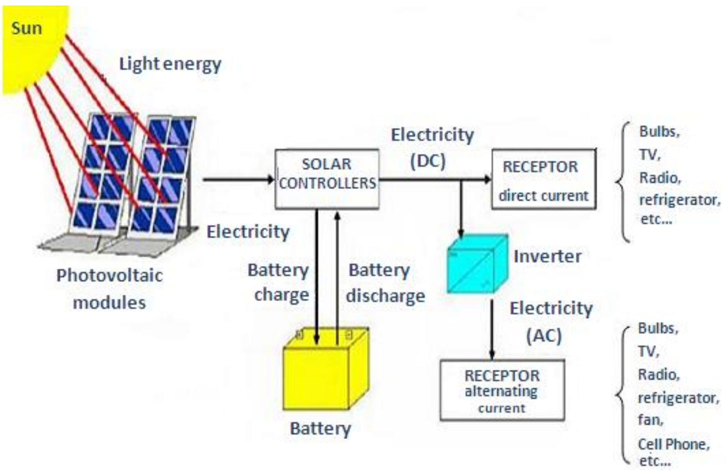

Figure 7 – photovoltaic panel systems. [19]

2.2 Description of the method

This method allows to determine the efficiency of solar panels. As a result of my own work, the following scheme for evaluating the effectiveness was proposed. The main factors of evaluation of the efficiency of power systems can be combined into four main steps as the most influential in the design of these kinds of systems:

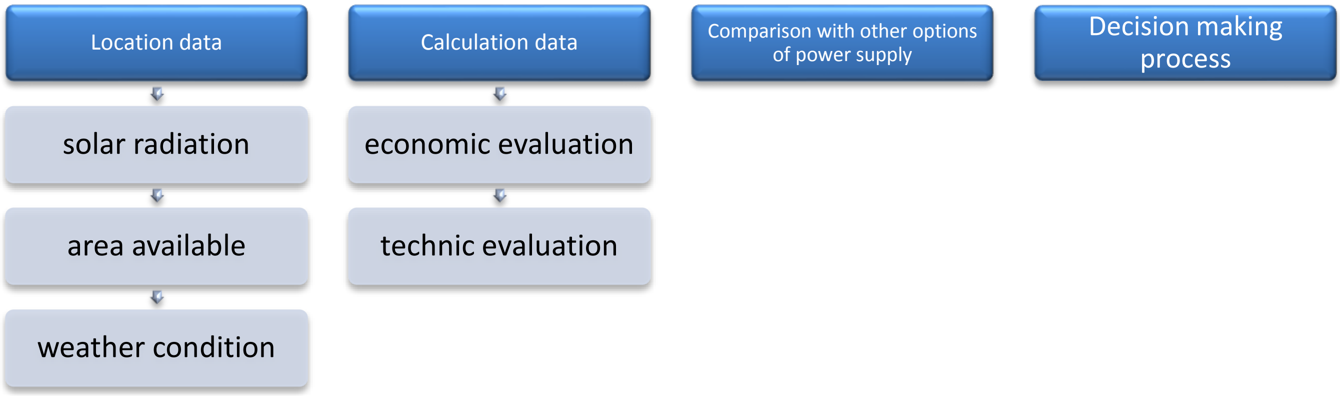

Figure 8 – Method for evaluation the efficiency of power system.

Location data.

Solar insolation is a measure of solar radiation energy received on a given surface area in a given time. It is commonly expressed as average irradiance in watts per square meter (W/m2) or kilowatt-hours per square meter per day (kW·h/(m2·day)) (or hours/day).

Solar energy systems depend on sunlight, therefore solar panels will generate less energy in cloudy and rainy weather, and of course at night solar panel will not work.

In regions where winter daylight hours are greatly reduced and increased cloudiness, the effect of the solar panels will be low, characterized by low power output of solar panels. For example, in the North-West region, in the period from October until the end of January the average daily electricity generation of the solar panels will be five to seven times lower than in the summer month (Figure 6). And in this way low cost solar power plant which successfully copes with the task of supply of houses in the summer in the winter may be almost useless.[23]

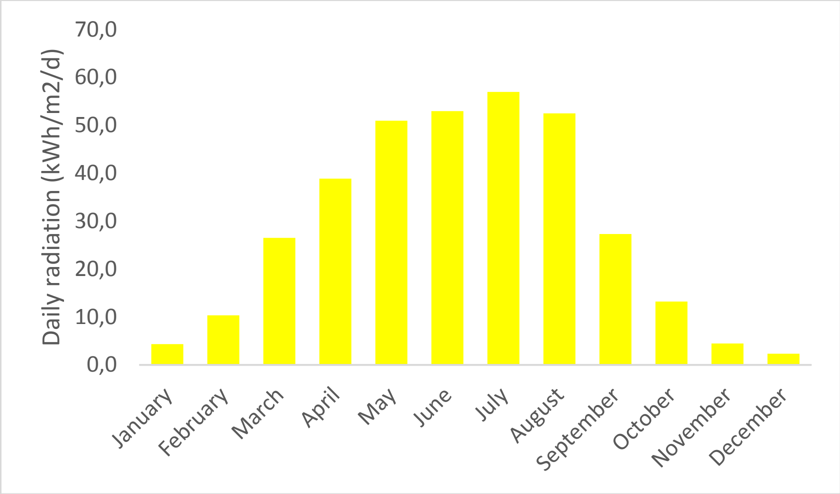

Figure 9 – Summer and winter solar radiation.[18]

Design and configuration.

Several factors should be considered when selecting a site and designing the solar power plant. The quality of the resource is an obvious primary consideration however there are some other significant issues that should be considered when siting power facilities:

- Flood prone areas – Construction of solar plants in areas prone to flooding could result in the damage of PVs and associated infrastructure. In general, construction in flood prone areas should be avoided.[20]
- Extreme weather – Snow has a potential negative impact on the ability to harvest solar energy. In most locations where solar has been installed around the world, the tilt of the solar panels has been adequate to cause normal snowfall to slide off and not accumulate. However, the potential in some of regions for snow to accumulate to a depth of two meters or more means that, at some locations, panels might need to be placed on an elevated rack in order to function during typical snow seasons. There is little comparable data to make recommendations in this regard, but it is a consideration.[20]
- On the positive side, research suggests that PV solar panels are more efficient in cold weather and, therefore, it is possible that solar systems installed in the generally cold regions may actually produce more electricity per unit than similar projects in more temperate zones.[20]
- Air pollution - Air pollution is a common issue in the major cities and industrial areas. A heavy concentration of suspended dust has the potential both to decrease the net solar insolation and to accumulate dust on panels, requiring more frequent cleaning to avoid a loss of efficiency. This may be an important consideration for regions with high air pollution.[20]
- Seismicity, mudflows, and landslides - Construction of solar plants in areas of high seismicity or in areas prone to mudflows and landslides could result in the damage of solar panels and associated infrastructure. In general, construction in high risk areas for these hazards should be avoided.[20]

- Proximity to transmission grid and loading – In general, facilities should be located proximate to existing substations with capacity on the transmission grid. Solar facilities become to become less economical at increasing distances from substations due to the costs associated with extending distribution or transmission lines to the solar plant.[20]

Calculation data.

Under the technical evaluation refers to everything related to the system's performance, all technical efficiency indicators and risks related to the system's operation.

Under the economic evaluation of power system it is understood effective ratio between economical effect (result) and costs influenced this result. The less costs and the higher value of result in production are, the higher economic efficiency is.

In this category of inputs, the parameters regarding the economic data for the evaluation of the PV plant are given. Cost data about the equipment (e.g. cost of PV modules, cost of inverter(s), electrical equipment, etc.) are defined in this category. The costs of the transportation and installation of the PV plant are also defined in this category of inputs.

Financial parameters also include the discount rate (in which the performance of the PV plant will be compared), the debt ratio, the taxation rate and the governmental or other grants. Moreover, the price that the produced energy is sold, the energy escalation rate, the national inflation and the expected lifetime of the PV plant (during which the net annual cash flows are calculated)

There are many factors which can be considered as indicators of economic efficiency. At times minimal investment or production costs has the biggest importance for designer and at other times - maximum revenues obtained from the electricity sale, low payback period or high payability and so on.

However, the most used economic indicators for the power project evaluation are levelized cost of energy or electricity price.

Comparison with other options of power supply.

Comparing the all parameters renewable energy options to traditional power sources is critical for decision-makers, policy experts, investors, and regulators to determine the most efficient and cost-effective way to supply electricity.

The problem is that comparing these costs "apples-to-apples" can be difficult and confusing. That means that businesses, policymakers, and other groups may be choosing an electricity option based on inaccurate or incomplete information.[21]

Decision making process.

Decision making is a daily activity for any human being. There is no question about that. When it comes to business organizations, decision making is a habit and a process as well.

Effective and successful decisions make profit and unsuccessful ones make losses. Therefore, decision making process is the most critical process.

In the decision making process, we choose one course of action from a few possible alternatives. In the process of decision making, we may use many tools, techniques and perceptions.

In addition, we can make our own private decisions or may prefer a collective decision.

Decision making is the thought process of selecting a logical choice from the available options. When trying to make a good decision, we must weight the positives and negatives of each option, and consider all the alternatives. For effective decision making, we should be able to forecast the outcome of each option as well, and based on all these items, determine which option is the best for that particular situation. Although decisions can be made using either intuition or reasoning, a combination of both approaches is often used. Whatever approach is used, it is usually helpful to structure decision making in order to reduce more complicated decisions down to simpler steps, to see how any decisions are arrived at and plan decision making.

3. Implementation of proposed methodology for given location.

Tomsk region is a federal subject of Russia. It lies in the southeastern West Siberian Plain, in the southwest of the Siberian Federal District (Figure 7). Its administrative center is the city of Tomsk. Population: 1 047 453 (in 2015). [14]

Figure 10 – Tomsk region. [16]

Tomsk region is rich in natural resources, such as: particularly oil, natural gas, ferrous and non-ferrous metals, peat, and underground waters. Forests are also among the most significant assets of the region: about 20% of the West Siberian forest resources and located in Tomsk region. Industry makes up about half of the gross regional product, while agriculture contributes 19% and construction 13%. Chemical and oil industries are the most developed in the region, followed by machine construction. The Tomsk region main export items are: oil (62.1%), methanol (30.2%), and machines (4.8%). [15] Map of naturel resources and companies engaged in their production are presented in the Figure 8

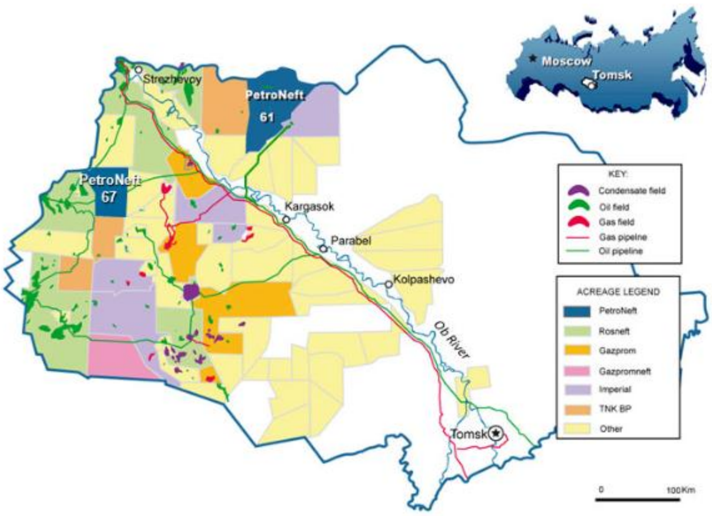

Figure 11 – Map of naturel resources. [17]

The Tomsk region is divided into 16 municipal districts Fig.3. Most of the settlements located in a hard to access area without central power supply. The object of investigation was chosen of Stepanovka settlement, number 4 in Figure 9.

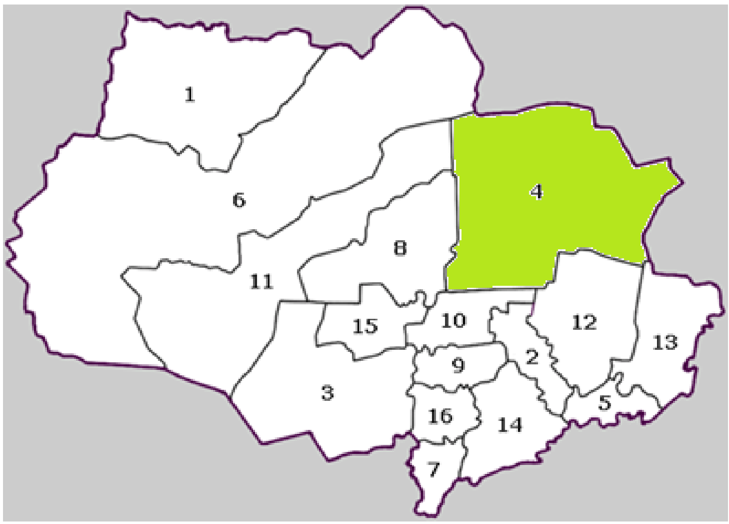

Figure 12 – Regions of Tomsk. [15]

3.1 The object of investigation.

For 2015 the population of Stepanovka was 2163 people. [14] The typical daily load curve and annual load curve of Stepanovka settlement is shown in the Figure 10 and Figure 11. We can observe the fluctuations in the morning and evening. That means we need a reliable and shiftable energy source, which can cover the peak loads and provide reasonable-cost electricity for the base load. The source of energy should comprise technical and economic efficiency and reliability.

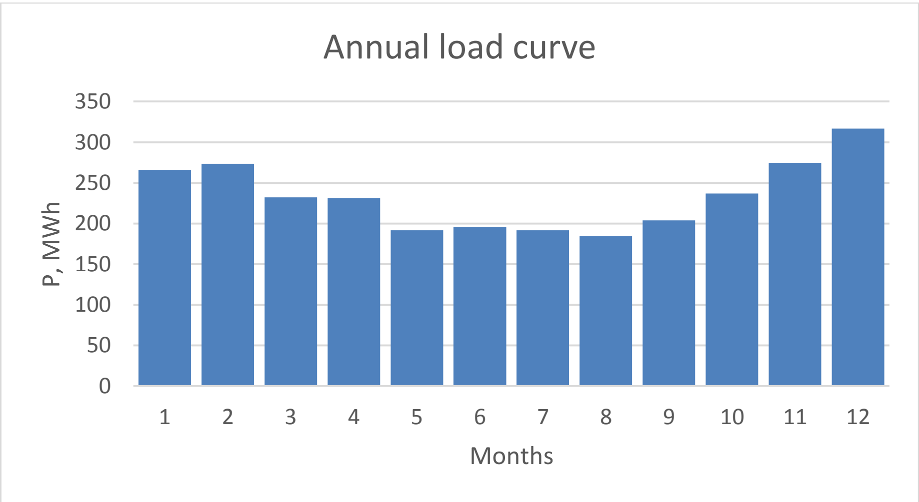

Figure 13 –Annual load curve [15]

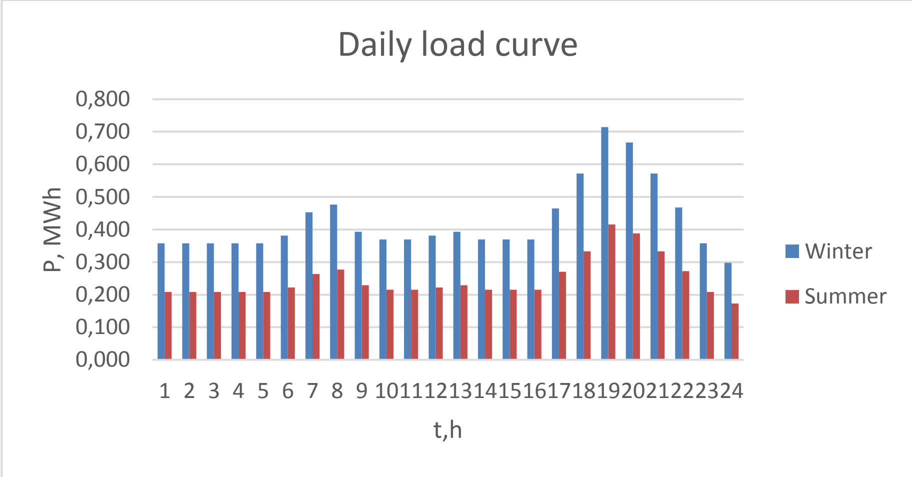

Figure 14 – Daily load curve [15]

To obtain the most careful information about potential solar energy resources in the city of Tomsk will use the functional program simulator «Homer» Solar Resource. This feature uses internet data NASA and display complex information about solar radiation for the given latitude and longitude. (Appendix 1)

The coordinates for the village of Stepanovka, Tomsk region – latitude 58°38′, longitude 86°45′

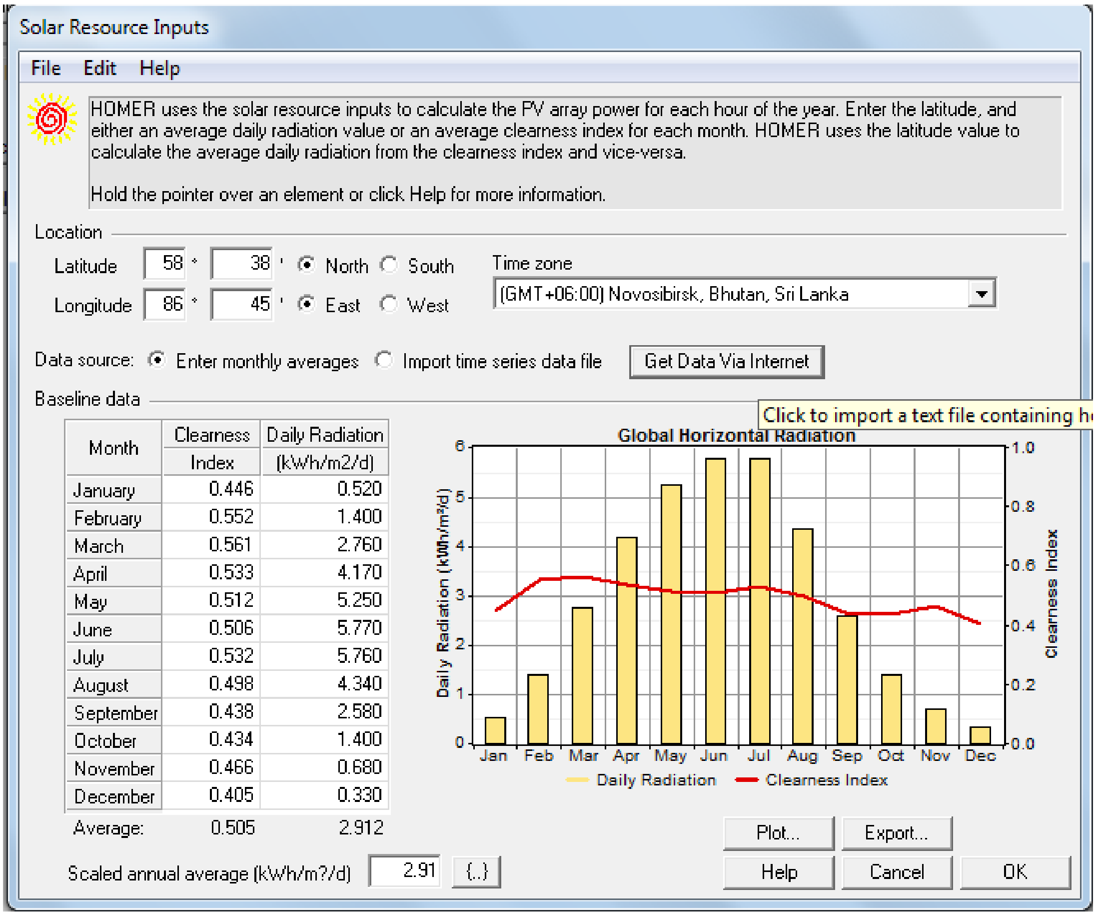

Figure 15 – Interface function Solar Resource program Homer

The table on the left in Figure 12 showing data the average daily solar radiation received on a horizontal surface area of $1m^2$ and the average cloudiness for each month and their average value. For clarity the data shown in the graph on the right.

The value hourly and monthly solar radiation have been derived based latitude and on the based average monthly and annual values of solar radiation. To obtain these data was used the software Homer. This algorithm is based on the realistic hourly and daily data. For example, if one hour is cloud there is a relative high probability that the next hour will also be cloud. As well, one cloudy day is likely to be followed by another cloudy day.

The hourly solar radiation and daily solar radiation for two days in year from different season (December and July) Stepanovka settlement is presented in (Fig. 13–16). To obtain information about potential solar energy resources we will use the functional program simulation «Homer» Solar Resource.

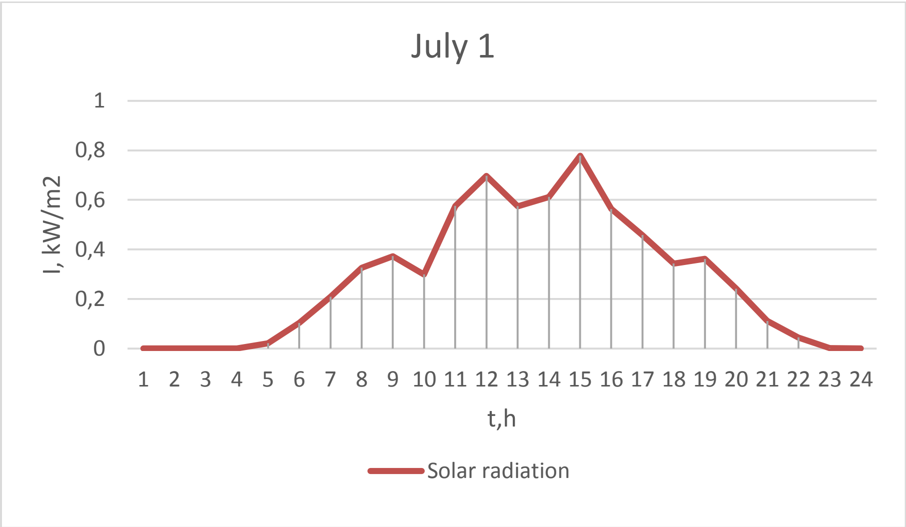

Figure 16 – Hourly solar radiation for July. [18]

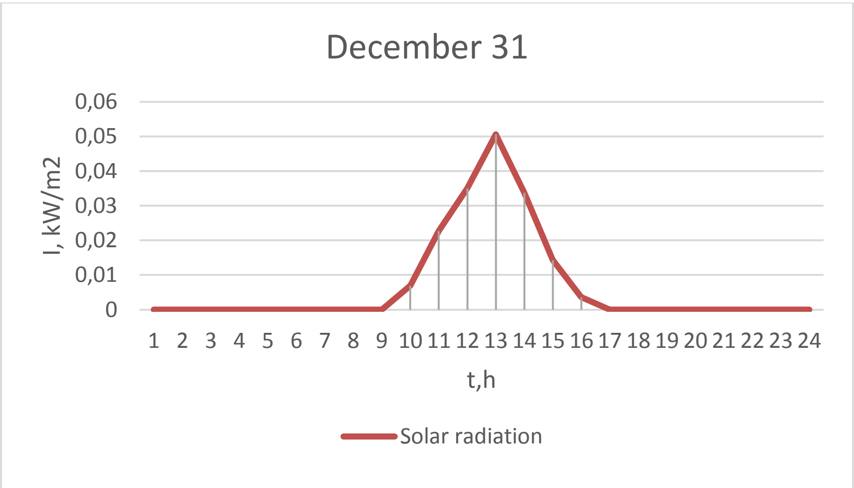

Figure 17 – Hourly solar radiation for December. [18]

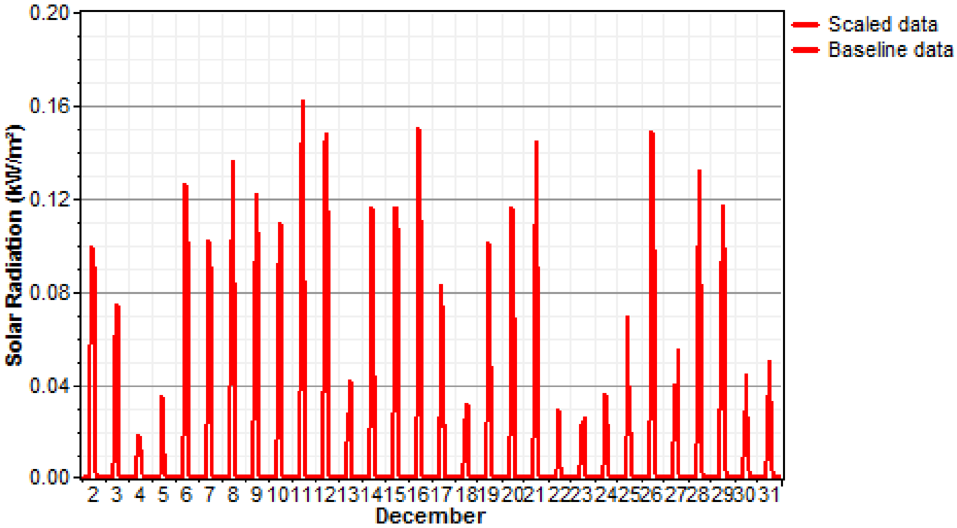

Figure 18 – Daily solar radiation for December.[18]

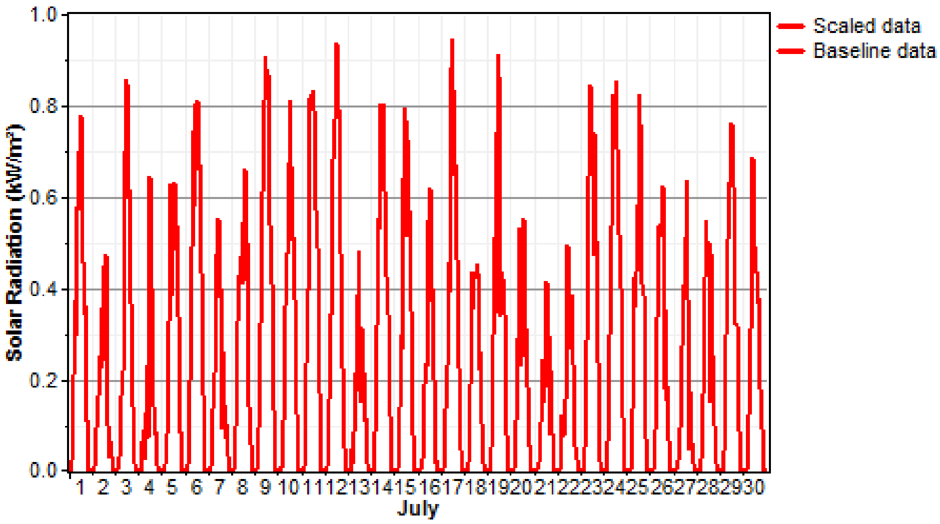

Figure 19 – Daily solar radiation for July.[18]

3.2 The main components of power system

3.2.1 Diesel generator.

Diesel generator this a device that functionally converts diesel fuel into electricity, this a two separate devices (diesel engine and generator) that work together in order to produce power. A diesel engine burns diesel fuel in order to produce motion for the generator, which convert the motion into electricity by using electromagnets. Diesel generator (power plant) is widely used as a source of primary or standby power supply. As the main sources the generator are used in region without centralized power supply and as a standby in case of availability of centralized network operating with a hick-up.

In the technical part, we have chosen to supply the village with three units of diesel generators able to cover the load of 2600 kW.

Table 2 – Diesel power plant [15]

Settlement	Model diesel generators	Power (kW)	Actual load (th. kWh)	Actual load (hour)	Develop (th.kWh)
Stepanovka	11D100	1000	905	2899	2616
	DG72M	800	1126	3596	
	DG72M	800	738	2265	
	DGR 224 (reserve)	224			

Table 3 – The price of diesel generators [15]

Model	Power (kW)	Price (RUB)
11D100	1000	33 600 000
DG72M	800	19 110 000
DG72M	800	19 110 000
DGR 224	224	5 880 000

Table 4 – The actual diesel consumption [15]

Settlement	For 2015 year		
	Number ton per year	Price (RUB/ton)	Amount of expenses, (RUB)
Stepanovka	775	39 650	30 728 750

We should also consider the yearly price of fuel for the diesel generator. Fuel costs are calculated by using the value of average fuel consumption, current diesel price in the region and taking into account predicated fuel price growth in nominal values. The annual diesel fuel consumption is 775 ton per year. The price for the diesel fuel is estimated to 39 650 rubles per ton [22]. The annual diesel engine oil consumption is 30 ton per year. The price for the oil estimated to 520 rubles per liter [22]. The cost related to the transportation of diesel estimated 870 000 rubles each year, due to long distance between supplier and customer.

Table 5 – Consumption of fuel by diesel generator [15]

Month	Diesel fuel (Tons)	Oil (Tons)
January	73,7	2,9
February	75,7	2,9
March	64,3	2,5
April	64,1	2,5
May	53,1	2,1
June	54,2	2,1
July	53,0	2,1
August	51,1	2,0
September	56,4	2,2
October	65,6	2,5
November	76,1	2,9
December	87,8	3,4

Table 6 – Cost of fuel by diesel generator [15]

Month	Total price diesel fuel (RUB)	Total price oil (RUB)
January	2 921 585	1 853 994
February	3 002 298	1 905 213
March	2 548 329	1 617 131
April	2 540 752	1 612 323
May	2 105 452	1 336 088
June	2 150 146	1 364 450
July	2 102 487	1 334 206
August	2 024 849	1 284 939
September	2 236 899	1 419 502
October	2 599 502	1 649 605
November	3 016 683	1 914 342
December	3 479 767	2 208 207

3.2.2 PV panels.

We will calculate the amount of electricity produced by PV panels for every day by the usage of the program HOMER. The formula used for the calculation of power output of a series of PV panels is:

$$P_{\mathrm{REAL\ PV}} = P_{\mathrm{PV}} \cdot f_{\mathrm{PV}} \frac{G_T}{G_{TSTC}}, \mathrm{kW}$$

Where:

P_{PV},kW – sum of nominal value of PV panels installed;

f_{PV},% – is the PV derating factor, we took it equal to 80%;

G_T, kW/m^2 – is the solar radiation incident of the PV array in the current time step;

G_{TSTC}, kW/m^2 – is the incident radiation at standard test conditions.

Photovoltaic (PV) devices senate electricity directly from sunlight via an electronic process that occurs naturally in certain types of material, called semiconductors. Electrons is these materials are freed by solar energy and can be induced to travel through an electrical circuit, powering electrical devices or sending electricity to the grid. PV devices can be used to power anything from small electronics such as calculators and road signs up to homes and village.

In this project uses the solar photovoltaic system connected to the network (Figure 20)

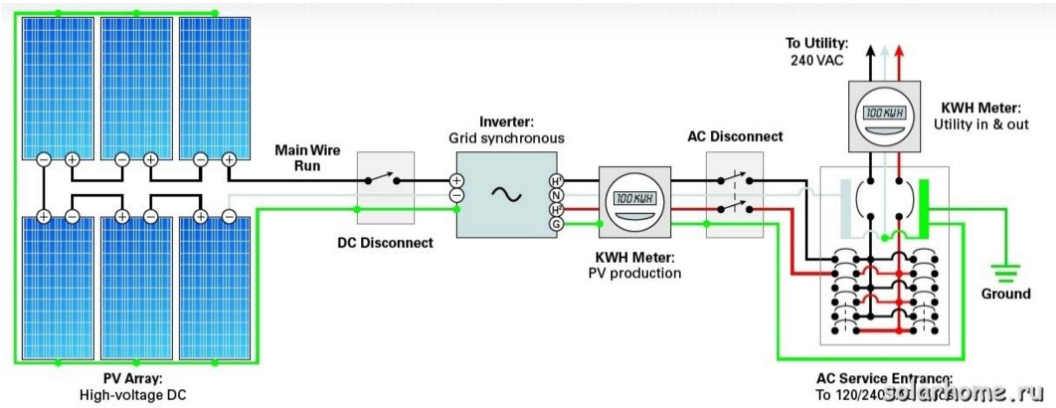

Figure 20 – Typical batteryless scheme connected to the network. [24]

From a performance standpoint, batteryless system produces more electricity than the battery. Firstly, part of the energy will be lost in the charge-discharge battery (up to 20%) part of the energy is lost in the less efficient inverters and battery charge controllers.

Compared with the battery systems connected to the network, batteryless system can be cheaper by 20-40% due to the absence of batteries and the associated parts of the system. Apart from the significant capital investment when installing a battery system, we need to change the batteries every 7-8 years. This further reduces the attractiveness of grid connected battery system. Moreover, it is very difficult to predict the cost of the battery after 7-8 year, because the cost of lead over the past few years has increase three times.[24]

Table 7 presents the solar panels and necessary electronic equipment.

Table 7 – Set of the equipment, used for solar panels installation, source:[25]

Equipment	Units	Price per unit (RUB)	Total price (RUB)
PV module “CHN 300-72P” 300 W	1 600	23 040	36 864 000
Inverter “SolarLake 30000-TL-PM”	16	464 240	7 427 840

4. Inputs for economic model of system

To process a realistic evaluation of investment, we need to create an economic model. For the economic evaluation of the project, we will use the net present value (NPV). For the comparison of projects, we will use values of minimum prices on electricity produced by different technology. This methodic is good because we can compare the prices on electricity with the existing in the region. The calculations for the model will be implemented in Excel, as it is a robust and widely used tool for such kind of tasks. The created model can be observed in Appendix 6

The main components of economic model of the project are described below.

4.1 Investment cost

The aim of this thesis is to evaluate different options for power generation with using the solar panels and diesel generators, it could be quite time-consuming to select equipment. That is why it was decided to calculate investment costs by using specific prices of equipment. Investment is defined as all economic items needed to carry out the accomplishment of the plant. The aim of the initial investment is to give a start to the activity. The necessary investment cost are shown in table 8.

Table 8 – Investment costs for the project: [25]

Item	Units	Total price (RUB)
Diesel generator	4	77 770 000
PV module	1600	36 864 000
Inverter	16	7 427 840
Installation and transportation		12 199 184
Diesel tank	1	420 000
Total price:		134 611 024

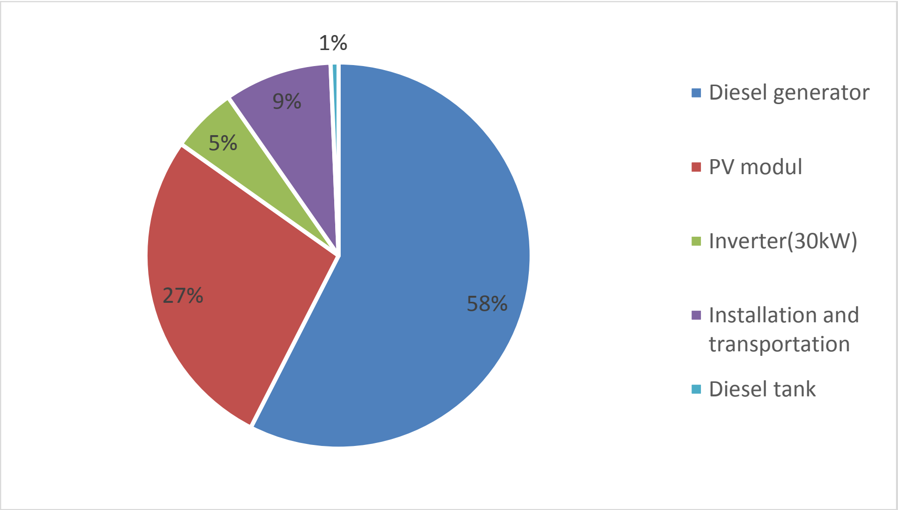

Figure 21 – Investment cost for the project.

As we can see, the main part of investment goes to buying and installation of solar panels and diesel generators. Moreover, we should consider, that diesel generator have high operational cost due to the fuel consumptions.

4.2 Operation and maintenance costs

Solar panels do not require constant maintenance, but from time to time, they require attention throughout the service life of approximately 25 years. Depending on the location of the solar panels can accumulate tree leaf or mud, then you will need from time to time clear them of trees leaf and mud. A yearly maintenance the solar panels, including the prophylactic and emergency examinations will cost 80 000 rubles a year [25].

Maintenance of diesel generator is an issue that needs to be approached seriously: on time and professional maintenance increases the lifetime and reduce maintenance costs (by reducing the number of emergency situation). For the diesel generator, the yearly maintenance is estimated to the 176 000 rubles a year [26]. We should also consider the yearly price of fuel for the diesel generator.

Fuel costs are calculated by using the value of average fuel consumption, current diesel price in the region and taking into account predicated fuel price growth in nominal values. The annual diesel fuel consumption is 775 ton per year. The price for the diesel fuel is estimated to 39 650 rubles per ton [22]. The annual diesel engine oil consumption is 30 ton per year. The price for the oil is estimated to 520 rubles per liter [22].

Wages are calculated by using average value of wages for given industry and taking into account the change of wage according to the region. The wages for the branch of industry for the personnel of 2 people 798 240 rubles yearly [27].

The operation and maintenance cost in the first year are shown in table 9.

Table 9 – Operational and maintenance costs

Operational costs	Cost (RUB)
Maintenance of PV panels	80 000
Maintenance of diesel generator	176 000
Transportation of diesel fuel	870 000
Wages	798 240
Fuel for diesel generator	42 907 578
Total price:	44 831 818

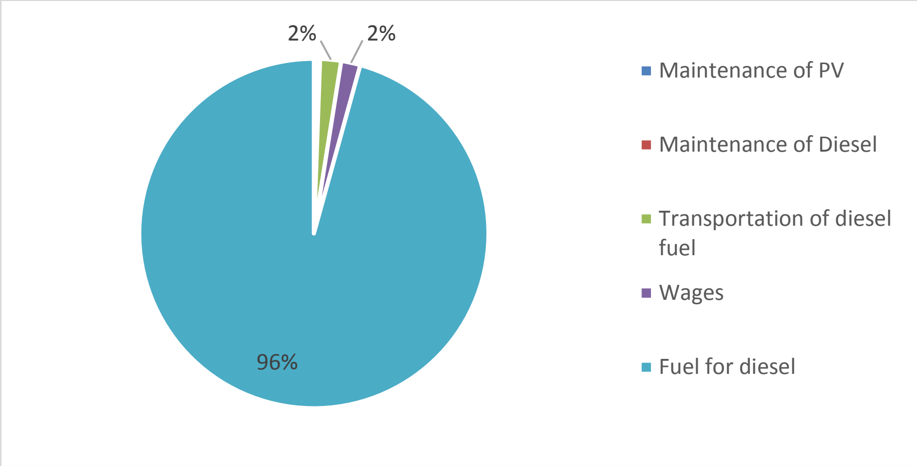

Figure 22 – Circular chart of operation and maintenance costs

As we see in the Figure 22 the proportion of the solar panels is very small, and will remain small over the lifetime of the equipment. The main part of this is fuel for diesel generator.

4.3 Subsidy

Money that is paid usually by a government to keep the price of a product or service low or to help a business or organization to continue to function.

Subsidy for diesel fuel:

In accordance with the law, the Tomsk region provides subsidies to local budgets for the compensation of costs to supply electricity from diesel powered stations. Subsidies are granted in the amount of 25 020 rubles. [35]

Subsidy for PV panels:

Ministry of energy of Russian Federation finalized the rules of granting money from the federal budget subsidies to compensate the cost of technological connection of generation facilities with total generated capacity no more than 25MW.

The subsidy is granted to the owner of the generating facility in an amount not exceeding 50% of the cost of technological connection of the generating facility, but not more than 30 million rubles on a single generating facility (the size limit for the grant).[36]

4.4 Escalation rates

The escalation rates this is a percentage at which an annual change in the price levels of the goods and services occurs or is expected to occur. For future calculation, we need to define the rates, which are subject to inflation every year. The figure 23 present the inflation rate in Russia by years in the last ten years. The current rate of which is 1,6%. The Central Bank of Russian Federation defined the target inflation equal to 8,1%.[28]

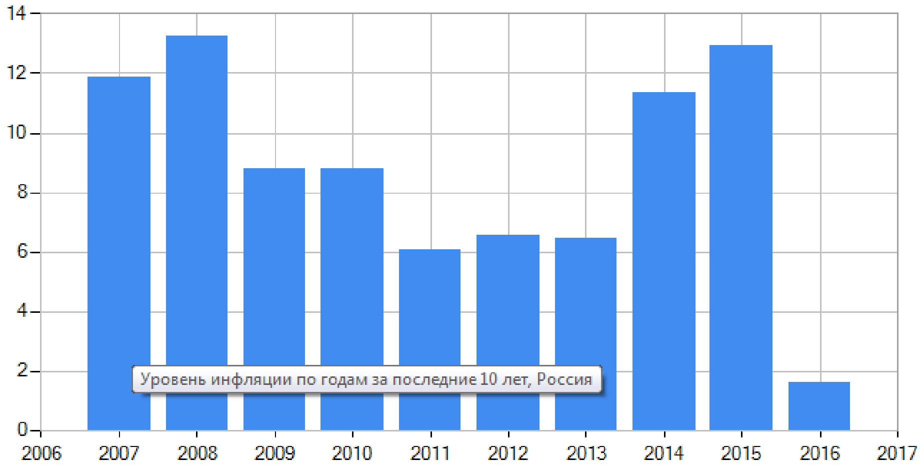

Figure 23 – Yearly inflation rate in Russia [28]

The rate for the growth of wages usually said to be slightly faster than the rate of inflation, after analyzing escalation rate we set it 8,5%.

Price of the fuel is a hardly predictable parameter. The growth rate of diesel fuel is dependent on many factors such as: the current price of oil, transportation to the region, etc. Due to the difficult economic situation in the world and falling oil price. Analyzing the data prices for diesel fuel [29], we sat the escalation rate for the fuel to 3%.

The income tax for organizations in Russian is equal to 20% according to the Tax Code of the Russia Federation [30].

The type of project's investment can be done by the own founds or by the bank loan. The most influencing factor in the choice of the type of investment is the value of discount rate.

Discount rate refers to the investment rate used to determine the present value of future cash flow. It takes into account the time value of money and the risk or uncertainty of future cash flows.

To estimate the expected discount rate for our investment the Capital Asset Pricing Model (CAMP) has been selected to define the rate. We will use three inputs for the calculation: risk free rate, market risk premium and beta.

The discount rate is calculate on the basis of the following formula:

$$r_{CAPM} = r_f + \beta \cdot (r_m - r_f) = 9{,}21 + 0{,}67 * (10{,}16) = 16{,}03\%$$

Where

r_f – is the risk free rate which is defined from the profitability of Russian governmental bond, which are currently equal to 9,21% for Russia-2018 bonds.[31]

r_m – is the expected market return is the return the investor would expect to receive from a broad stock market indicators. The market risk premium for Russia is around 10,16%. [32]

β – A stock beta is used to mathematically describe the relationship between the movements of an individual stock versus the entire market. Investors van then use a stock's beta to measure the risk of a security. The unlevered beta coefficient for power companies 0,5.[33]

The levered beta coefficient is calculate of the following formula:

$$\beta_L = \beta_U * \left(1 + \frac{D}{E} * (1 - t)\right) = 0{,}5 * (1 + \frac{30\%}{70\%} * (1 - 0{,}2)) = 0{,}67$$

With all of the given data, we create Excel economic model of the project, which we will use to calculate the efficiency of the investments.

To calculate the effects of financing we use the weighted average cost of capital (WACC).

The Weighted average cost of capital is used to calculate a particular company's cost of capital, the combination of the cost of equity and the cost of debt. A company's assets are financed by either debt or equity, and the WACC is the average of the costs of these sources of financing, each of which is weighted by its respective use in the given situation. By taking a weighted average, we can see how much interest the company has to pay for every euro it finances. [34]

To calculate WACC, multiply the cost of each capital component by its proportional weight and take the sum of the results. The method for calculating WACC can be expressed in the following formula:

$$WACC = r_{equity} \cdot \frac{E}{E + D} + r_{debt} \cdot \frac{D}{E + D} \cdot (1 - t)$$

Where:

r_{equity}– rate of return by CAPM;

r_{debt} – cost of debt;

D – market value of debt;

E – market value of debt;

t – tax rate.

This project is profitable not only for business, but also for a municipality, so administration of area can assist in receiving the less expensive loan. We assume that the share of equity in capital structure is 70% and bank minimum interest rate is 11% [28]. We will calculate the WACC with different shares and bank interest rates. The analysis is present in the Table – 10

Table 10 – WACC with different bank interest rate and shares of equity

		Share of equity					
Bank interest rate		95%	90%	85%	80%	75%	70%
	11%	15,67%	15,31%	14,95%	14,59%	14,22%	13,86%
	11,2%	15,68%	15,32%	14,97%	14,62%	14,26%	13,91%
	11,4%	15,69%	15,34%	14,99%	14,65%	14,30%	13,96%
	11,6%	15,69%	15,36%	15,02%	14,68%	14,34%	14,01%
	11,8%	15,70%	15,37%	15,04%	14,71%	14,38%	14,05%
	12%	15,71%	15,39%	15,07%	14,75%	14,42%	14,10%

The lowest rate of return we can get is when the share of equity is 70% and bank interest rate is 11%. For further calculations we will use the WACC equal 13,86%.

4.5 Investment criteria

4.5.1 Revenues

The project is done as for the business investments and for municipality investment. The calculation of revenue shows the potential price for selling the electricity or the price on saved electricity, which can be compared to the existing current price. Revenues are calculated for the minimum projects price and its predicted growth.

The revenue is calculate of the following formula:

$$Revenue = C_{min} \cdot W \cdot \sum_{n=1}^{T} (1 + r_i)^n , RUB$$

Where

C_{min}– minimum price of electricity;

W, kWh – generated electricity

r_i, % – escalation rate

4.5.2 NPV

NPV stands for the Net Present Value of cash flows generated by the project. It has been used to analyze the profitability of the investment. For the calculation of the NPV the net cash flows and discount cash flows generated during the project's lifetime of 20 years were required.[38] The lifetime of projects is taken equal to 20 year, since this is the average lifetime of the main equipment in system (PV panels, invertor and diesel generator). NPV of the project set to be equal zero.

The NPV is calculate of the following formula:

$$NPV = \sum_{n=1}^{T} \frac{CF}{(1+r)^t} - C_0$$

Where

C_0– total initial investment costs

Cash flow is the net amount of cash and cash-equivalents moving into and out of a business.

The CF is calculate of the following formula:

$$CF = EAT - Depr - Inv$$

Discounted cash flow

$$DCF = \frac{CF_t}{(1+r)^t}$$

The Tax is calculate of the following formula:

$$Tax = t \cdot EBT$$

The EBT is calculate of the following formula:

$$EBT = Revenues - Total\ costs$$

The EAT is calculate of the following formula

$$EAT = EBT - Tax\text{es}$$

4.5.3 Minimum price of electricity

The minimum price of the sold electricity was calculated with the use of the “Solver” function in the excel model, under the condition that NPV equal zero. The minimum price for the project is 16,5 RUB/kWh. This price is higher than the price for the customers, connected to grid. However, this price a slightly lower then the price from diesel generator 16,6 RUB/kWh. This will allows us to save money from dotation by the region administration, which pays the difference between the official tariff for electricity and the tariff, which comes from the operation of the complex. As well to decrease cost of fuel and the transportation costs.

We will use the same economic model for calculation of each scenario, changing only capital input data of these calculations.

5. Scenario analysis

The aim of this work is the exploration of the influence of available options for the development of the energy system, managing possible scenarios, measures of achievement of agreed objectives and developing economic models for each scenario. To achieve the present goals there can be formed a number of alternative scenarios with different characteristics and indicators. This project uses two scenarios to assess the impact of PV panels. Both scenarios are based on use diesel generators and PV panels.

5.1 First scenario

For the purpose of power supply by means of combination of solar and diesel power sources it was decided to install the 1600 PV panels with nominal power 0,3 kW each, and total nominal power 480 kW, and three types of diesel generator with nominal power 1000 kW and two types diesel generator with nominal power 800kW. The total nominal power of diesel generators is 2600 kW.

In this scenario, maximized number of solar panels that could be installed and the total energy generated of the solar panels didn’t exceed the daily load in the season when solar panels produce the maximum amount of energy (Appendix 2).

The greatest advantage of this system is large power output. A 480kW system is capable of producing more than one-fourth the settlement electricity, and, at various times, almost one third the total power consumption (Appendix 3). Based on current costs, the maximum system size also has a lifetime of 20 years. The greatest disadvantage to this system is the cost of implementation. Constructing a system of this size takes a large initial (134 611 024 rubles) capital investment, operational and maintenance costs (44 831 818 rubles) for each year. The capital investment consists of 1600 (HSE300-72M Helios SolarWorks, 24B) solar panels (36 864 000 rubles), sixteen (SolarLake 30000-TL-PM) inverters (7 427 840 rubles) and installation costs. To fit 1600 panels it is needed to deliver solar panels to the settlement. The price of installation and transportation is taken as equal amounts (12 199 184 rubles) which is 10% of the total price all equipment. Also installation of a fuel tank for the storage of fuel of volume of 40 000 liter (420 000 rubles) should be taken into account. The Operational and maintenance costs consist of maintenance of PV panels (80 000 rubles) and maintenance of diesel generator (176 000 rubles). A yearly maintenance the solar panels and diesel generator includes the prophylactic and emergency examinations. Fuel for diesel generator (42 907 578 rubles) and transportation of diesel fuel (870 000 rubles) by a rental truck would also cost. The wages for this branch of industry for the personnel of 2 people (798 240 rubles) are also included. This system does not require a storage.

The total system energy profile for this option is represented in the Appendix 2

This scenario has high power efficiency value and quite low value of the minimum electricity price due to the significant saving of fuel by PV panels.

The results of minimum price of electricity are presented in Table 11.

Table 11 – Total minimum price of electricity for first scenario

	Without subsidy	Diesel subsidy	PV subsidy	PV+Diesel subsidy
Business	16,66р.	16,62р.	15,76р.	15,72р.
+ Value added tax	19,66р.	19,62р.	18,60р.	18,55р.
	With tax	Without tax	With + subsidy	Without + subsidy
Municipality	15,53р.	14,87р.	14,72р.	14,17р.
+ Value added tax	18,32р.	17,54р.	17,37р.	16,72р.
Current price	16,6р.			

5.2 Second scenario

This scenario is similar to previous one. For the purpose of power supply by means of combination of solar and diesel power sources it was decided to install the 3000 PV panels with nominal power 0.3 kW each, and total nominal power 900 kW, and three types of diesel generator with nominal power 1000 kW and two types diesel generator with nominal power 800kW. The total nominal power diesel generators 2600 kW.

In this scenario, the number of solar was chosen so that the total energy generated of the solar panels was a higher than the daily load in the season when solar panels produce the maximum amount of energy. (Appendix 4).

The greatest advantage of this system is the large power output. A 900kW system is capable of producing more than one-third the settlement electricity, and, at various times, almost half the total power consumption (Appendix 5). Based on current costs, the maximum system size also has a lifetime of 20 years. The greatest disadvantage to this system is the cost to implementation. Constructing a system of this size takes a large initial (177 241 920 rubles) capital investment, operational and maintenance costs (38 425 792 rubles) for each year. The capital investment consists of 3000 (HSE300-72M Helios SolarWorks, 24B) solar panels (69 120 000 rubles), thirty (SolarLake 30000-TL-PM) inverters (13 927 840 rubles) and installation costs. To fit 3000 panels it is needed to deliver solar panels to the settlement. The price of installation and transportation is taken as equal amounts (16 074 720 rubles) which is 10% of the total price all equipment. Also installation of a fuel tank for the storage of fuel of volume of 40 000 liter (420 000 rubles) should be taken into account. The Operational and maintenance costs consist of maintenance of PV panels (80 000 rubles) and maintenance of diesel generator (176 000 rubles). A yearly maintenance the solar panels and diesel generator includes the prophylactic and emergency examinations. Fuel for diesel generator (36 501 552 rubles) and transportation of diesel fuel (870 000 rubles), by a rental truck would also cost. The wages for this branch of industry for the personnel of 2 people (798 240 rubles) are also included. This system does not require a storage.

The total system energy profile for this option is represented in the Appendix 4

This scenario also has high power efficiency value and quite low value of the minimum electricity price thanks to the more significant saving of fuel by a larger number of PV panels. But this scenario will be profitable if we connect the additional load in the period when we have a surplus of generated energy.

The results of minimum price of electricity are presented in Table 12.

Table 12 – Total minimum price of electricity for second scenario

	Without subsidy	Diesel subsidy	PV subsidy	PV+Diesel subsidy
Business	16,81p.	16,77p.	15,12p.	15,08p.
+ Value added tax	19,83p.	19,79p.	17,84p.	17,79p.
	With tax	Without tax	With + subsidy	Without + subsidy
Municipality	15,44p.	14,57p.	13,97p.	13,31p.
+ Value added tax	18,22p.	17,20p.	16,49p.	15,70p.
Current price	16,6p.			

6. Sensitivity analysis

A sensitivity analysis is a technique used to determine how different values of an independent variable will impact a particular dependent variable under a given set of assumptions. This technique is used within specific boundaries that will depend on one or more input variables. Sensitivity analysis is a way to predict the outcome of a decision if a situation turns out to be different compared to the key prediction(s). [37]

Sensitivity analysis is particularly important for planning of a project with a long lifetime project. Some of the parameters may change considerably during the lifetime of the project and we should be able to evaluate these changes and how appraise important they will be for the profitability of the project. The most important parameters, which bring the most considerable changes, are regarded to:

6.1 NPV dependence on the discount rate

Discount rate is one of the most important factor. If the project will be treated as to provide the minimum possible price of electricity, discount rate is the only way of satisfying the needs of investor. The dependence of NPV on the discount rate is presented in the Figure 24.

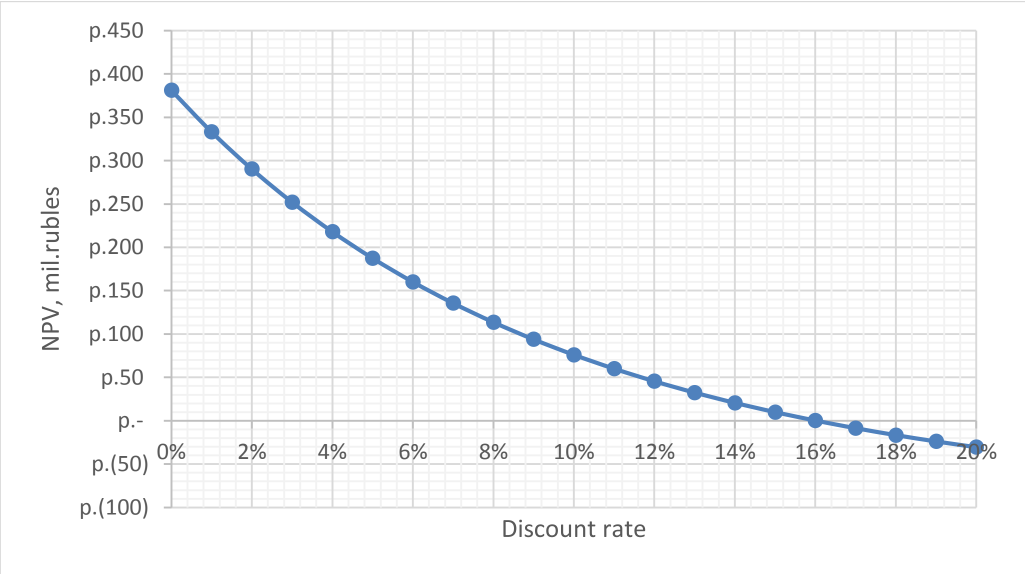

Figure 24 – NPV dependence on the discount rate

This graph shows us a strong dependence of NPV to the discount rate, which can be explain by the long lifetime of the project, and the minimum price of electricity depends on NPV. As long as the discount rate increases the NPV value decreases. In the point of the graph where NPV is zero, the value of the internal rate of return is found. The discount rate of the project is 16,03%. If NPV of the project increases the minimum price of electricity will be decrease, and if NPV decreases and the price of electricity will be growth.

6.2 NPV dependence on the price of electricity

The price of electricity is the most important parameter for the profitability of the project, because largely, the price of electricity makes our project profitable or not and it is the only one parameter, bringing the positive cash flows. Price of electricity in the region is not a subject of competition, as there are no competitors for the off-grid systems, but the subject of dotation by the region administration, because this settlement is located in the decentralized area and the main energy source is diesel power plant. The regional budget pays the difference between the official tariff for electricity and the tariff, which comes from the operation of the complex.

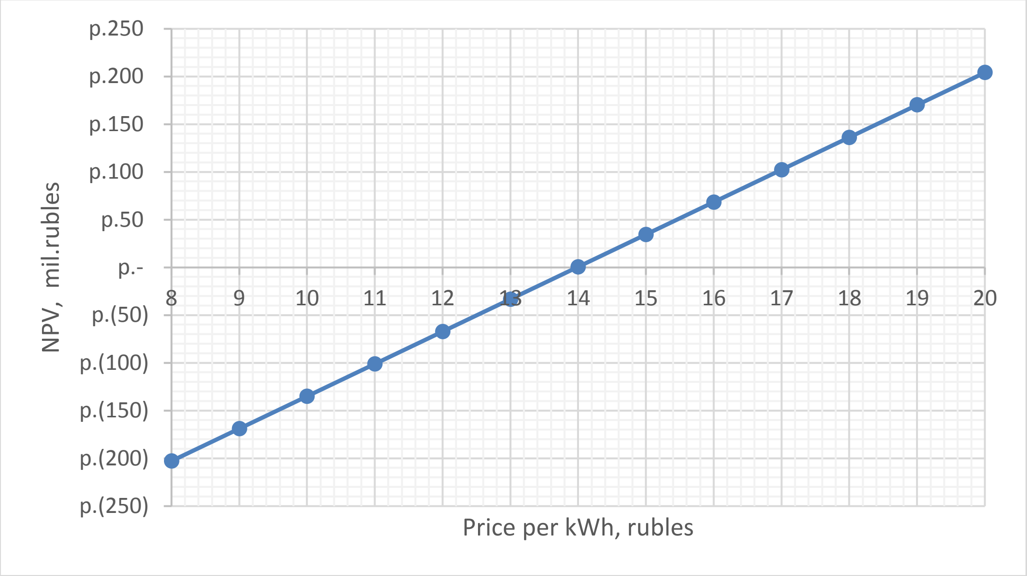

Figure 25 – NPV dependence on the price of electricity

As we can see in Figure 25, the NPV is highly dependent on the price of electricity. This graph shows the break-even point on, in which the profitability of the project will be zero, will be only to provide covering all operating expenses and capital expenditures. On crossing of line with horizontal axis you can the value of price on electricity is 13,98 RUB/kWh.

6.3 NPV dependence on the price of fuel

Currently, the price of electricity in the settlement is very high, because the diesel generator provides the energy supply in the Stepanovka settlement. One of the reasons, why it is so expensive is a high cost of fuel and especially the transportation costs.

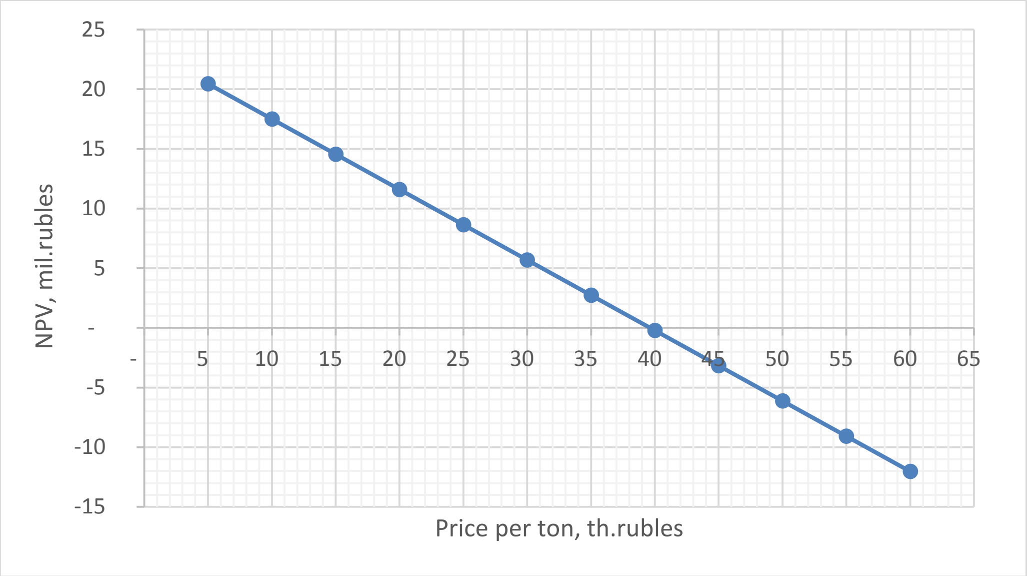

Figure 26 – NPV dependence on the price of fuel

As we can see, there is a certain influence of fuel price on the NPV of the project. The cost of diesel fuel is one of the most important parameters in the operating costs. On this chart, we can see that the significant increase in diesel fuel prices will effect on EBIT and on the Cash Flow and accordingly the project will not be profitable. It means, the investor will have to increase the price of 1 kWh. However, the set of generating equipment (PV panels) is designed to reduce the dependency on the fuel.

6.4 WACC dependence on discount rate and percentage of own money

Figure 27 – WACC dependence on discount rate and percentage of own money

As we can see in Figure 27, the WACC depends on discount rate, percentage of own money and bank interest rate. The WACC is a highly depends on the percentage of own money. It can be seen from Tables 10. In this table, we can see that the increase in share of equity will increase WACC

CONCLUSION

The PV systems technology is a form of renewable energy production that is rapidly developing globally. The source for the PV energy production is the solar energy, therefore the impacts to the environment are considerably little. Countries around the world adopt PV systems as a reliable alternative form of energy production.

In our days, the purchase and installation of PV systems is still very expensive. The purchase of the appropriate equipment, especially the PV modules, could arise up to 50% of the total initial costs of the PV system. This fact could be balanced out by the relatively high state subsidies for such projects, which could add up to 50% of the total initial costs of the project.

In this paper, methods for the economic evaluation of PV plants are presented. This method takes into account all the installation phases of every PV plant type. The economic evaluation is based on the individual technical parameters of every PV plant. In the evaluation process, the initial costs of the PV plant and the annual cash flows resulted by the operation of the PV plant, play a significant role. The economic evaluation is implemented with the use of financial criteria.

The proposed method is applied for the economic evaluation of an off-grid photovoltaic station located in decentralized area of the settlement Stepanovka at the prefecture of Russia and the main conclusions from this application are the following:

- The results of the investment evaluation prove the general profitability of the project with the specified parameters. The project could be profitable for business investor but not much. The project could be even more profitable for municipality investors, if it is possible to find a good possibility to take a low interest loan. This is a possible scenario, as the project is interesting not only for the business investors, but also to municipality. The project has also the nonmonetary value, as it creates 2 new working places.

- The project allows decreasing of the governmental subsidies: from 46 451 282 rubles to 39 427 829 rubles. This proves that the project would be particularly interesting for government that may support it by different means: cheaper loans, tax remissions and other.

- PV plant can help reduce the use of diesel generators, leading to less maintenance and decreasing of the emissions and noise of the diesel generator, it will help with preservation of nature and increase quality of life in the area.

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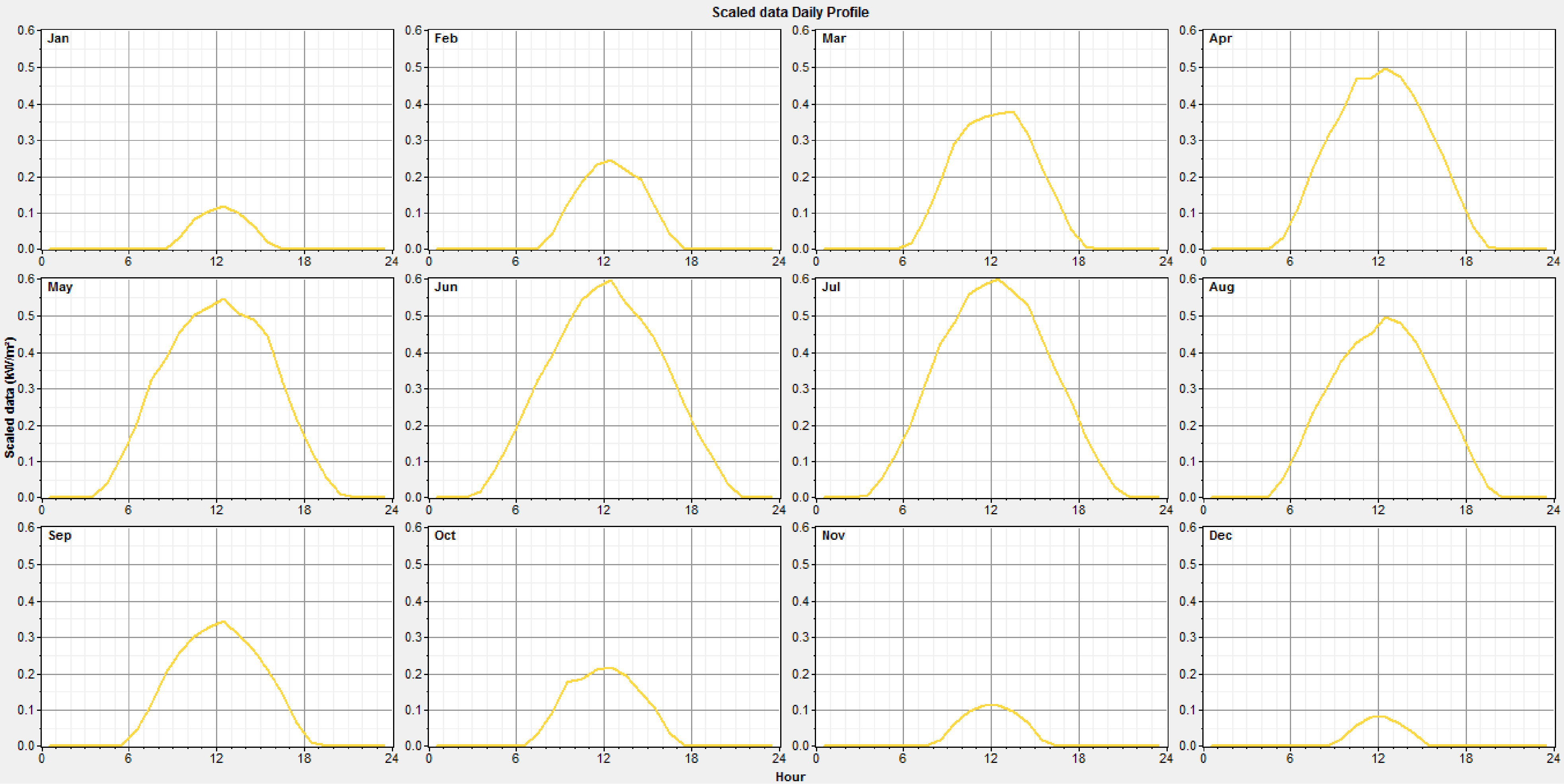
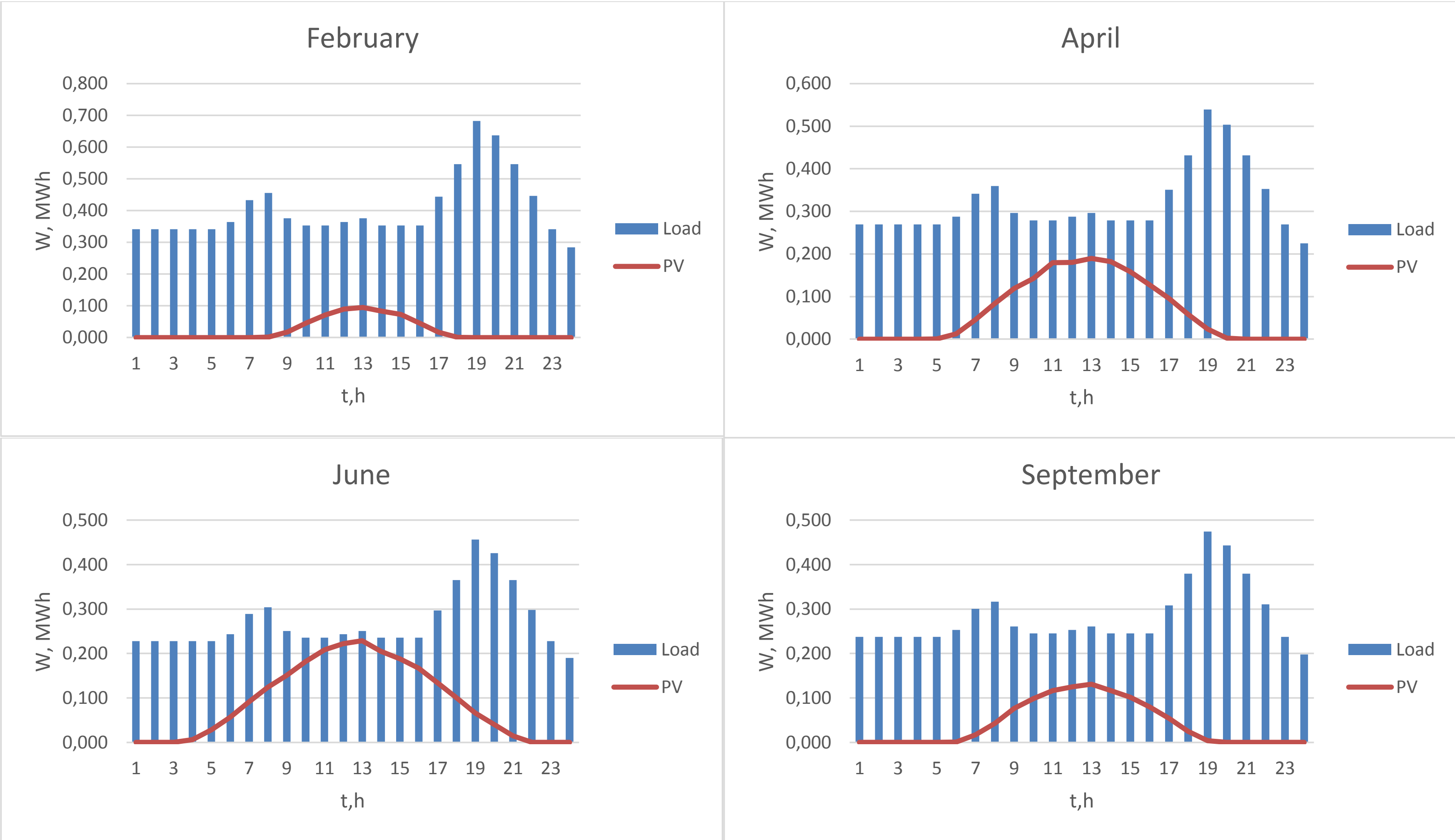
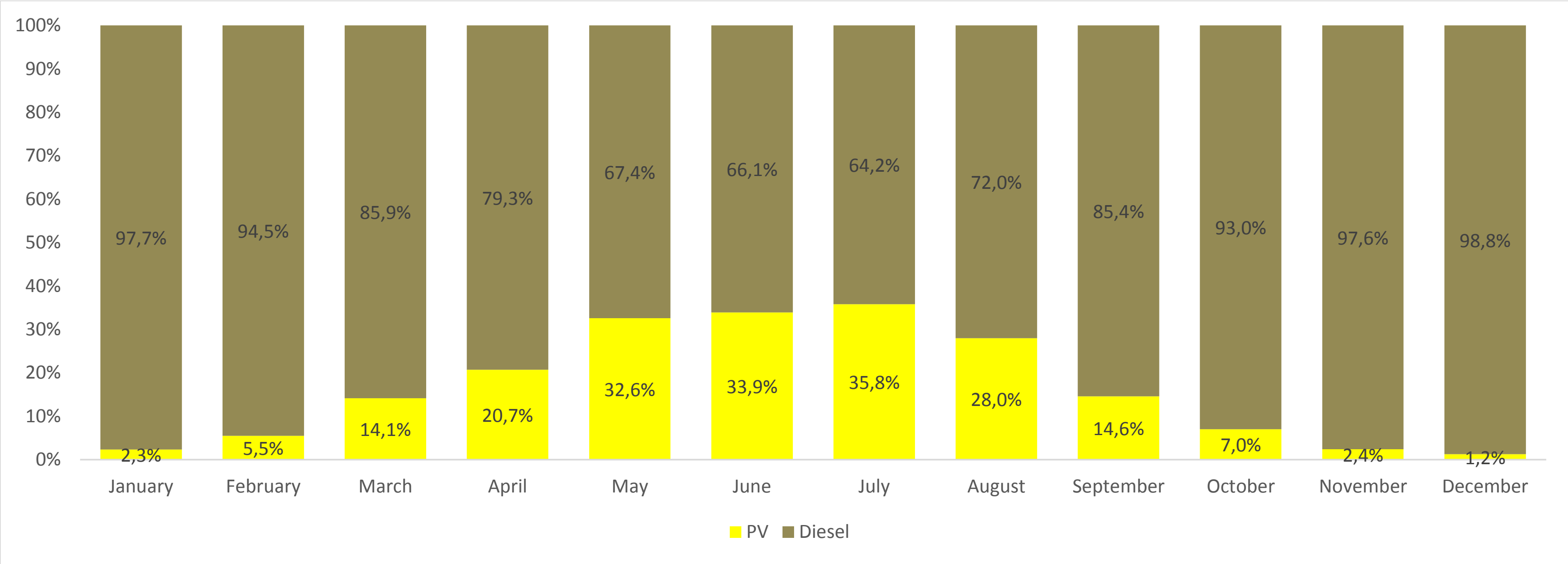
Appendix 1 – Solar radiation profile for Stepanovka settlement



Appendix 2 – First scenario, energy balance

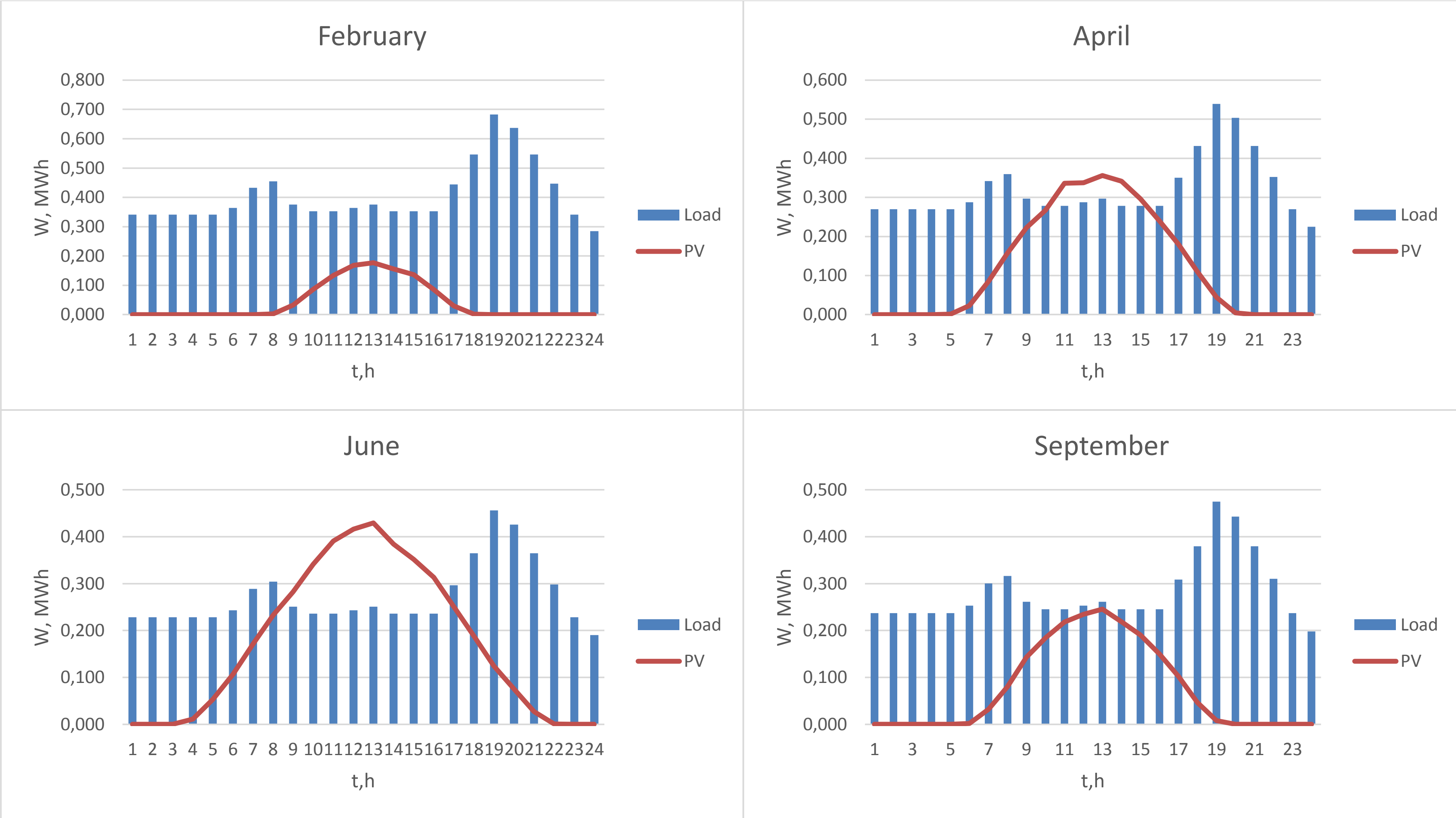


Appendix 3 – First scenario, energy balance (continuation) and save money

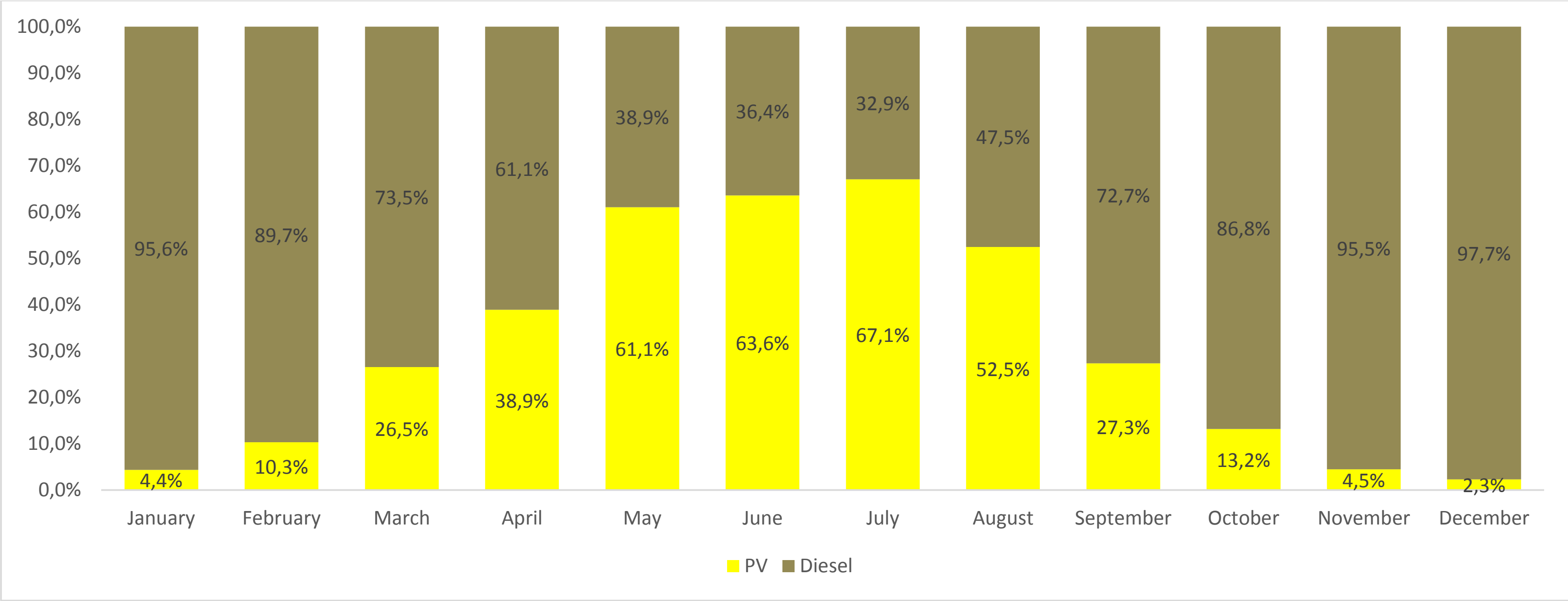


Save money (RUB)											
January	February	March	April	May	June	July	August	September	October	November	December
111 025	269 965	589 276	861 624	1 120 859	1 192188	1 229 791	926 606	533 025	298 911	117 432	70 470

Appendix 4 – Second scenario, energy balance



Appendix 5 – Second scenario, energy balance (continuation) and save money



Save money (RUB)											
January	February	March	April	May	June	July	August	September	October	November	December
208 173	506 185	1 104 892	1 615 545	2 101 610	2 235 352	2 305 857	1 737 386	999 422	560 459	220 185	132 132

Appendix 6 – Screenshot of economic model

	0	1	2	3	4	5	6	7	8
Year	2016	2017	2018	2019	2020	2021	2022	2023	2024
Capital investment	134 611 024								
Maintenance of PV panels	0	80 000	80 000	80 000	80 000	80 000	80 000	80 000	80 000
Maintenance of diesel genera	0	176 000	176 000	176 000	176 000	176 000	176 000	176 000	176 000
Transportation of diesel fuel	0	870 000	870 000	870 000	870 000	870 000	870 000	870 000	870 000
Wages	0	866 090	939 708	1 019 583	1 106 248	1 200 279	1 302 303	1 412 998	1 533 103
Fuel for diesel generator	0	44 194 805	45 520 649	46 886 269	48 292 857	49 741 643	51 233 892	52 770 909	54 354 036
Depreciation	0	6 730 551	6 730 551	6 730 551	6 730 551	6 730 551	6 730 551	6 730 551	6 730 551
Total		52 917 447	54 316 909	55 762 403	57 255 656	58 798 473	60 392 746	62 040 458	63 743 690
Revenues		50 405 852	54 488 726	58 902 313	63 673 400	68 830 945	74 406 252	80 433 158	86 948 244
EBT		-2 511 595	171 817	3 139 909	6 417 744	10 032 472	14 013 506	18 392 700	23 204 554
Taxes		-502 319	34 363	627 982	1 283 549	2 006 494	2 802 701	3 678 540	4 640 911
EAT		-2 009 276	137 454	2 511 927	5 134 195	8 025 978	11 210 805	14 714 160	18 563 643
CF		4 721 275	6 868 005	9 242 479	11 864 746	14 756 529	17 941 356	21 444 711	25 294 194
DCF	-134 611 024	4 068 952	5 101 257	5 916 411	6 545 633	7 016 179	7 351 822	7 573 267	7 698 519
NPV	2								
Minimum price		16,66							
		19,66							