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ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ»
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Реферат

Выпускная квалификационная работа 94 с. 18 рис., 41 граф., 22 табл., 41 источников, 3 приложения.

Ключевые слова: возобновляемые источники, аккумуляторные батареи, солнечная электростанция, *экономия* солнечной электростанции

Объектом исследования является солнечная электростанция, находящаяся в Республике Алтай.

Цель работы – разработка новой модели фотоэлектрической солнечной станции.

Методы исследования – аналитический, проектный и изучение литературы.

Поиск новых возобновляемых источников энергии – актуальная задача для нашего времени, так как невозобновляемые источники с каждым днём все более исчерпывают себя и через некоторое время прекратят своё функционирование. Другой не менее важной причиной является децентрализация источников. Для бесперебойной работы сети энергоснабжения необходимо наличие нескольких небольших электростанций с меньшей энергией, вырабатываемой возобновляемыми источниками. Однако, с другой стороны, солнечная энергия и энергия ветра имеют существенный недостаток – нестабильный поток энергии, который вызывает нестабильную работу всей сети электроснабжения. Данную проблему можно решить путем использования батарей или других путей сохранения энергии.

Однако в данной работе не рассматриваются сети электроснабжения, в связи с чем работать необходимо в автономном режиме. Таким образом, жилой дом находится в полной зависимости от нефти, и целью данной работы является максимальное снижение этой зависимости. Я оптимизировал каждый компонент фотоэлектрической солнечной станции для одного жилого дома, находящегося в Республике Алтай рядом с селом Балыктуюль.

Целью данной работы является исследование выбранного места в Республике Алтай и разработка всех компонентов оптимизации использования солнечной энергии. В первой главе представлена теоретическая часть, рассмотрены виды возобновляемых источников энергии, описаны все компоненты фотоэлектрической солнечной станции. Вторая глава – практическая часть, в которой описаны автономные системы, рассчитано излучение солнца в течение всех месяцев и выбран оптимальный угол наклона солнечных панелей. Затем рассмотрено потребление энергии выбранным домом. Вследствие проведенных расчетов определена оптимальная площадь панелей, батарей и других компонентов. В итоге произведен расчет конечной цены.

Третья глава представляет собой экономическую часть. В ней рассмотрена экономическая оценка инвестиций и основные показатели, такие как чистый дисконтированный доход, внутренняя ставка доходности, период окупаемости и дисконтированный период окупаемости. В следующий главе описан анализ чувствительности, который помогает лучше понять зависимость стоимости проекта от входящих переменных. Анализ чувствительности показывает реагирование стоимости проекта на изменение входящих переменных.

Последняя часть - социальная ответственность, в которой описывается, как возобновляемые источники энергии влияют на природу и жизнь людей. Затем идет заключение, в котором описаны основные результаты данной работы.

Abstract

The thesis reflect suggest optimal stand- alone PV-station which would be situated in the Altai Republic. PV- station would produce energy for one family house. It is necessary to design PV- station for lesser depend on diesel. Batteries are used for better use energy from PV- station. Program PVGIS was used for calculation optimal angle and average irradiance in chosen area. The thesis also suggest optimal operating mode of equipment and describe which equipment can work together.

The next aim of the thesis is the creation of an economical model and investment evaluation. This chapter determines which variant is better.

Key words: renewable energy, PV- station, batteries, investment evaluation.

Abbreviations

PV- photovoltaic
DC- direct current
AC- alternating current
TFSC- thin-film solar cells
DoD- depth of discharge
LiFePO4- the lithium iron phosphate
RUB- ruble
EUR- euro
CF- cash flow
CCF- cumulative cash flow
DCF- discount cash flow
CDCF- cumulative discount cash flow
PP- payback period
DPP- discount payback period
NPV- net present value
IRR- internal rate of return
CTU- Czech Technical University in Prague
TPU- Tomsk Polytechnic University

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1 Introduction

It is necessary to find another energy sources than non-renewable sources, because non- renewable sources are finishing and after a while they will be gone. Another important reason is decentralization of sources. There would not be only a few electrical power stations with a high power. It is good for network, if there would be also a lot of small power station with smaller power, like renewable sources. But on the other hand solar energy and wind energy have a big disadvantage, unstable power, what causes to unstable network. We can solve it with batteries, or another way to save energy.

But there isn´t electrical network in my case, therefore it is necessary to work in the regime stand- alone. Therefore the house would be dependent for a diesel and therefore it would be good to reduce this dependence. I optimized each component for PV- station system for the house, which will be situated in the Altai Republic close by town Balyktuyul. I decided to explore solar panels as a key renewable power source for a couple of reasons. Firstly, there isn´t any moving parts, thus the maintenance is easier. Secondly, it is scalable, thus the highest power is restricted only by the area and the lowest limit is tens of watts. Thirdly, it shows the owner´s attitude about sustainable energy sources.

This thesis´ goal is to explore selected location in the Altai Republic and design each component for optimal use power from PV- station. I am using batteries for optimal use solar power. First chapter calls theoretical part and I am going to introduce renewable energy sources, after this I am going to describe each component of PV- system. I am introducing also with selected location and weather condition. The main chapter is practical part, where I describe stand- alone system, and where I will calculate irradiance during all months and I will choose optimal angle of solar panels. The next part is about house consumption. And thanks to those calculations I will design optimal area of solar panels and batteries and another component. Then I will be able to calculate total price.

The next main chapter is economic part, where I´m explaining economic evaluation of investment efficiency and basic concepts. After this I am calculating NPV, IRR, payback period and discount payback period. I will examine two variants of PV- station. The next part is sensitivity analysis, which is for better understanding of dependency of project value on different input values. Sensitivity analysis shows the character of project value, when the value of inputs are changed.

The last part is social responsibility, where is describe how renewable sources affect on nature and life. After this chapter is conclusion, where I´m writing about results.

2 Theoretical part

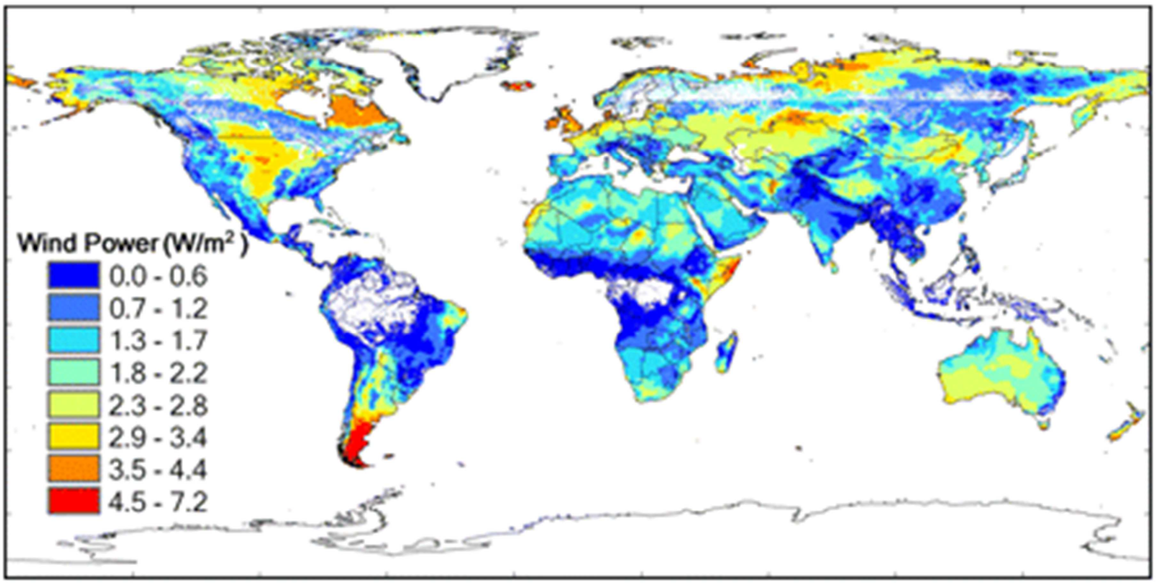
2.1 Renewable energy sources

When people started to generate electricity they used non-renewable sources. In the beginning coal and wood was used. Then oil, natural gas and uranium were used. But those sources are not for all the time, we are drawing it fast. And it will be gone. It is a reason, why is necessary to find other possibilities.

There are many practically infinite sources. We call them renewable energy sources. In this group is Sun, whose energy we can use everywhere on the world. On deserts, mountains or on a small island. Water, which is in rivers, flowing down from mountains to oceans. The wind, the Moon´s energy or geothermal power. We have many choices. But we have problem with renewable energy and it is economically effective

2.1.1Wind´s energy

The potential of the wind power is very different in the world. It depends on a lot of conditions. As we can see in the figure, some regions have better conditions then another and it´s a reason why many wind turbines have been built for example in northern Germany, in Denmark or on desert in USA.



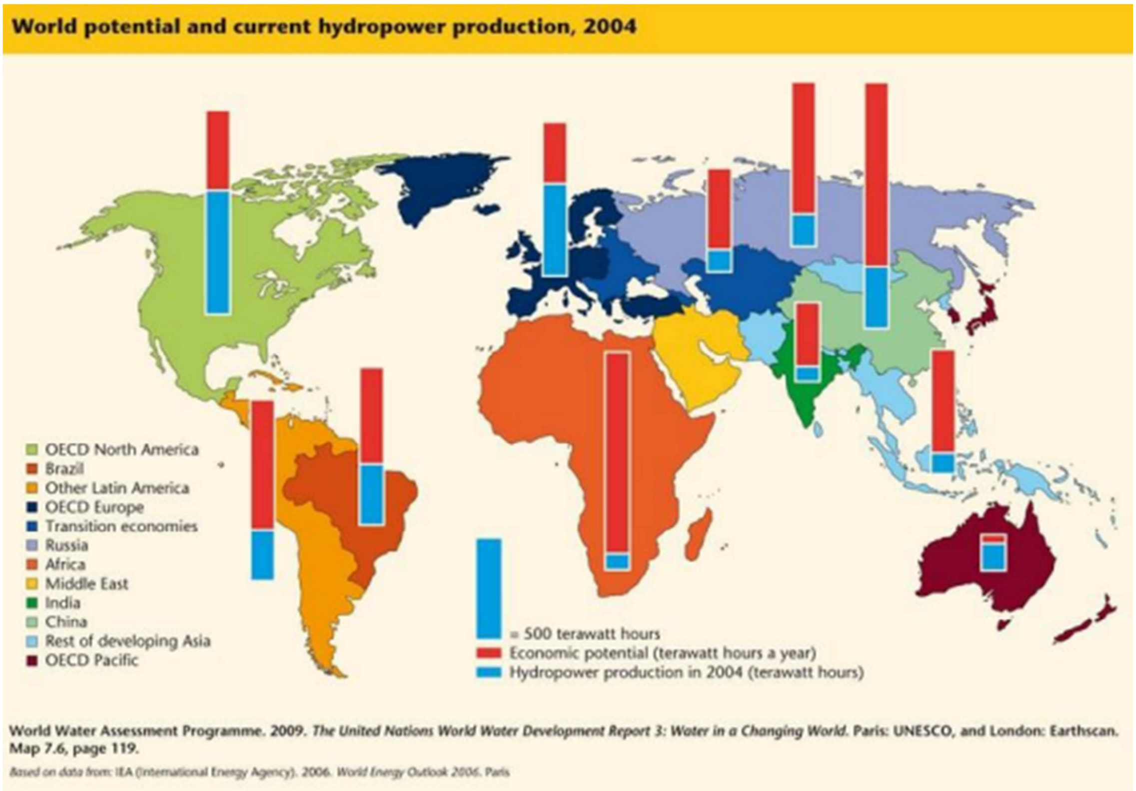
Picture 1- Global potential for wind- generated electricity [1]

The potential of wind power as a global source of electricity is assessed by using winds derived through assimilation of data from a variety of meteorological sources. The analysis indicates that a network of land-based 2.5-megawatt (MW) turbines restricted to nonforested, ice-free, nonurban areas operating at as little as 20% of their rated capacity could supply >40 times current worldwide consumption of electricity, >5 times total global use of energy in all forms. Resources in the United States, specifically in the central plain states, could accommodate as much as 16 times total current demand for electricity in the United States. [1]

2.1.2Hydropower

Hydropower capable of meeting base load electricity requirements, but it capable of meeting peak´s requirements too. There are three types of hydropower station:

- Pumped storage- water is pumped to a higher reservoir and if we need peak´s energy water would be released. It´s very important station, because it is one of the few economically viable options of electricity storage.
- Run of river- the flow of a river generates electricity.
- Reservoir- electricity is generated through the release of stored water

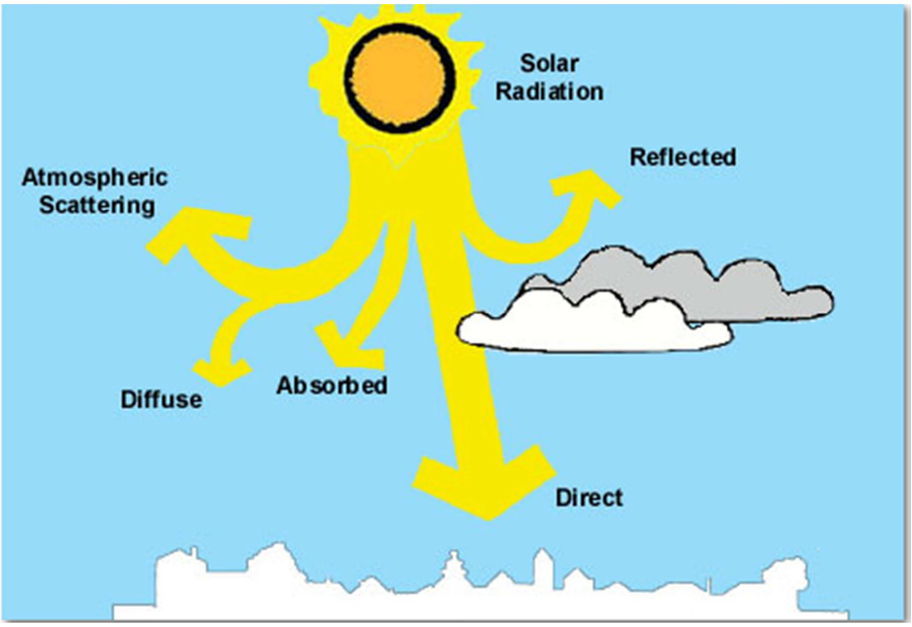


Picture 2- World potential and current hydropower production [2]

2.1.3Sun´s energy

,,Solar energy, is present at any point in the earth´s surface. The amount of energy sent by the sun to the Earth is enormous. This, power of solar radiation, covering the area of 10km^2, on a summer cloudless day makes 7…9 million kilowatt.

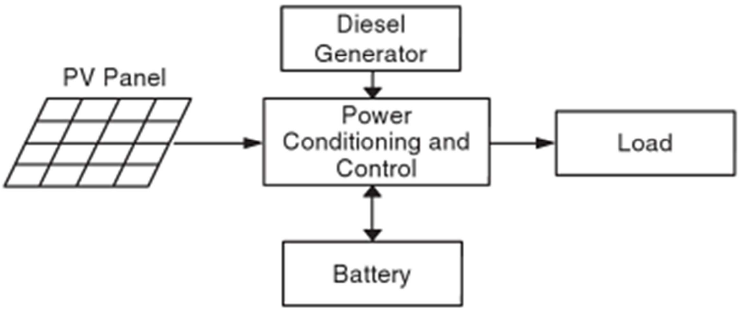
Radiation energy passing through the atmosphere, gets scattered and absorbed. Reaching the earth´s surface, solar radiation is partially reflected. Non-reflected portion of radiation is absorbed and transformed into heat. Heated surface, in turn, becomes a source of natural radiation directed to the atmosphere. Atmosphere, heated by thermal exchange with the earth´s surface, is also a source of radiation directed toward the surface and into space.´´ *[3]*



Picture 3- Atmospheric reduction of sunlight [4]

2.2 Analysist of system

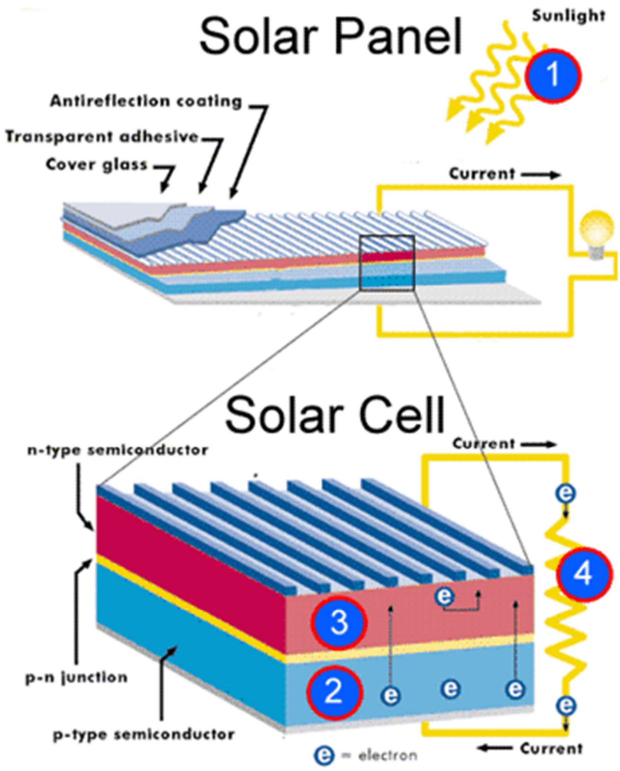
Stand- alone PV System



Picture 4- Stand- alone PV system [3]

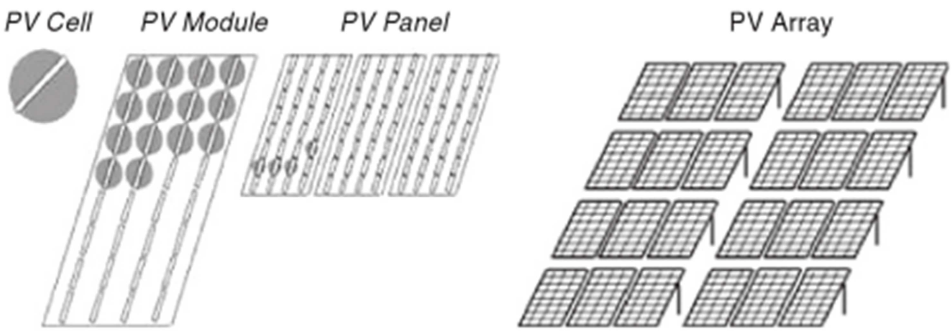
2.2.1Solar panel technologies

Photovoltaic panels are composed of solar cells, which are semiconductors devices. Cells convert sun´s light energy to electric energy. Solar cells use for transformation the photoelectric effect, in which electrons are emitted from the material due to absorption of the photons. Solar cells consist of two desk, where the first desk is P-type, where predominate places „holes´´, which can accept the free electrons. The second desk is N-type, which is negative charged because there are predominated negative electrons. Between these desks is place called P-N junction, where holes and electrons make pairs. Sunlight is the electromagnetic radiation, which is consisted from oscillating photons. If photon has enough energy, semiconductors absorb photon. During the absorption photons emit electrons from semiconductor and make hole- electron pair. These emitted electrons are removed by electrodes like DC.



Picture 5- Solar Cell [5]

Typical produce of silicon solar cells is about 0,5V. If we want higher voltage we have to connect in series to form a solar module. A panel consists of several models. A collection of solar panels is called solar array.



Picture 6- Terminology regarding solar panels [3]

A lot of solar panels which are produced are from silicon semiconductor material.

There are three basic types:

- Thin-film modules
- Polycrystalline modules
- Monocrystalline modules

Differences between those materials are in efficiency of energy conversion, material, price and engineering processes.

Voltage and current characteristics vary on different insolation levels. In the next figure it can be seen dependence current on isolation.

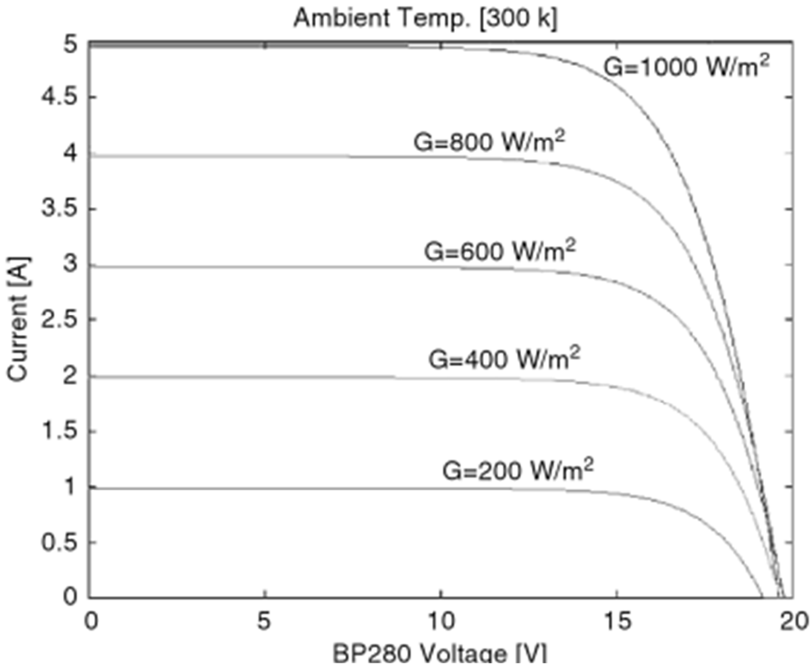


Figure 1- Typical current/ voltage characteristic curves for different insolation

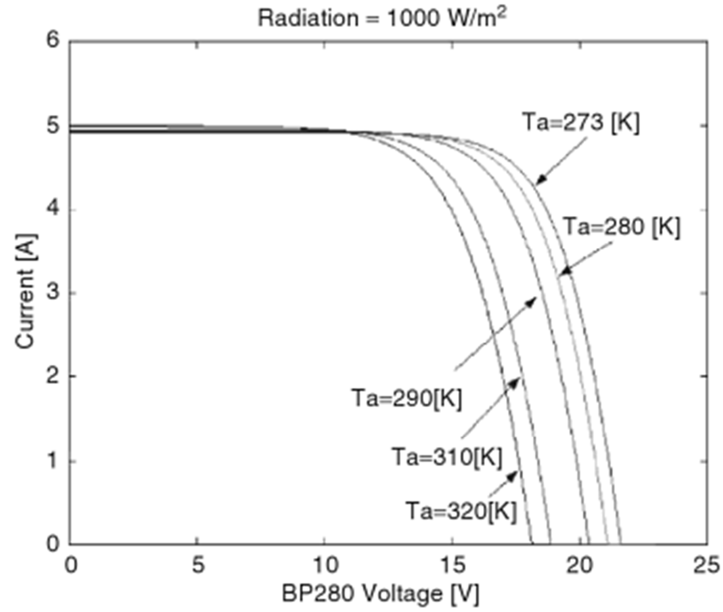


Figure 2- Effects of temperature on silicon solar cells [3]

In the figure of effect of temperature on silicon solar cells it can be seen that current/ voltage characteristic is depended on temperature. If solar cells work in lower temperature then they have better efficiency.

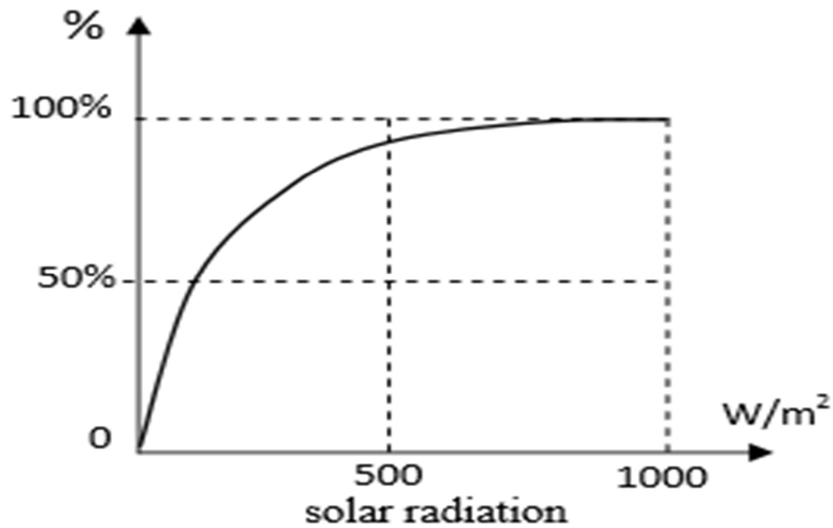


Figure 3- Efficiency dependence of photoconversion on solar radiation [6]

The figure 3 shows that in the range of the solar radiation intensity change from 800 to 1000W/m^2 photoconversion efficiency varies only slightly.

Consequently, power of the photovoltaic modulus on a cloudy day is reduced compared to the solar one just because of the lower solar energy incident on the receiving surface of photoconverter. Usually, when a small cloud covers, solar panel can produce up to 80% of its maximum capacity. In overcast conditions, this value is reduced to 30 %. *[6]*

2.2.1.1 Shadow effect

,,Solar panels consist of many series-parallel connected cells should take into account shadow effect that occurs in case of partial panel blackening. If a cell in a series circuit of completely obscured, it is converted from power source to customer. Series circuit of illuminated cells makes current flow, heating shaded cell by power losses, caused by its internal resistance.

Thus, there is a reduction of electrical power tapped off from the panel. To minimize the negative impact of the shadow effect on solar panel capacity, series circuit of photoelectric module is split by bypass diodes for a few short sections.

Consequently, power generated by the unit increases at lower temperatures. However, maximum power at various temperatures corresponds to different voltages. To remove this shortcoming photovoltaic power plant should by fitted with a voltage regulator.´´ [6]

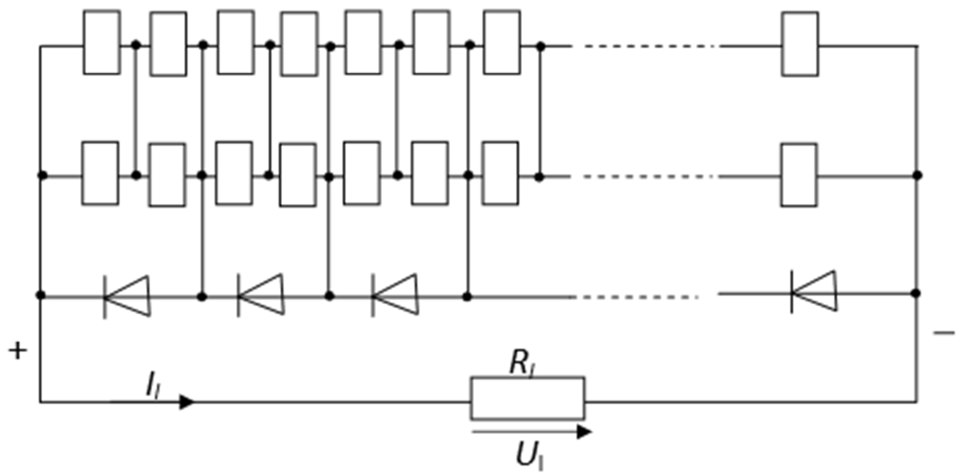


Figure 4- Bypass diodes connection circuit

2.2.1.2 Monocrystalline silicon solar cells

Monocrystalline silicon has used for decades in solar cells, mostly it´s made by using Czochralsky process, where ingot up to 2 meter in length are grown from a seed crystal.

Advantages:

- Monocrystalline solar panels have the highest efficiency rates since they are made out of the highest-grade silicon. The efficiency rates of monocrystalline solar panels are typically 15-20%.
- Monocrystalline silicon solar produce up to four times the amount of electricity as thin-film solar panels.
- Monocrystalline solar panels live the longest. Most manufacturers put 25-years warranty.
- Usually they are better than polycrystalline solar panels during low-light conditions.

Disadvantages:

- Monocrystalline solar panels are the most expensive
- If the solar panel is partially covered with shade, dirt or snow, the entire circuit can break down [7]

Picture 7- Monocrystalline silicon solar cells

2.2.1.3 Polycrystalline silicon solar cells

It´s made by using another process than Czochralski process. Raw silicon is melted and poured into a square mold, which is cooled and cut into perfectly square wafers. The efficiency is typically 13- 16%.

Advantages:

- The process for production is simpler and cost less. The amount of waste silicon is less.

Disadvantages:

- Lower efficiency than monocrystalline solar panels. Typically 13- 16%.
- Lower space-efficiency. If we need the same electrical power as we would with a solar panel made of monocrystalline silicon we would need cover a larger surface. [14]

Picture 8- Polycrystalline silicon solar cells [7]

2.2.1.4 Thin-Film Solar Cells (TFSC)

Depositing one or several thin layers of photovoltaic material into a substrate is the basic gist of how thin- film solar cells are manufactured. It also call thin- film photovoltaic cells (TFPV). The different types of thin- film solar cells can be categorized by which photovoltaic material is deposited onto the substrate:

- Amorphous silicon (a-Si)
- Cedmium telluride (CdTe)
- Copper indium gallium selenide (CIS/CIGS)
- Organic photovoltaic cells (OPC)

<u>Advantages</u>

- Mass-production is simple and cheap.
- Their look. Their homogenous appearance is interesting for architects.
- Shading and high temperatures have less impact
- When we have much space it could be good choice(for example- deserts)

<u>Disadvantages</u>

- Monocrystalline solar panels produce up to four times the amount of electricity as thin-film solar panels for the same amount of space.
- Usually thin- film solar panel has shorter warranty. Because thin- film solar panel tend to degrade faster than polycrystalline and monocrystalline solar panel
- If we have lesser low space it means that cost of PV-equipment would be higher. [7]

Picture 9- Thin-film solar cells

2.2.2Battery charging

We need storage the energy for demand during lower solar irradiation and nighttime. Several types of batteries are available such as the lead acid, nickel-cadmium, lithium, sodium sulfur etc. For example lead acid battery is typically used to guarantee several hours to a few days of energy storage. Acid battery is used in the widespread application. [3]

Factors are considered in the selection of batteries for PV applications.

- Low charging/ discharging current
- Long duration charge and discharge
- Low self-discharge
- Low cost
- Long life time
- Less maintenance requirement
- High energy storage efficiency
- Varying and irregular charge/discharge
- Deep discharge (70-80% depth of discharge)

[3]

Manufacturers of battery specify the nominal number of complete charge and discharge cycles as a function of the depth of discharge. It can be seen in the next figure.

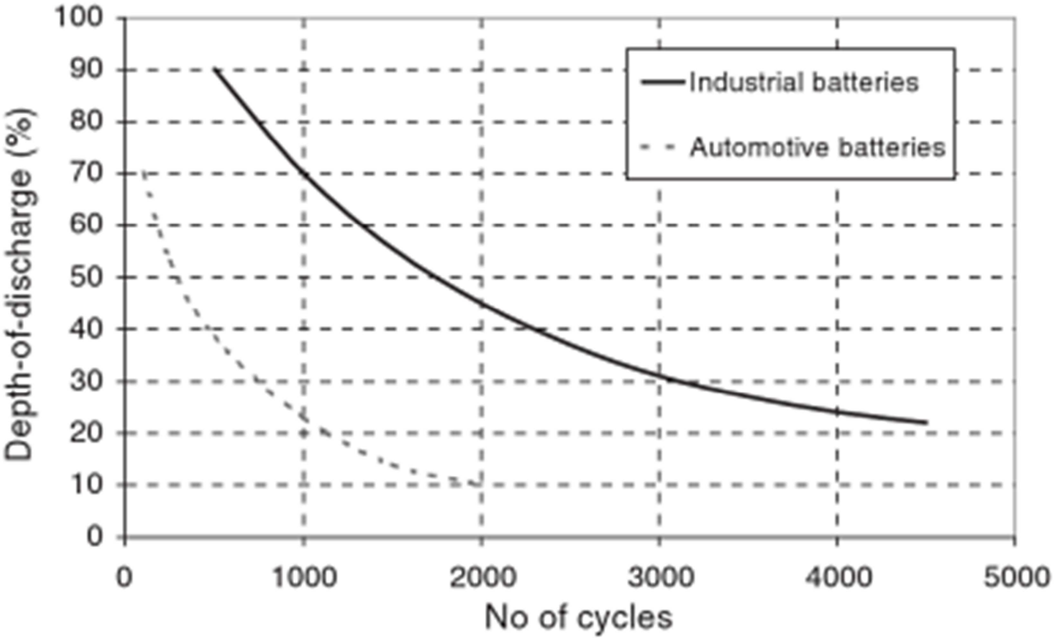


Figure 5- Nominal number of battery cycles vs depth of discharge [3]

2.2.2.1 Types of batteries

We know a lot of types of batteries and main property for us during choosing is depth of discharge. LiFePO4 has the best value of depth of discharge and you can see another types of batteries and compare values.

2.2.2.1.1 lithium–sulphur battery

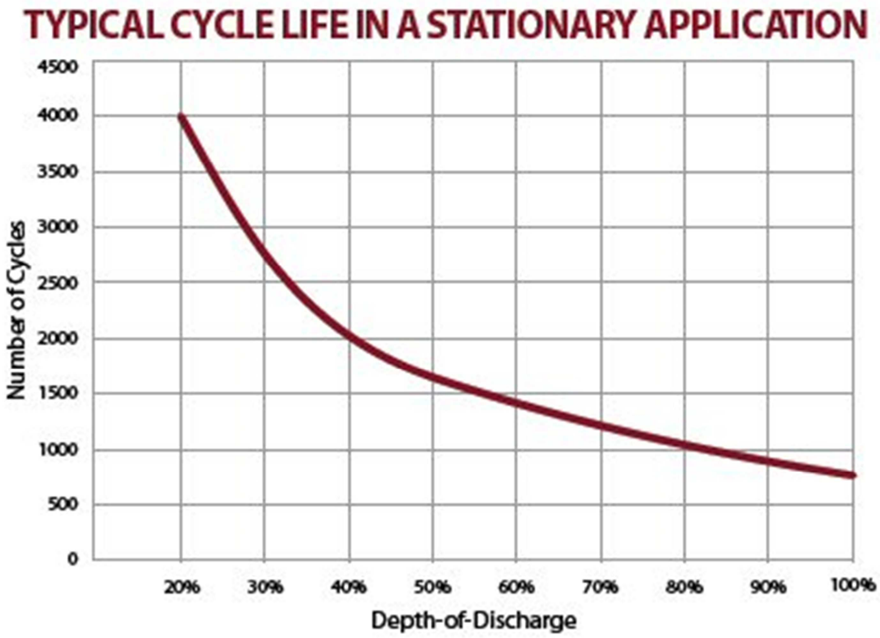


Figure 6- Depth of discharge of lithium- sulphur battery [8]

2.2.2.1.2 Nickel-Iron battery

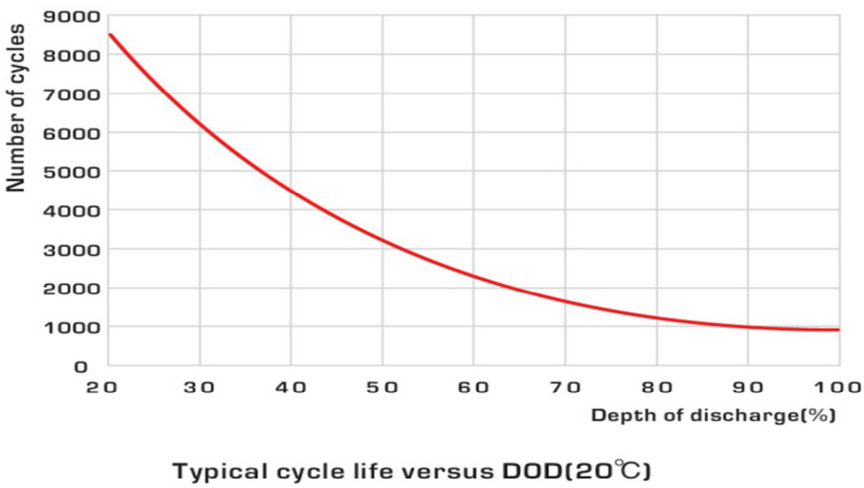


Figure 7- Depth of discharge nickel- iron battery [9]

Figure 7 shows depth of discharge nickel- iron battery

2.2.2.1.3 LiFePO4

The lithium iron phosphate (LiFePO4) is a type of rechargeable battery, which was researched in 1996. It has the greatest number charge/ discharge cycles. That is a reason why this technology is mainly adopted in applications requiring long life.

Major advantages of LiFePO4 are:

- Cycle life: from two thousand to several thousand (chart)
- Safe technology (no thermal runaway)
- Environment (very low toxicity- use of iron, graphite and phosphate)
- Calendar life
- Operational temperature range: up to 70°C
- Very low internal resistance. Stability or even decline over the cycles.
- Constant power throughout the discharge range.
- Ease of recycling

[9]

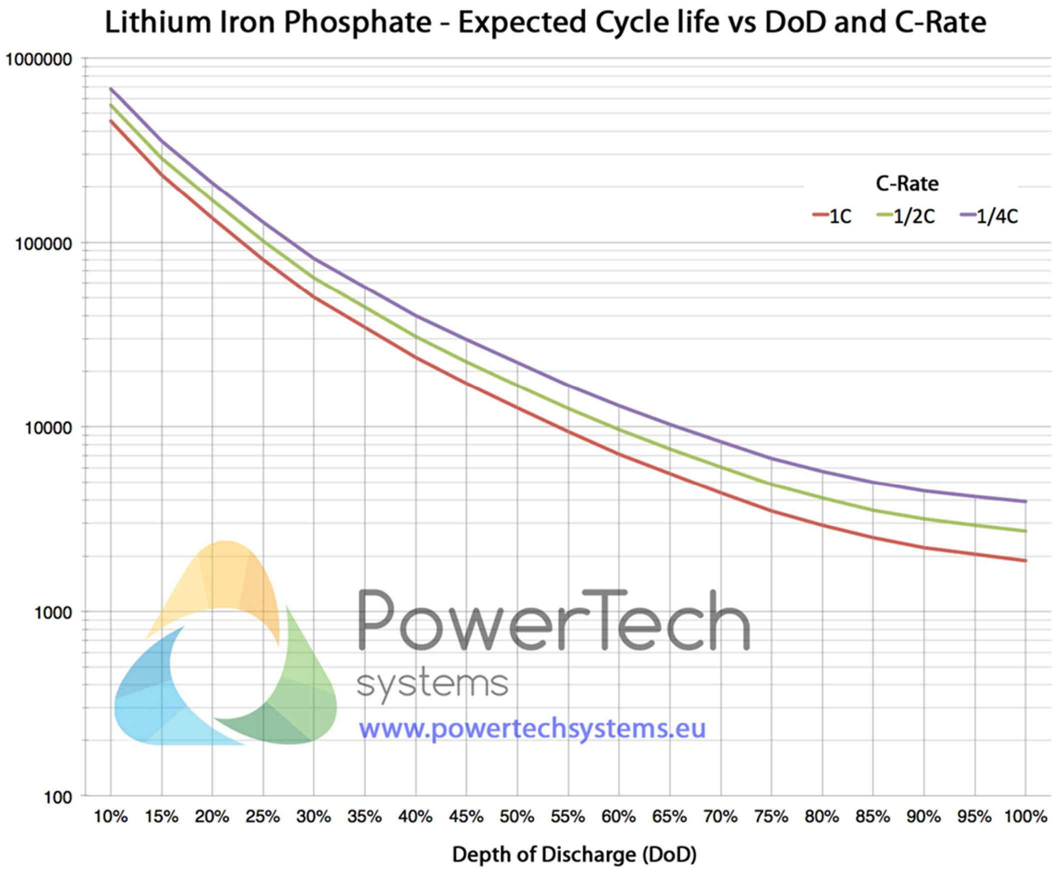


Figure 8- Depth of discharge of LiFePo4 [10]

The previous figure shows the estimated number of cycles for LiFePo4 according to the discharge power and DOD figures. The test conditions are those of a laboratory (constant temperature of 25 ° C, constant charging power and discharge). We can see in the figure that if depth of discharge is 100%, number of cycles would be 2000. If depth of discharge is 80%, number of cycles would be 3000. If depth of discharge is 55%, number of cycles would be 8000.

2.2.3 Inverter

We need in electrical network AC voltage because a lot of appliances need 230V, 50Hz. But electricity, which is produced from solar panel, is DC. Inverter transforms power from DC to AC. Mostly stand- alone inverters operate at 12, 24, 48, 96, 120 or 240V DC.

Inverter should have those features

- Sinusoidal output voltage
- High efficiency at light loads
- Less harmonic generation. Electronic appliances could be damage.
- Photovoltaic inverter must be able to withstand overloading for short term. (For example: starting currents from refrigerator)
- Adequate protection arrangement for short circuit, over/under – voltage etc.
- Surge capacity

  [3]

2.2.4 Diesel generator

The diesel generator is the most widely used option for the isolated system and definitely one of the most effective. A modern diesel generator, well designed for the intended load, is a very effective, reliable and relatively easy in maintenance device. The desirable load for generator is 25-80% of nominal. Higher load decreases lifetime of diesel generator; lower load provokes the higher fuel consumption and carbonization effect due to the gases in the cylinders of generator.

2.3 Conditions in Altai republic and Balyktuyul

The Altai Republic is situated in the middle of Russian on south, on the board with Mongolia, China and Kazakhstan. The area of the republic is 92 600km^2 and has 206 000 inhabitants. There are mountainous country and all those information are causes why there are a lots of place, which couldn´t connect with electrical network and it´s necessary use station stand- alone.

The Altai Republic has a temperate continental climate with hot summers, but summers are short. And the republic has long and cold winters, which are frosty.

Picture 10- Map of Russia [11]

I have chosen place, which is situated on the shores of lake. The lake is not far from Balyktuyul. Exactly position is: Location: 50°43'15" North, 88°14'39" East, Elevation: 1654 m a.s.l.,

Picture 11- Map of the Altai Republic [11]

Table 1- Average daily number of sunshine hours [12]

Month	January	February	March	April	May	June
Sunshine [hours]	5,4	6,1	7,8	9,7	11,2	12,9

Month	July	August	Septembe	October	Novembe	December
Sunshine [hours]	12,8	11,1	9,7	7	5,2	5,2

Table 2- Average monthly number of sunshine hours [12]

Month	January	February	March	April	May	June
Sunshine [hours]	167,4	183	241,8	291	347,2	387
Month	July	August	Septembe	October	Novembe	December
Sunshine [hours]	396,8	344,1	291	217	156	161,2

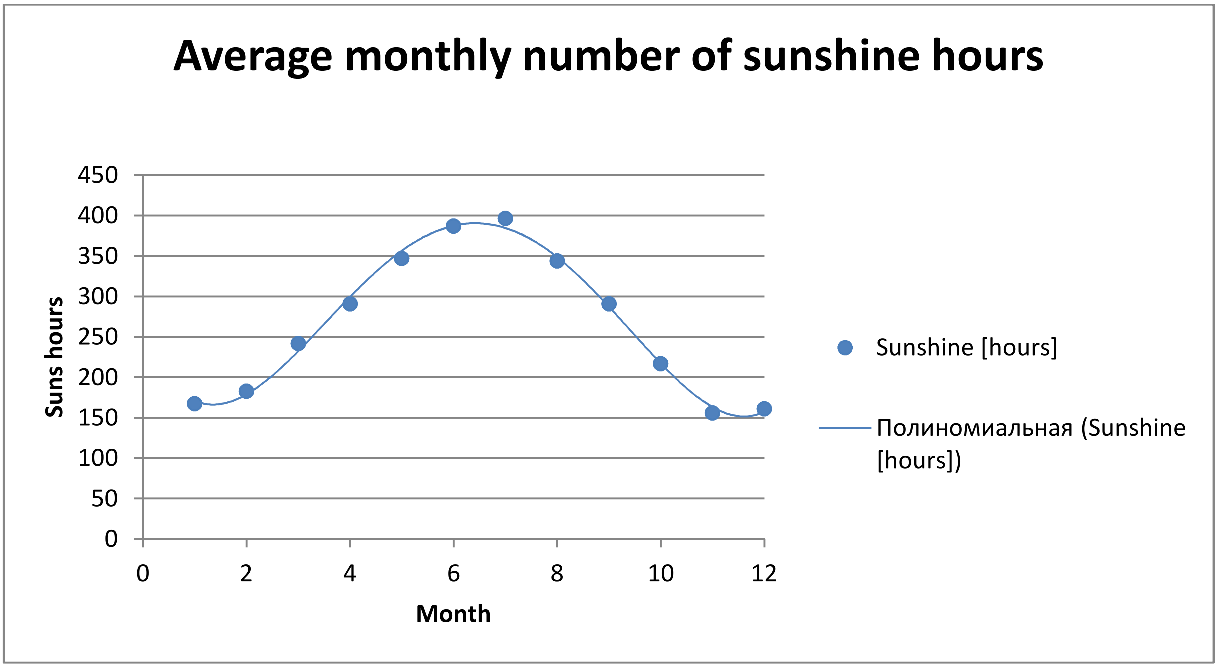


Figure 9- Average monthly number of sunshine hours

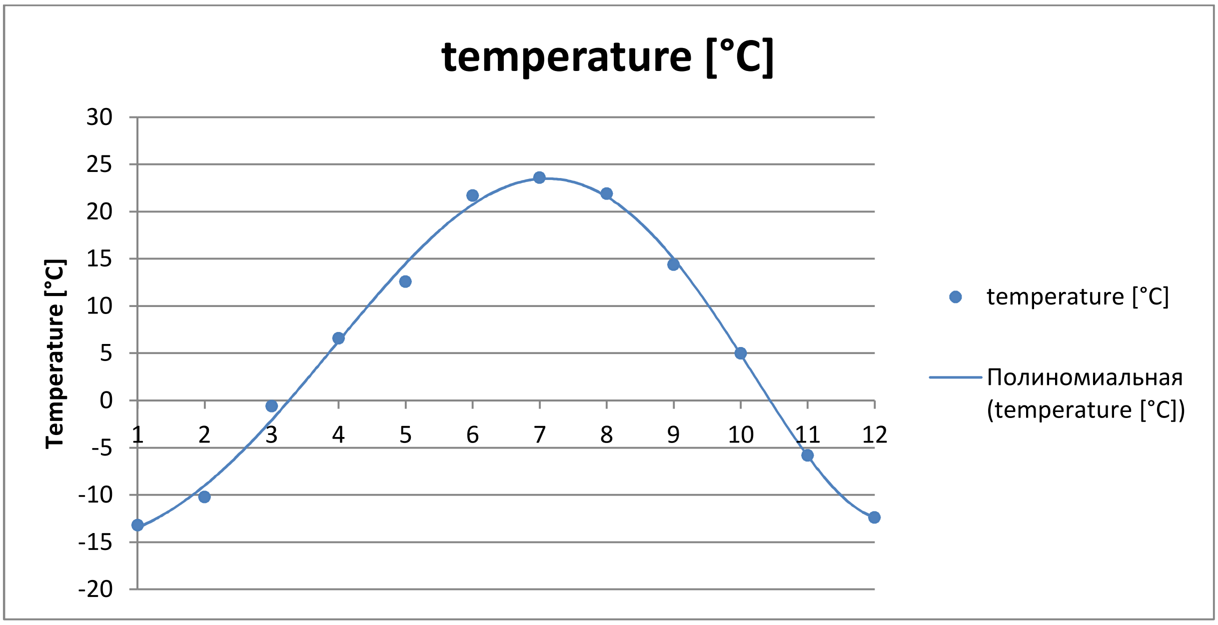


Figure 10- Day´s temperature in Balyktuyul [26]

3 Practical par

4 Economy

After explaining the core technical algorithms, I would like to complete the methodology explanation with an economical model. Installation of solar panels may make environmental sense straight on, because the power needed to produce panel is ‘repaid’ by the panel’s generation in the matter of years.

In this chapter I firstly calculated variant without diesel- generator because I needed to compare how much money I would save, when I would use PV- station with batteries. And from this variant I determined price of kWh. Usually I would compare energy from electric network, but it is not possible in my case, because network is very far and I can´t connect with network.

4.1 Economic evaluation of investment efficiency

4.1.1Cash flow

Cash flow is the net amount of cash and cash-equivalents moving into and out of the business. Positive cash flow indicates that a company's liquid assets are increasing, enabling it to settle debts, reinvesting in its business, returning money to shareholders, paying expenses and providing a buffer against future financial challenges. Negative cash flow indicates that a company's liquid assets are decreasing. Net cash flow is distinguished from net income, which includes accounts receivable and other items for which payment has not actually been received. Cash flow is used to assess the quality of a company's income, that is, how liquid it is, which can indicate whether the company is positioned to remain solvent. [31]

Cash flow is calculated as:

$$CFi = -I - IRi - MCi + Si \quad \text{[RUB]}$$

Equation 1- Cash flow CFi

Where i is current year, I symbolizes the initial investment, IRi is inverter renewal, MCi are maintenance costs, Si represents money saved using solar panels. Cumulative cash flow is a sum of capital flow from a project:

$$CCFi \ = \ \sum CFi \ i \ y = 0 \ [\text{RUB}]$$

Equation 2- Cumulative cash flow CCFi

Where i is current year. CCFi is used in some further economic indicators like PP (Payback Period).

4.1.2Discount Rate

The discount rate refers to the interest rate used in discounted cash flow (DCF) analysis to determine the present value of future cash flows. The discount rate in DCF analysis takes into account not just the time value of money, but also the risk or uncertainty of future cash flows; the greater the uncertainty of future cash flows, the higher the discount rate. [31]

It is more valuable to receive 1000 EUR today than the next year. The reason is you can use the money to bring you a benefit, most often an interest. Discount rate addresses this issue of differences in value of money in time. As a basic benchmark of a discount rate, I used 10-year bonds of EMU economies. The interest rates are not the same throughout those countries. For example, Slovakia yields interest rate of 0.5% and Greece has 11.43%. Most of the other states, however, have their rates between 1% and 3%. [32] Therefore, I will take 2% as a basis. The next question is: ,, Is the risk the same with invest money into European bonds and invest into photovoltaic power plant?´´ Government bonds are respected as a save investment. Sure, countries can go bankrupt, how happened couple of times in past decades, but we can say, that government bonds are save invest. On another side, there are many risks with photovoltaic power plan. For example inverters may not have lifetime as expected, panels may degrade faster, than we expected, weather may be unfavorable for years. Therefore I used a discount rate of 5%. I am doing a sensitivity analysis in one of the following chapters.

4.1.3 Discounted cash flow

A discounted cash flow (DCF) is a valuation method used to estimate the attractiveness of an investment opportunity. Discounted cash flow analysis uses future free cash flow projections and discounts them to arrive at a present value estimate, which is used to evaluate the potential for investment. If the value arrived at through discounted cash flow analysis is higher than the current cost of the investment, the opportunity may be a good one. [31]

$$DCFi = \frac{CFi}{(1+r)\hat{}i}\ [RUB]$$

Equation 3- Discounted cash flow DCFi

Where r represents discount rate and CF_i is cashflow in year i.

DCFi would be always smaller than non- discounted CFi, if discount rate is greater than 0%.

$$CDCFi = \sum_{y=0}^{i} DCFi\ [RUB]$$

Equation 4- Cumulative discounted cashflow

4.1.4 Payback period

Payback period (PP) is the time in which the initial cash outflow of an investment is expected to be recovered from the cash inflows generated by the investment. It is one of the simplest investment appraisal techniques.

$$PP = number\ of\ years\ untill \sum_{y=0}^{i} CFi\ became\ positive\ [RUB]$$

Equation 5- Payback period

Payback method advantages and disadvantages:

PP is useful from a risk analysis perspective. Advantage is quick picture of the amount of time that the initial investment will be at risk. In this method is the best choice invest, which has payback method lowest. It tends to be more useful in industries where investments become obsolete very quickly, and where a full return of the initial investment is therefore a serious concern. This method has those disadvantages:

- *Asset life span*. If an asset's useful life expires immediately after it pays back the initial investment, then there is no opportunity to generate additional cash flows. The payback method does not incorporate any assumption regarding asset life span.
- *Additional cash flows*. The concept does not consider the presence of any additional cash flows that may arise from an investment in the periods after full payback has been achieved.
- *Cash flow complexity*. The formula is too simplistic to account for the multitude of cash flows that actually arise with a capital investment. For example, cash investments may be required at several stages, such as cash outlays for periodic upgrades. Also, cash outflows may change significantly over time, varying with customer demand and the amount of competition.
- *Time value of money*. The method does not take into account the time value of money, where cash generated in later periods is work less than cash earned in the current period. A variation on the payback period formula, known as the discounted payback formula, eliminates this concern by incorporating the time value of money into the calculation.

[33]

4.1.5Net Present Value (NPV)

NPV includes the value of money in time. Net present value indicates, what is the net benefit, when carrying on with the project at current terms. In comparison to payback period.

$$NPV = \sum_{t=1}^{T} \frac{Ct}{(1+r)^\wedge t} - Co \text{ [RUB]}$$

Equation 6- Net present value

Where Ct means net cash inflow during the period t, C_o represents total initial investment costs, r is discount rate and t represents number of time periods.

A positive net present value indicates that the projected earnings generated by a project or investment (in present dollars) exceeds the anticipated costs (also in present dollars). Generally, an investment with a positive net present value will be a profitable one and one with a negative net present value will result in a net loss. This concept is the basis for the NPV rule, which dictates that the only investments that should be made are those with positive net present values. [31]

I calculated NPV for 20 years. It was difficult to determine lifetime of system but I have chosen this value because I design DoD 60% and it is mean that lifetime of batteries would be around 20 years. Solar panels could work for a long time, but batteries represent the most part of price, therefor I have chosen lifetime of system 20 years.

4.1.6Internal Rate of Return (IRR)

Internal rate of return (IRR) is a metric used in capital budgeting measuring the profitability of potential investments. Internal rate of return is a discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero. IRR calculations rely on the same formula as NPV does. [31]

$$NPV = \sum_{t=1}^{T} \frac{CFt}{(1+IRR)^\wedge t} = 0 \text{ [RUB]}$$

Equation 7- Internal rate of return [%]

To calculate internal rate of return using the formula, one would set net present value equal to zero and solve for the discount rate r, which is here the internal rate of return. IRR cannot be calculated analytically. We must instead be calculated either through trial-and-error or using software programmed to calculate internal rate of return.

Generally speaking, the higher a project's internal rate of return, the more desirable it is to undertake the project. Internal rate of return is uniform for investments of varying types and, as such, internal rate of return can be used to rank multiple prospective projects a firm is considering on a relatively even basis. Assuming the costs of investment are equal among the various projects, the project with the highest IRR would probably be considered the best and undertaken first. [57]

4.2 Evaluation of project

For evaluation of my project is necessary to calculated cost, if I would use only diesel- generator. And then I compare my variant with variant without PV-station.

4.2.1Variant without PV- station

This variant is without PV-station and there will be only diesel- generator. Also there will not be batteries. This variant is for comparison and determine profitability of project with PV- station and with batteries. Usually I have seen only diesel-generator on houses in the Altai Republic, but this variant is not ecologic and it is consuming a lot of diesel.

My diesel generator has consumption 1.4l/h for 3000W. I assume work of diesel generator 20hours per one day, but consumption is not 3000W all the time. Average consumption of kWh and this value is 0.9l/kWh. [23]

It is very hard to predict prices for longer time period. The fuel price depends on many factors as political or economical situation. I determined the price of diesel from average price of diesel from last 2 years plus transport. I determined price of one liter 38RUB. Prediction a price is very difficult, because nobody knows, what will happen in the future. For prediction of prices I checked website yandex.ru and I found prices in the past. Prices have been unstable and after consultation with my supervisor I assume increasing of this price by 3% every year. The next important value is inflation, I calculated average inflation from last 15 years and it is 11.48%. I am keeping this value for next 20 years. [34]

Then I calculated how much I would pay for diesel for a year. I multiplied price of a liter [RUB/l], average consumption of generator [l/kWh] and consumption [kWh/year]. This value is changing, because increase diesels price. The next costs are maintenance costs. I have included: oil change, filters, work, cleaning. It is necessary do it two times in a year in this variant. I have chosen this value 8000RUB in the first year and then this value will increase, due to inflation. I chose maintenance cost after consultation with firm,, *Namir´´*. [35] After those calculations I was able to calculate average price of kWh in this system. I summed cost of diesel [RUB/year] and maintenance cost [RUB/year] and divided consumption [kWh/year]. This value is changing too, due to inflation and increasing costs of diesel. Average price of kWh is 35.2RUB/kWh in the first year.

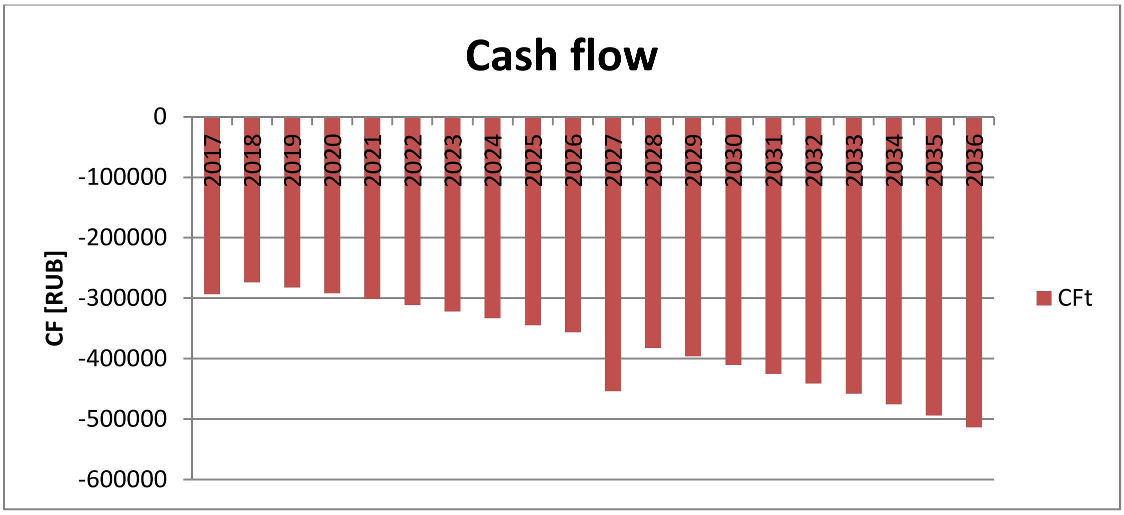


Figure 11- Cash flow in variant without PV-station

The previous figure shows cash flow in variant, where is used only diesel-generator. In the first year is include invest costs and I predict change a diesel-generator after ten years. I assume to buy the same diesel- generator like in the first year and its price increase in accord with inflation.

4.2.2 Compare variant without PV- station and with PV- station (34m²)

I have designed PV- station, which has $34m^2$. Energy from this PV- system with batteries cover consumption during 9 months, but I have to remember for efficiency drop. I have chosen this value 2% per one year. [36] It means, I will need more energy from diesel generator every year. I calculated how much energy I will need from diesel- generator from consumption of months, which wouldn´t be covered by energy from PV-station.

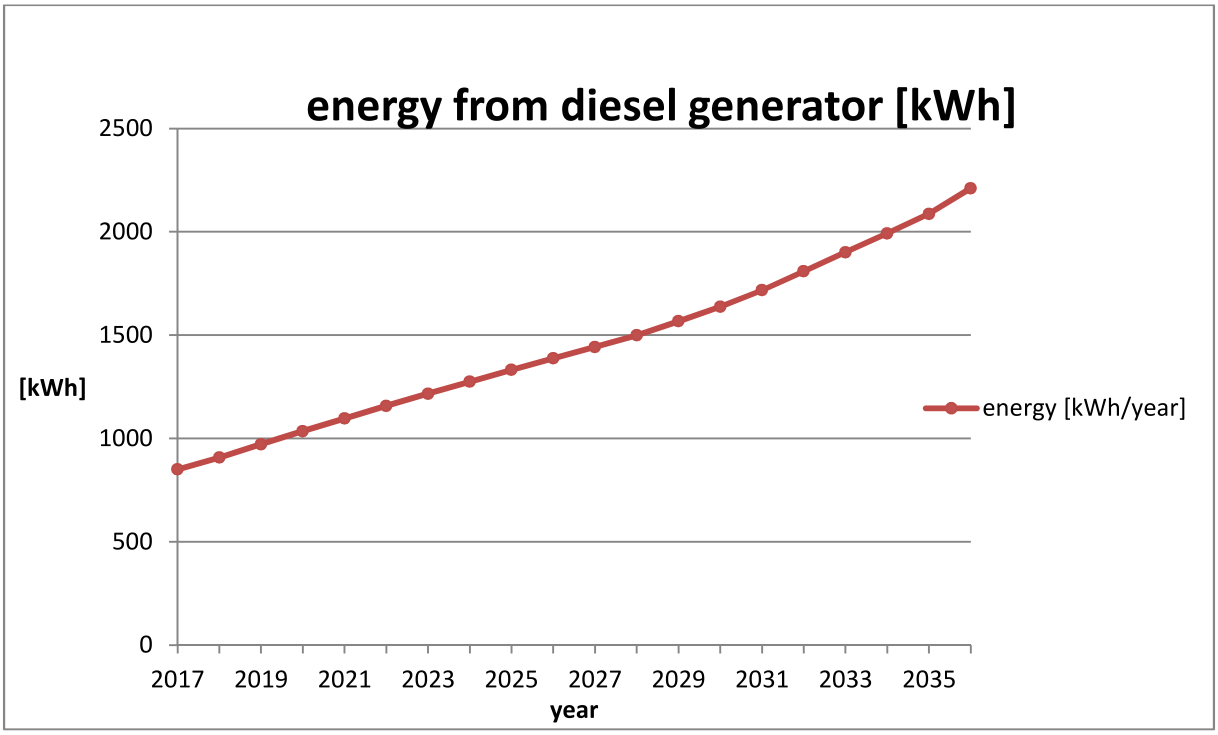


Figure 12- How much energy I need from diesel generator

The previous figure illustrates how much energy I will need from diesel generator every year. Increase of energy is because efficiency is falling every year, but not for more than 50%, what somebody could think from the previous figure. It is because we don´t use all energy during some month and everything is calculated in appendix. I included to calculations, PV- station will not work during one week in summer. Reason could be for example bad weather. It means I include energy (average consumption during summer per one week) to energy, which I will need from diesel- generator. I did not include invest price of diesel- generator, because I would buy it also if I would not use PV- station.

Another cost is maintenance cost, which I calculated sum maintenance costs of diesel generator and maintenance costs of system. I consulted about maintenance costs of diesel generator with firm,, *Namir´´* and they recommend me that I will do changing oil and filters once in a year during first ten years and then two times. I also save money for no replacement diesel- generator, which is necessary in variant without PV- station, but I will use diesel- generator not so much like in variant without PV- station. I will use diesel- generator more during years, because efficiency of system is falling and I will need more energy from diesel- generator. Maintenance costs of system I determined 0.35% from price of solar panels. I determined maintenance costs after consultation with Ing. Rostislav Krejcar, Ph.D., who was my supervisor in the Czech Republic in CTU. I also calculated how many energy I will save from diesel generator and this value equals different between consumption of house and how much energy I will use from diesel- generator. I did not include for calculation profitability price of diesel- generator, protection PL7-B20/1 Eaton, because I would need to buy it also in the case, when I would choose variant without PV- station

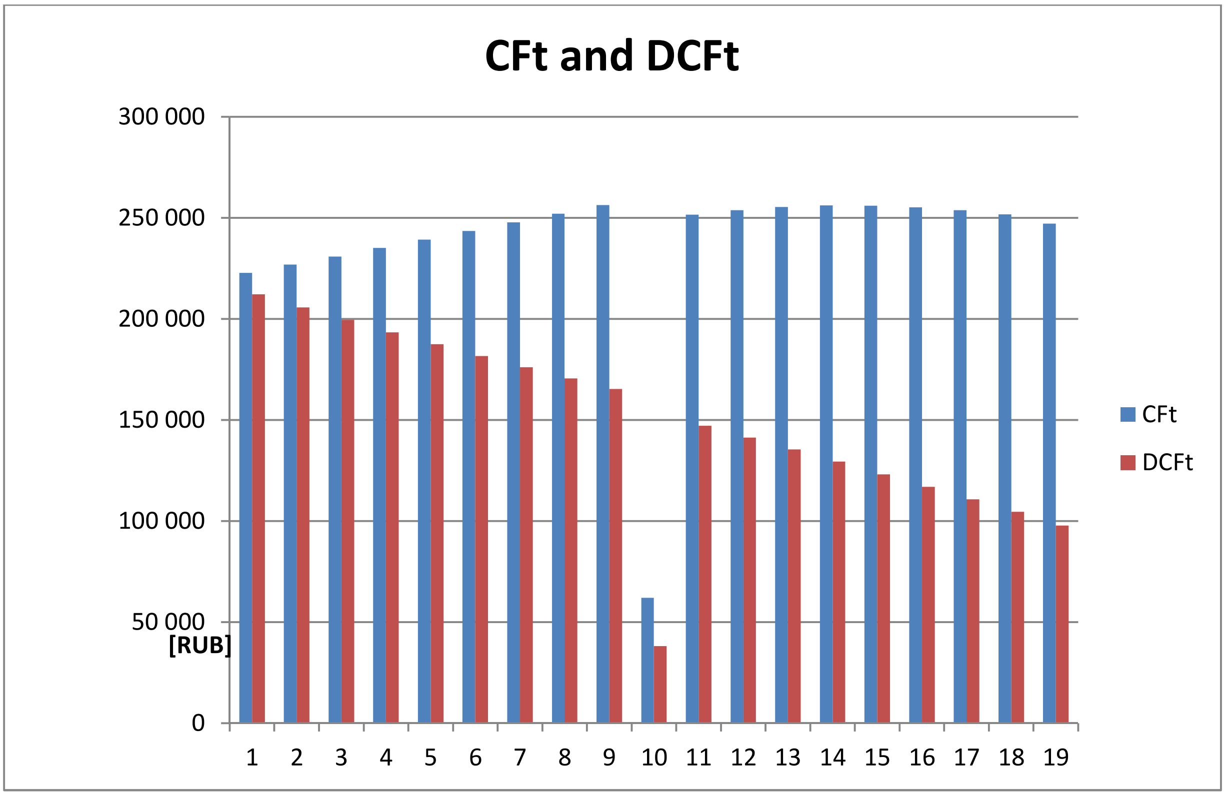


Figure 13- CFt and DCFt

I can see in the previous figure CF and DCF during individual years. CF rises because price of diesel increase, but vice versa save energy from diesel- generator is falling. I put CFt and DCFt from first year (not zero year, where is invest), because CF in zero year is lower than -2 500 000RUB and figure would not be well-arranged. CFt and DCFt is lower in tenth year, because I assumed replacement new inverter.

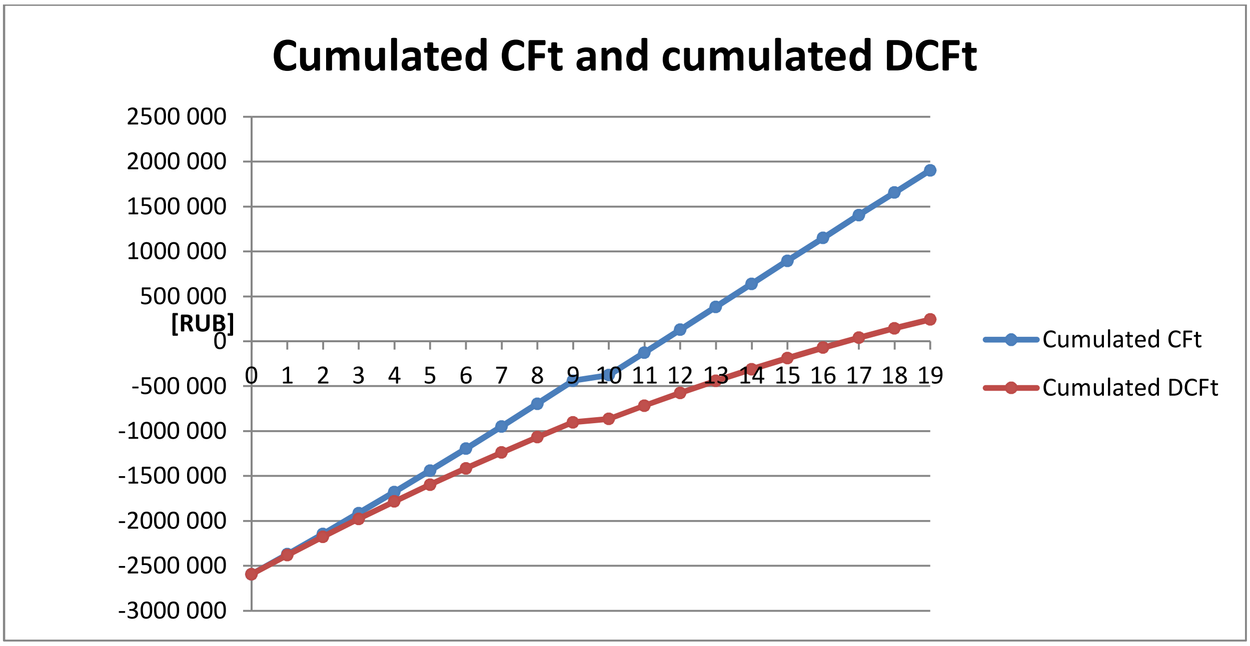


Figure 14- Cumulated CFt and cumulated DCFt

Table 3- Results of variant with 34m2

NPV [RUB]	**242 681**
IRR [%]	**6.10%**
PP [years]	**11.49**
DPP [years]	**16.52**

As we can see in the previous figure, CF and DCF are lower in tenth year than other years, because I assume change inverter after ten years. I determine discount rate 5%. NPV equals cumulated DCF in last year, what is 242 681RUB. The next important value is IRR, which describes discount rate, when NPV would be zero. IRR is 6.1% in our project, it means if discount rate would be lesser than 6.1% NPV would be positive and vice versa if discount rate would be higher, NPV would be negative. We can read payback period in previous figure. This point is where cumulate CFt crosses 0. Payback period is 11.49 years without include discount. But better factor is discount payback period. This value we can find, where cumulate DCFt crosses 0. Discount payback period is 16.52 years.

4.2.3 Compare variant without PV- station and with PV- station (27m²)

Power from this PV- station, which has area $27m^2$ and power is 3.1kWp. I chose this area, because energy from this PV- station covers consumption during six months in the first year. I assume efficiency falling 2% per one year, like the previous variant. The next change is replacement new diesel- generator over ten years together with new inverter. I calculated prices in the future using inflation, which I kept 11.48%. This value is average for last fifteen years. [34] I replacement diesel- generator, because it will work often that in previous variant and I decided like this after consultation with firm ,, Namir´´. [60] Energy from PV- station will covered no month after ten years, thanks to falling efficiency. It means, I will use diesel- generator on all months, but not all the time of course.

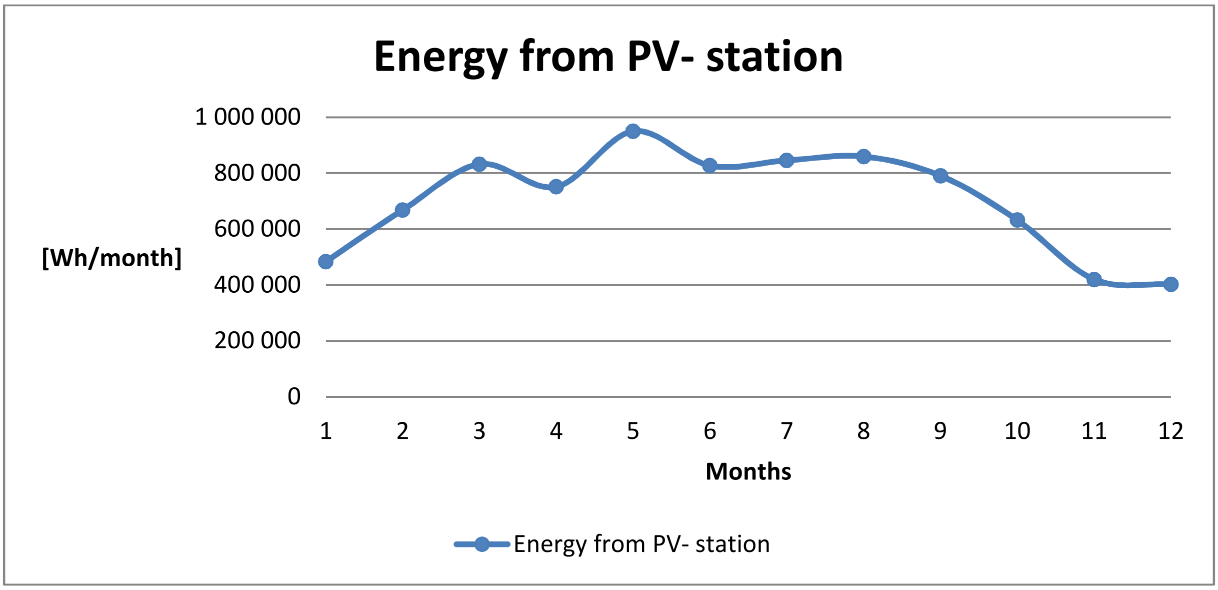


Figure 15- Energy from PV-station

Figure 32 shows yearly energy production of PV- station in first year. I can see, peak is in May and the lowest production is in December. Unfortunately consumption is the highest in December too. Then it was necessary compare daily production and daily consumption.

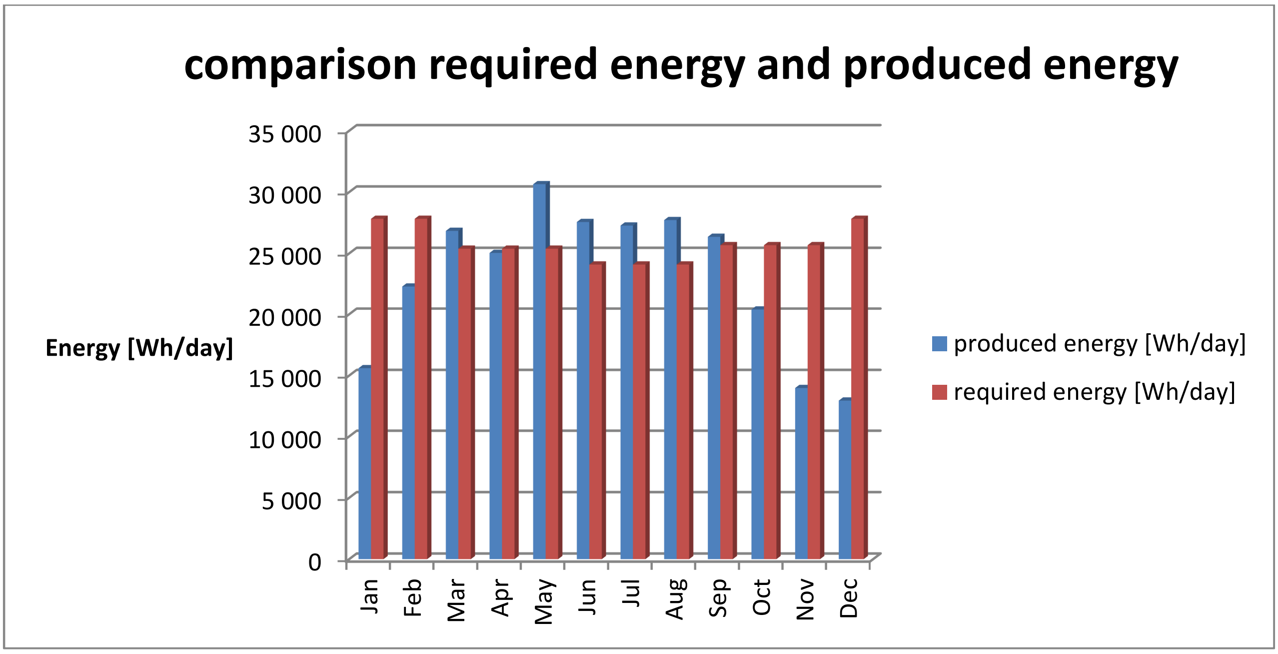


Figure 16- Comparison required energy and produced energy

The previous figure shows comparison required energy and produced energy. Required energy is higher than produced during six months. Otherwise required energy is lower than produced energy during another six months. Produced energy is falling every year and after ten years is lower than required energy on all months. Therefore diesel- generator will be used in all months, but of course not for all the time.

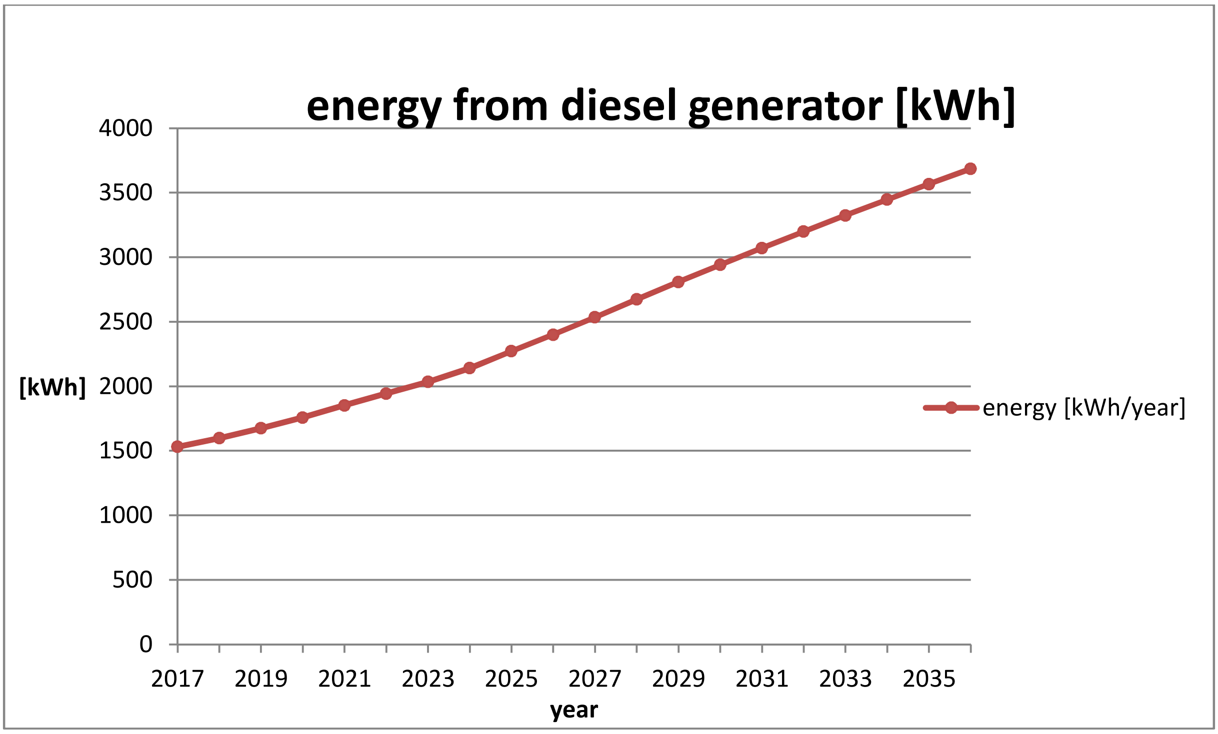


Figure 17- How much energy I need from diesel generator

I calculated how much energy I will need from months, which their consumption is not covered from PV- station. Another calculations are the same like in variant with $34m^2$.

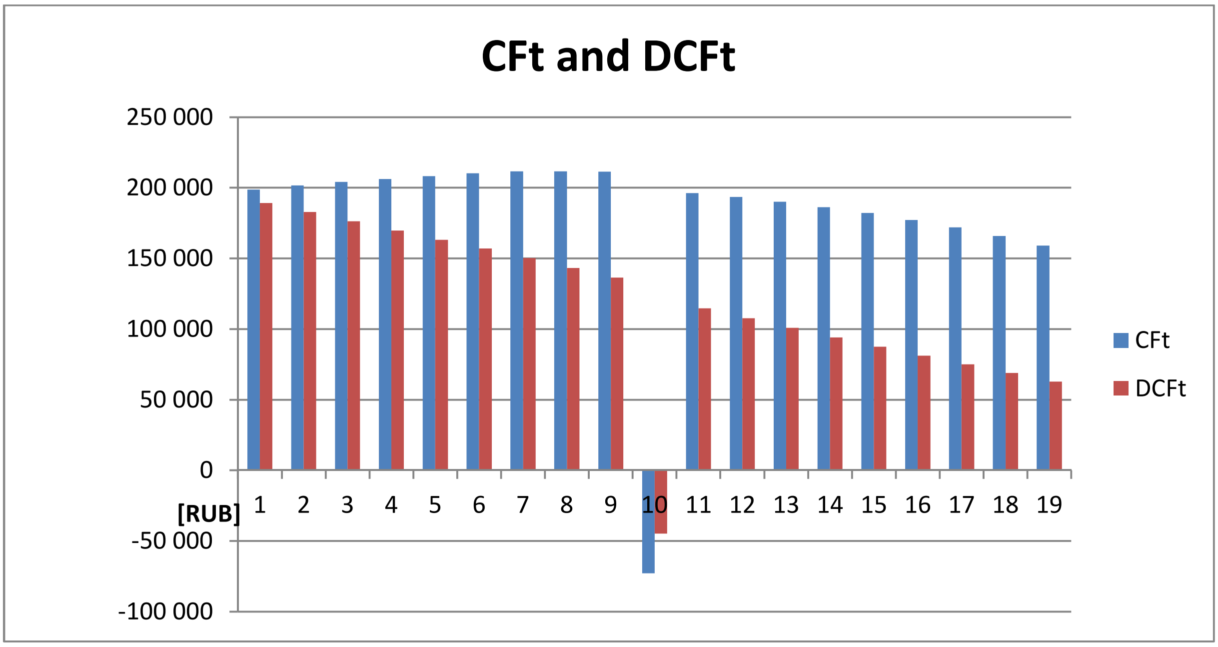


Figure 18- CFt and DCFt

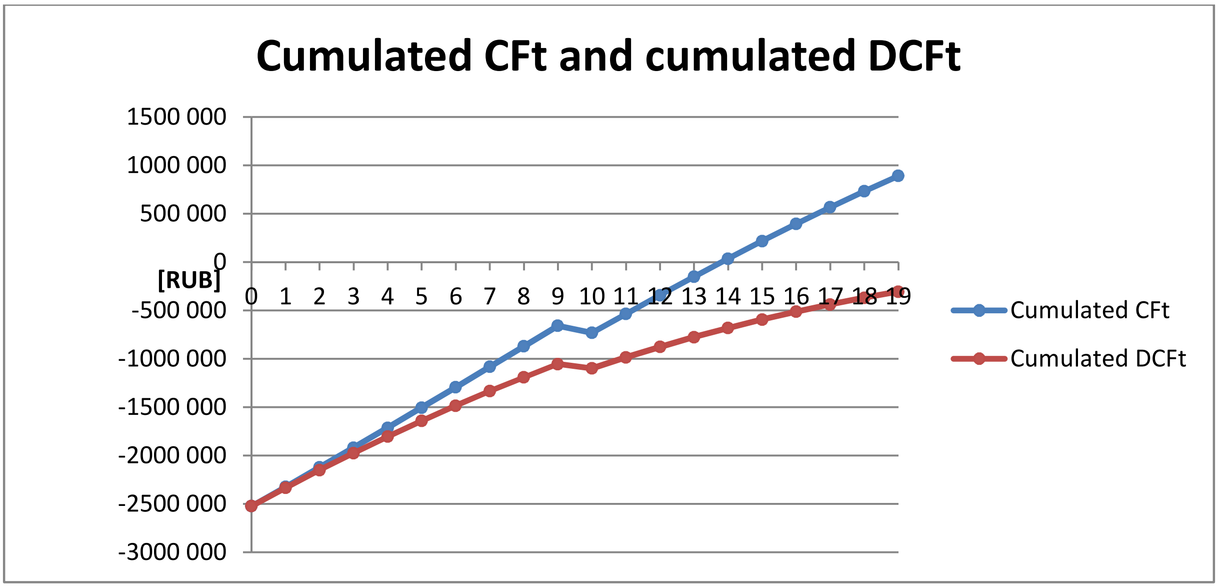


Figure 19- Cumulated CFt and cumulated DCFt

The previous figure shows cumulated CFt and cumulated DCFt with variant area 27m^2 of solar panels. We can drop CF in tenth year, it is because I replacement new inverter and diesel- generator. Reason, why CF is not constant, is increasing price of diesel and falling efficiency of system.

Table 4- Results of variant with 27m2

NPV [RUB]	**-306 520**
IRR [%]	**3.38%**
PP [years]	**13.82**
DPP [years]	**-**

I determine discount rate 5% like in the previous variant and then I will able to compare it. NPV equals cumulated DCF in the last year, what is -306 520RUB. Another important value is IRR, which describes discount rate, when NPV would be zero. IRR is 3.38% in our project, it means if discount rate would be lesser than 3.38% NPV would be positive and vice versa if discount rate would be higher, NPV would me negative. We can read payback period in the previous figure. This point is where cumulate CFt crosses 0. Payback period is 13.82 years without include discount. But better factor is discount payback period. This value we can´t find, because cumulate DCFt does not cross 0. It would cross 0 after 20 years, but I assume 20 years life time.

4.3 Sensitivity analysis

I did sensitivity analysis for better understanding of dependency of project value on different input values. Analysis shows the character of project value, when the value of inputs are changed.

The first analysis shows dependency on value of discount. It has been calculated for values from 0 to 10 percent. Result of analysis is shown in the next figure:

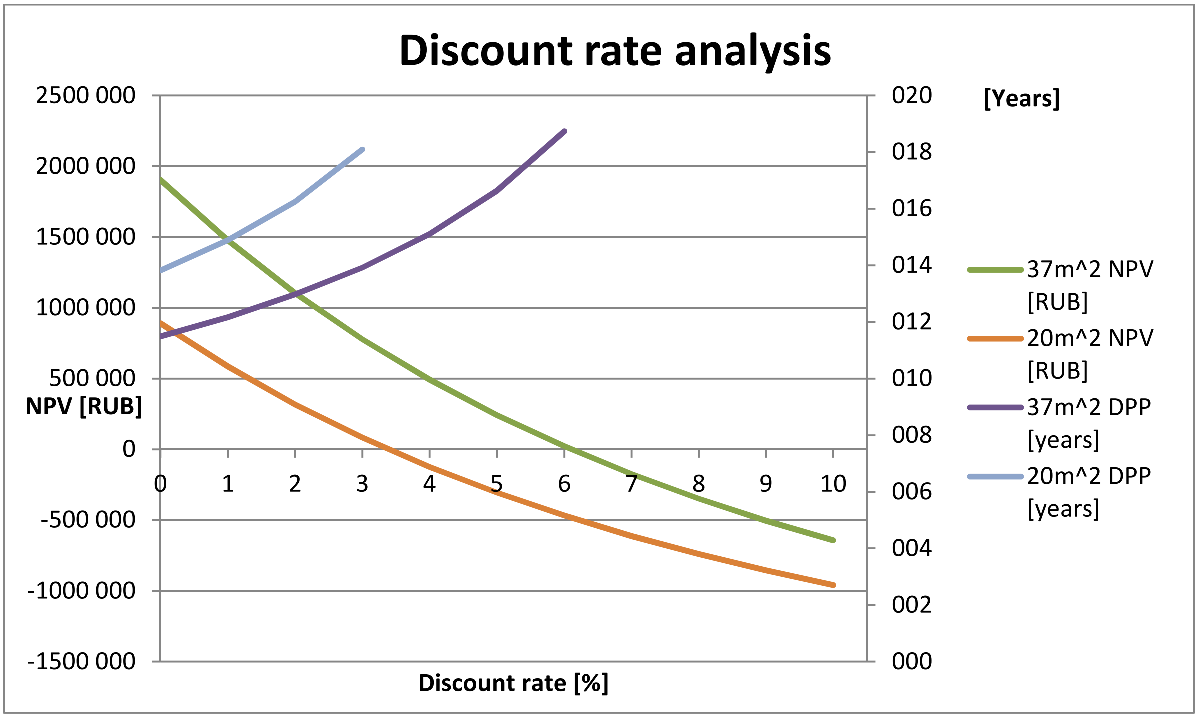


Figure 20- Results of discount rate analysis

By changing the discount rate the NPV value varied inversely.NPV value is the highest with the lowest discount rate. Value of discount rate, when NPV is 0, equals IRR. Discount payback period finishes in the same moment, where NPV starts to be negative.

Price of fuel for diesel- generator is very important for results in my case, because it is not possible connect to network. It is very hard to predict prices for longer time period. The fuel price depends on many factors as political or economical situation. Correlation between evolution of fuel price and NPV value was counted in range from -10% to +10%.

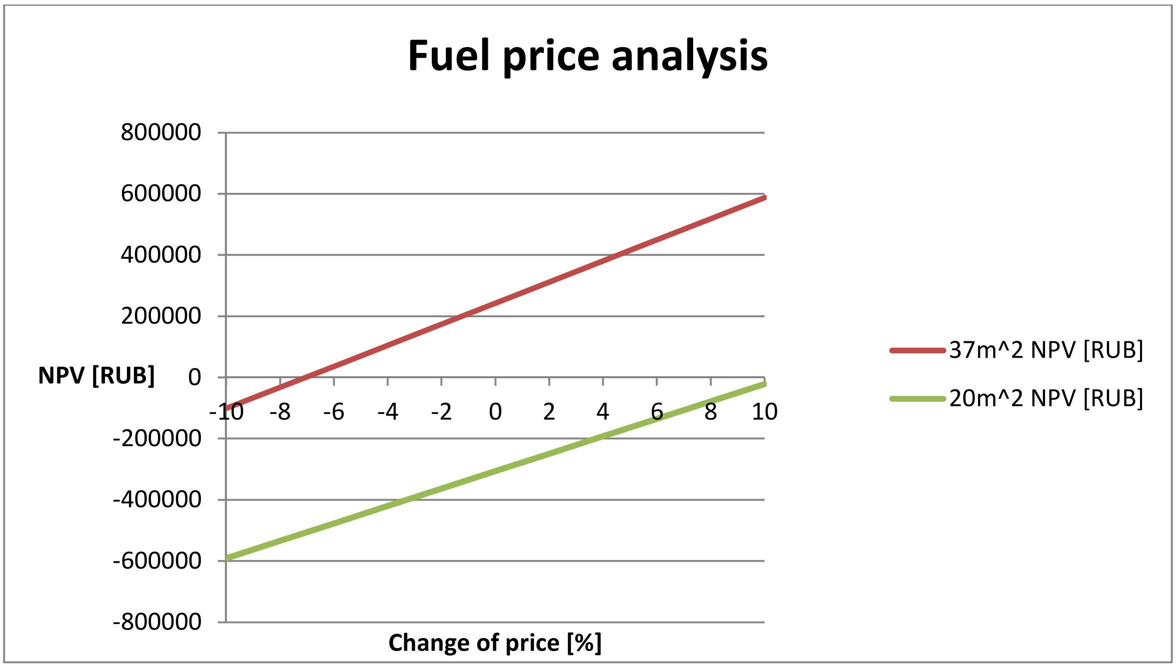


Figure 21- Fuel price analysis results

The figure 38 shows strong dependence between fuel price and NPV value. Fuel price is very important input value for results.

The next sensitivity analysis is about inflation.

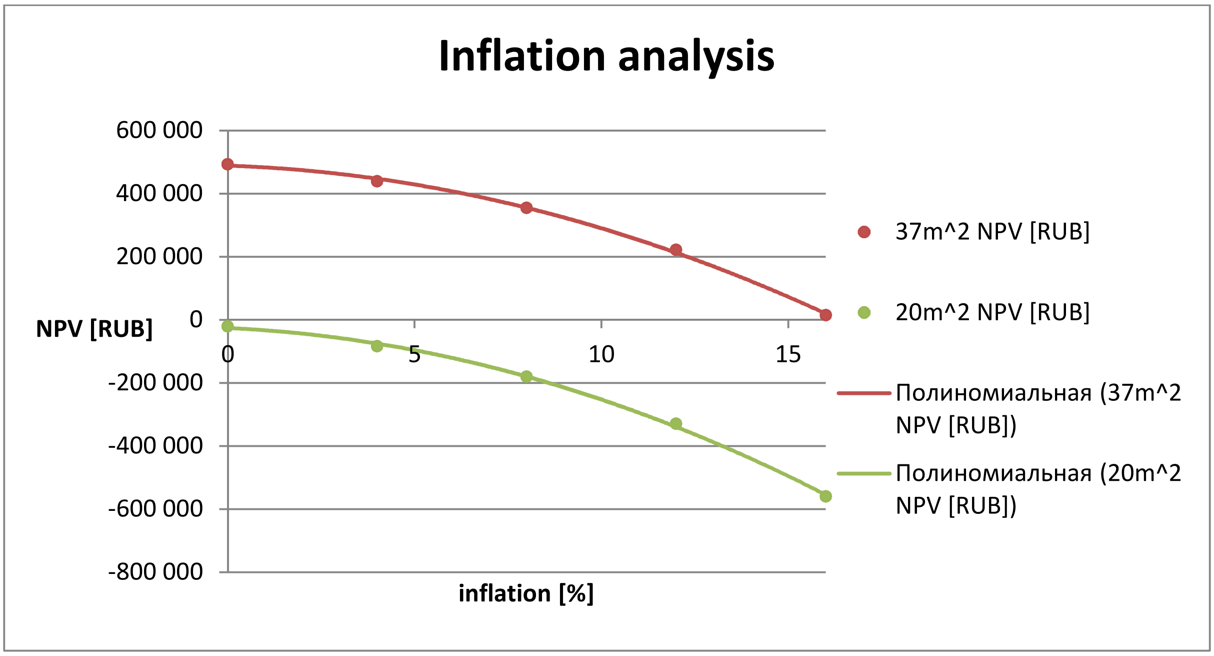


Figure 22- Inflation analysis

The previous figure show sensitivity analysis, when inflation is changing. We can see, if inflation would be 16%, NPV of variant with $37m^2$ would be 0, it means discount payback period would be around 20 years. NPV of variant with $20m^2$ would be negative in each case.

5 Social responsibility

Conclusion

6 Sources