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**«НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ
ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ»
/ NATIONAL RESEARCH TOMSK POLYTECHNIC UNIVERSITY**

School of Energy & Power Engineering
Отделение – Division for Power and Electrical Engineering
Направление подготовки – 13.04.02 Электроэнергетика и электротехника / Direction – Electric Power and electrotechnics
Магистерская программа –MA Course – Electric Power Generation and Transportation

МАГИСТЕРСКАЯ ДИССЕРТАЦИЯ / MASTER'S THESIS

Тема работы / Theme
« Проектирование системы электроснабжения с использованием ВИЭ по действующим тарифам на электроэнергию в Чехии / Designing a power supply system with RES at current electricity tariffs in the Czech Republic»

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УТВЕРЖДАЮ/APPROVED:

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на выполнение выпускной квалификационной работы / for the execution of the graduate qualification work

В форме / Form:

магистерской диссертации / master thesis

Студенту / Student:

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5АМ9Ч	Петруй Якуб / Petrůj Jakub

Тема работы / Theme:

« Проектирование системы электро-снабжения с использованием ВИЭ по действующим тарифам на электроэнергию в Чехии / Designing a power supply system with RES at current electricity tariffs in the Czech Republic»	
Утверждена приказом директора (дата, номер) / Approved by order of the Rector (date, number)	Приказ № 148-49/с от 28.05.2021

Срок сдачи студентом выполненной работы / Deadline student work done::	01.08.2021

ТЕХНИЧЕСКОЕ ЗАДАНИЕ / PRELIMINARY SPECIFICATIONS:

Исходные данные к работе / Initial data	Introduce current state in solar energetics and different technology of solar power systems. Present typical consumer of solar energy and their load charts overview. Choose one type of customer and design according his needs solar system. Determine cost of this system and choose the most economically effective variant. Evaluate cost per generated kWh. Design comparable systems in Czech republic, make technical-economic analysis and compare conditions. Find out the best supply variant for different conditions

Перечень подлежащих исследованию, проектированию и разработке вопросов / List to be investigated, design and development issues	– Technology of solar cells – Generations of solar systems; – Constructions of solar systems; – Types of the systems; – Current state on solar market; – Opportunities for solar systems in Czech Republic;

Консультанты по разделам выпускной квалификационной работы	
Раздел / Chpter	Консультант / Consultant
Финансовый менеджмент, ресурсоэффективность и ресурсосбережение / Financial management and pollution savings	Сурков Михаил Александрович / Surkov Mikhail
Социальная ответственность / Social responsibility	Сурков Михаил Александрович / Surkov Mikhail
Раздел, выполняемый на английском языке / Chapter carried out on English language	Сурков Михаил Александрович / Surkov Mikhail

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Задание принял к исполнению студент:

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Направление подготовки 13.04.02 Электроэнергетика и электротехника
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Форма представления работы:

Магистерская диссертация

КАЛЕНДАРНЫЙ РЕЙТИНГ-ПЛАН
выполнения выпускной квалификационной работы

Срок сдачи студентом выполненной работы:	

Дата контроля	Название раздела/ вид работы	Максимальный балл раздела, %
	1. Literature overview	*8*
	2. Solar energy	*25*
	3. Potential of solar energy. Photoelectric effect. Principle of a photovoltaic cell.	*12*
	4. Types of photovoltaic systems. Main components of every photovoltaic system. Current legislative situation in Czech Republic.	*25*
	5. Evaluation of economic efficiency of investments	*10*
	6. Safety devices	*10*
	7. English chapter	*10*
	Complete Master thesis	*100*

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Должность	ФИО	Ученая степень, звание	Подпись	Дата
Доцент / Docent	Сурков Михаил Александрович / Surkov Mikhail	к.т.н./ /Ph.D		01.10.2020

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Планируемые результаты обучения по ООП

Код результата	Результат обучения
	Универсальные компетенции
P1	*Совершенствовать* и развивать свой *интеллектуальный* и *общекультурный уровень*, добиваться *нравственного и физического совершенствования* своей личности, обучению новым методам исследования, к изменению научного и научно-производственного профиля своей профессиональной деятельности.
P2	*Свободно пользоваться русским и иностранным языками* как средством делового общения, способностью к активной социальной мобильности.
P3	*Использовать* на практике *навыки и умения* в *организации* научно-исследовательских и производственных работ, в *управлении* коллективом, использовать знания правовых и этических норм при оценке последствий своей профессиональной деятельности.
P4	*Иметь* представление о методологических основах *научного познания и творчества*, роли научной информации в развитии отрасли, навыки проведения работ с привлечением *современных информационных технологий*, синтезировать и критически резюмировать информацию.
	Профессиональные компетенции
P5	*Применять углубленные естественнонаучные, математические, социально-экономические и профессиональные знания* в междисциплинарном контексте в инновационной инженерной деятельности в области электроэнергетики и электротехники.
P6	Ставить и *решать инновационные задачи* инженерного анализа в области электроэнергетики и электротехники с использованием глубоких фундаментальных и специальных знаний, аналитических методов и сложных моделей в условиях неопределенности.
P7	Выполнять *инженерные проекты* с применением оригинальных методов проектирования для достижения новых результатов, обеспечивающих конкурентные преимущества электроэнергетического и электротехнического производства в условиях жестких экономических и экологических ограничений.
P8	Проводить инновационные *инженерные исследования* в области электроэнергетики и электротехники, включая критический анализ данных из мировых информационных ресурсов.

P9	Проводить *технико-экономическое обоснование* проектных решений; выполнять организационно-плановые расчеты по созданию или реорганизации производственных участков, планировать работу персонала и фондов оплаты труда; определять и обеспечивать эффективные режимы технологического процесса.
P10	Проводить *монтажные, регулировочные, испытательные*, наладочные работы электроэнергетического и электротехнического оборудования.
P11	*Осваивать новое* электроэнергетическое и электротехническое *оборудование;* проверять техническое состояние и остаточный ресурс оборудования и организовывать профилактический осмотр и текущий ремонт.
P12	Разрабатывать рабочую проектную и научно-техническую документацию в соответствии со стандартами, техническими условиями и другими нормативными документами; организовывать метрологическое обеспечение электроэнергетического и электротехнического оборудования; составлять оперативную документацию, предусмотренную правилами технической эксплуатации оборудования и организации работы.

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In Tomsk, 24th March 2020

Petrůj ....

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Tomsk Polytechnic University

Institute of Power Engineering

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Faculty of Electrical Engineering

Citation of this thesis:

Petrůj, Jakub. "Comparison of photovoltaics systems in Czech Republic". Master's thesis. Tomsk Polytechnic University, Institute of Power Engineering, 2020.

Abbreviations

AM	Air Mass Coefficient
MPP	Maximum power point
PVP	Photovoltaic power plant
NPV	Net present value
IRR	Internal rate of return
ERO	Energy regulatory office
CR	Czech Republic
CF	Cash flow
DCF	Discounted cash flow
VB	Virtual battery

Abstract

This final qualifying work contains 110 pages, 16 figures, 8 tables, 33 sources, 13 appendixes.

Key words: power supply, photovoltaics, solar systems, batteries, financial management, net present value.

Purpose of work: Designing and comparing multiple household photovoltaic systems at current electricity tariffs in the Czech Republic and calculating their rentability.

The object of the research is designing different types of photovoltaic systems and calculating their various rentability.

Research methods: mathematical modeling, comparison, analysis, several financial tools.

During the development process, several different photovoltaic systems were considered including one using battery system for storage of energy excess.

The result of the development is a recommendation regarding financial rentability of different household photovoltaic systems.

Content

1 List of figures

2 List of tables

3 List of graphs

4 Introduction

The total consumption of electric energy in a world and in Czech Republic is constantly increasing. This phenomenon started roughly from the start of twentieth century and is closely connected with increasing human population and with the development and expansion in all branches of modern industry.

With the increase in demand for electric energy, the requirements for its generation and reliability of distribution also increase. According to the yearly report about the usage of electrical system in Czech Republic released in 2014 by the Energy Regulatory Office the brutto energy generation is roughly 86 TWh. Under the term brutto energy generation we understand the total amount of energy generated on the generator terminals. But up to 84 % comes from thermal and nuclear power plants [1]. During these generating processes the traditional sources of energy are being used, mostly black and brown coal, uranium and natural gas. But supply of these sources is limited. Czech Republic is not capable to cover the whole consumption of these sources from its own resources, and that is why Czech Republic is partly dependent on supply of these sources from abroad. The consumption of black and brown coal is mostly covered by local resources. But small part is still imported from abroad, mainly from Poland. Considering the nuclear sources, Czech Republic has not any nuclear fuel producers. That is why Czech Republic is fully dependent on other countries in this matter. While processing these resources undesirable greenhouse gas emissions are produced that negatively affect the environment. That is why it is necessary to focus more on the usage of alternative and renewable energy sources, which provide us with a clean electric energy without a negative effect on the environment. But the problem might occur in the definition of renewable energy sources. General definitions fail at clear definition of what is or is not renewable energy source. That is why in strategic documents is mainly used an exhaustive definition, e.g. according to Act No. 165/2012 Coll, which deals with supported energy sources [1] "*by renewable sources of renewable non-fossil natural energy sources, which are wind energy, solar energy, geothermal energy, water energy, soil energy, biomass energy, landfill gas energy, sludge gas energy from wastewater treatment plants and biogas energy".*

Renewable energy sources are becoming an integral part of current energy systems in the process of filling the European Union's long-term energy and climate strategy, focusing in particular on decarbonization of energy and development of renewable energy sources utilization.

Among the most developing trends of near future in the production of clean electric energy are powerplant running on biogas, biomass and solar power plants. Solar power plants in 2015 generated roughly 2,27 TWh, which is about 2,5 % of the total generated electric energy and 24,4 % of electric energy generated from renewable sources. The biggest advantages of solar power plants are using local and unlimited sources of the Sun's energy and today already large technological availability. Other advantages are cleanliness of their operation and thus their gentleness to the environment.

Initially, however, photovoltaic power plants were not attractive to investors. Construction of photovoltaic power plants was stagnating due to their high initial costs and a long rentability. The change came in 2008, when the so-called solar boom started, which culminated in 2010. Solar boom was caused by a rapid decrease in prices for solar panels, by inappropriate and outdated state of aid for the construction of photovoltaic power plants, which did not respond flexibly to the fall in panel prices. Furthermore, the construction of solar plants was supported by guaranteed prices for the purchase of electricity into the grid from operators of solar power plants. The purchase price was limited by the Act No. 180/2005 Coll. by a maximum decrease of 5 % year-on-year. In recent years, however, prices of necessary components photovoltaic panels have fallen to such low levels of financial demands, that the subsidy programs supporting constructions of photovoltaic power plants were canceled in 2014.

Photovoltaic power plants also have their disadvantages. It is still their low efficiency that moves in the range of 15-20 % depending on the type of used solar panel and their dependence on time of the day, intensity of solar radiation and local climatic conditions.

Nowadays, a certain trend in the area of renewable sources is a certain shift of electricity production to a household and small company sector. These are the installation of your own small photovoltaic power plants as an alternative source for covering your own consumption. Especially for small photovoltaic plants with installed capacity up to 10 kW (so-called micro-resources) were launched new subsidies and support programs called “New Green Savings” just at the turn of 2015/2016. There is thus some effort to create a decentralized and partially independent electricity generation network.

In Czech Republic there is now a relatively new product considering household photovoltaic power plants, which is called a Virtual battery. In this work, we will take a closer look at this product, and we will compare it with a more traditional way of utilizing small photovoltaic power plants.

5 Solar energy

If we will heavily simplify the topic, it is the energy obtained from the Sun, the closest and most important star in our universe. Sun is the middle point of our planetary system and the source of life on earth.

It is necessary to add, that the Sun is not just a source of solar energy. Its energy gave the possibility for origin to other forms of energy, which are being used by humanity. For instance, we are talking about the fossil fuels, that arose by converting dead bodies of plants and animals millions of years ago, or a vapor-based water cycle and subsequent condensation [2].

Even wind energy is generated by uneven heating of the Earth's surface, where there is an effort to equalize the pressures [2].

We are without a doubt capable of using all these types of energies, although at first glance it may not be clear that their origin is in the Sun.

5.1 Origin of energy

Sun is made up of two main elements – hydrogen (70 %) and helium (28 %). The remaining 2 percent of other elements are negligible in comparison with the previous two elements.

All these elements are in the state of plasma. In its center is constantly occurring the so-called thermonuclear reaction (nuclear fusion), which consists of transformation couple of millions lighter nuclei to heavier helium nuclei while releasing a tremendous amount of energy (up to 10^{26} J). then it falls on the Earth's surface in the form of solar (electromagnetic) radiation [2, 3].

This transformation has been happening for several billion years and according to calculations it will be occurring for the same time in the future. It is precisely because if this fact that the Sun can be considered as humanity's perspective renewable energy source [2, 3].

5.2 Sunlight spectrum

As we can see in figure 1, the Sun radiates over a wide spectrum of wavelengths. In order to consider effects of passing through the atmosphere, we introduce the Air mass coefficient followed by a number. If the sun rays would hit the earth's surface perpendicularly, we would work with an Air mass coefficient AM1 [3,4].

For defining the incident spectrum, the most versatile coefficient is AM1,5, which means a deviation from the incident radiation about 48 °. For our use, the most energetically significant spectrum is visible radiation with wavelengths between 380 and 780 nm. It is proven, that with growing energy, the wavelength decreases [3,4].

In order to be this spectrum fully utilized by photovoltaic cells, energy must have a magnitude at least 1,12 eV, which corresponds to an infrared radiation with a limiting wavelength about 1105 nm [3,4].

With every energy transmission, there are losses associated. Because of this fact, not all radiation will fall on the earth's surface. Part of this radiation is reflected and part of it is absorbed. Ultraviolet or long-wave infrared radiation is stopped by the atmosphere [3,4].

In this case, losses have a positive impact. If all the spectrum of solar radiation would hit the earth's surface, it would have fatal consequences for all the life on Earth. Incident radiation can be also dispersed by a normal climatic conditions, such as clouds [3,4].

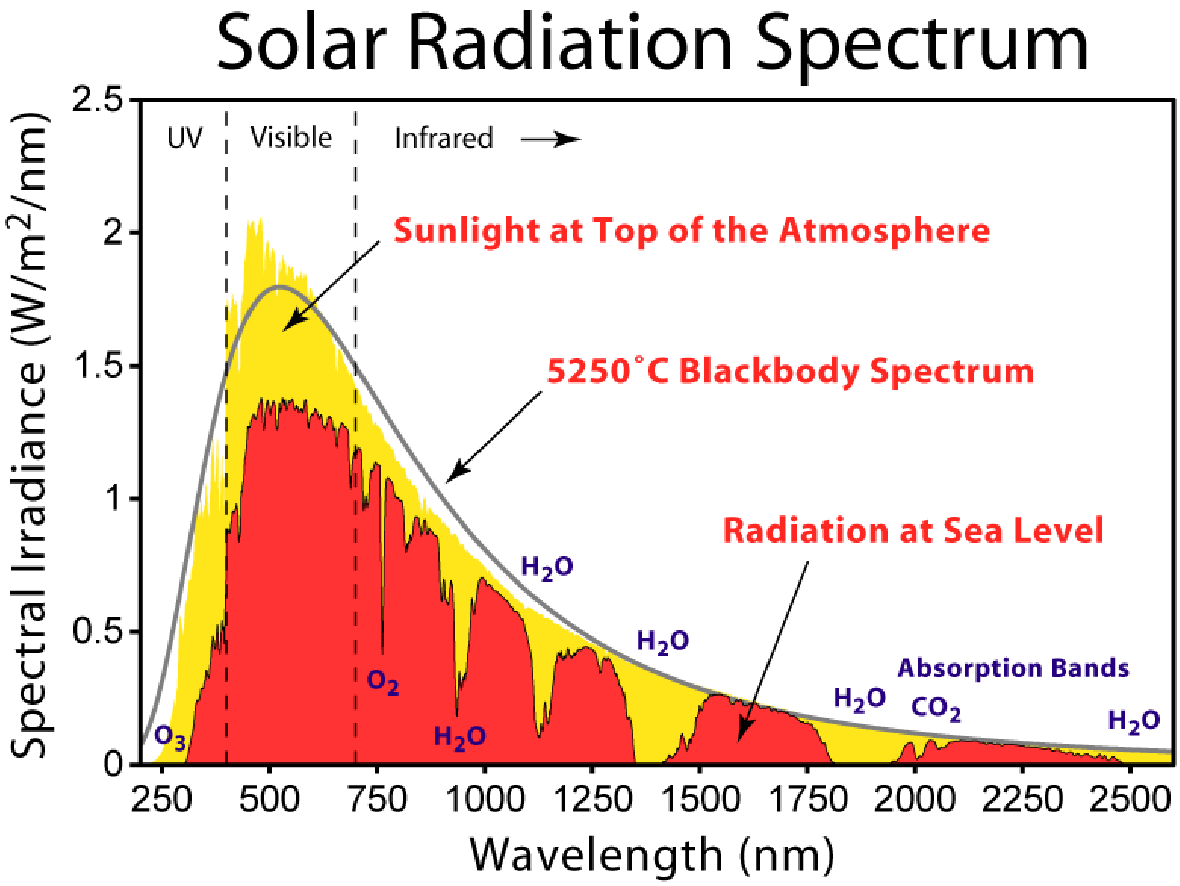


Figure 1 - Solar spectrum [4]

6 Potential of solar energy

Light scattering losses due to the light dispersion are not the only factor, reducing the potential of usage of solar energy. There are also other factors, whose influence on potential of solar energy is not negligible. We will take a closer look at these factors in the following chapters.

6.1 Prediction and variability

One of the main disadvantages is the inability to successfully and precisely predict solar energy supply. Using some specialized programs and a long-term statistical data, we can predict average total solar energy supply for estimated period (day, month, year). The real solar distribution over these periods varies every year. For shorter time periods a weather forecast comes to mind, but weather forecast is reliable only as a prediction for a near future-one or two days. But it cannot be considered as a reliable source of information for a longer period of time.

Especially due to a big weather variability during the year, we usually cannot fully rely only on a solar energy as a primary source of electrical energy. It is necessary to have another source of energy and using the solar energy as a complementary source.

For this reason, while modeling the photovoltaic system, it is more than recommended to work with as precise data as possible. That means avoiding using yearly average data and on contrary working with data for individual months, whether in terms of energy availability or its consumption.

The fluctuation of the available amount of solar energy can be compensated to a certain extent by its accumulation, when we are experiencing its excess. However, these systems are still limiting. In order to ensure reliable operation, we are usually forced to use some supplementary energy source.

6.2 Times of solar energy generation and its consumption

With a positioning of Czech Republic, there is an occurrence of a high variability in solar radiation between summer and winter periods. The position of the sun, which is much lower during winter than in summer, together with shorter days causes much less availability of solar radiation in winter than in summer. But both these periods might be problematic. This problem is shown in the next figure.

This figure shows the exact opposite in demand for a solar energy and its generation with solar panels. The figure shows a common problem of solar panels and their use as a source of energy. As we can see from the figure, the problem lies in a fact, that the biggest amount of energy is being produced when the energy is not needed. That is due to a simple fact. Majority of the people are not home. This also explains the fact, why there are two high demand peaks. One during morning and one during afternoon. It is because of the fact, that people consume a lot of energy for breakfasts, dinners and showers.

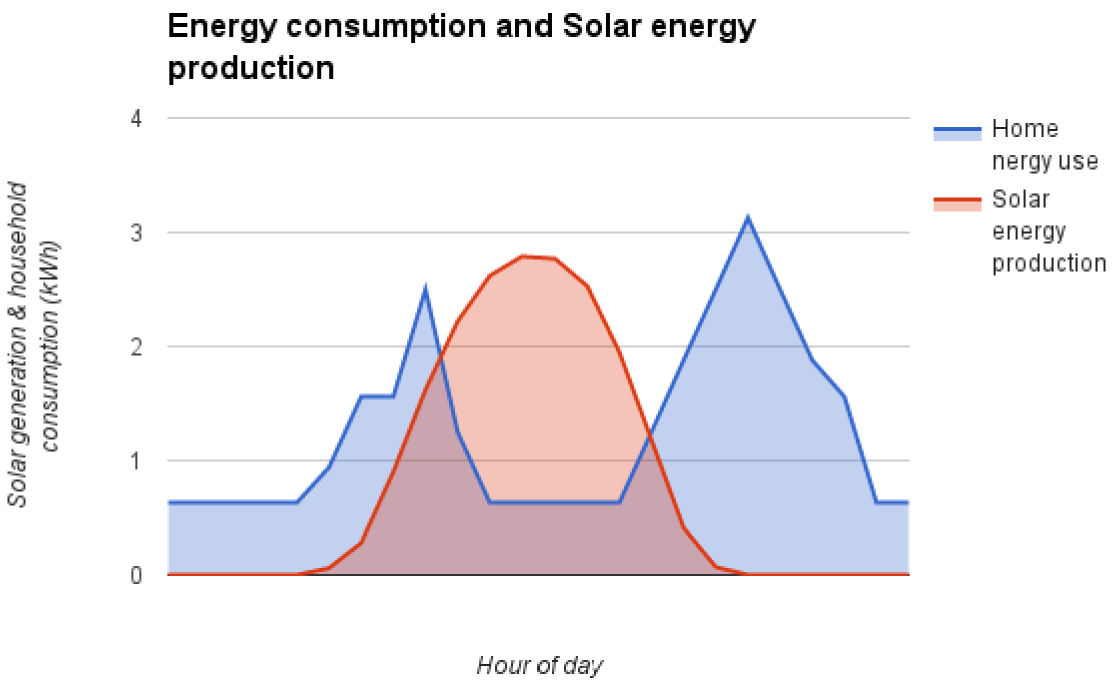


Figure 2 - Energy consumption and solar energy production [5]

7 Photoelectric effect

Photoelectric effect is a phenomenon in which electrically charged particles are being released from a material when electromagnetic radiation is being absorbed. This phenomenon can also be described as a process of ejecting electrons from a metal when light falls on it. The energy itself can be infrared, visible, ultraviolet light, X rays or even gamma rays and the released particles can be ions as well as electrons [6].

Photoelectrical effect was firstly discovered by the German physicist Heinrich Rudolf Hertz in 1887. He observed, that when ultraviolet light shines on two metal electrically charged electrodes, the light changes the voltage at the place where sparking takes place. This phenomena was later clarified by another

German physicist Philipp Lenard in 1902. He declared, that by illuminating the metal surface by light, electrically charged particles identical to electrons are being emited from the metal [6].

Photoelectric effect was later theoretically clarified by Albert Einstein in a year 1905, fow which he won a Nobel prize in 1921. Quantum physics looks at a solar radiation as an electromagnetic wave, that spreads in so-called quantitites of energy. Energy of this quantum is directly proportional to the frequency and a Planck constant and is inversely proportional to its wavelength. Quantum of radiant energy spreads at the speed of light. The quantum of energy is called photon. For the energy of one photon, the energy is as follows [6,7]:

$$E = h * f = h * \frac{c}{\lambda} \quad (1)$$

Where	E [J]	energy of photon
	h [J*s]	Plancks constant= $6{,}626 * 10^{-34}$
	f [Hz]	frequency of a photon
	c [m/s]	speed of light in vacuum $= 3 * 10^{-8}$
	λ [m]	wavelength

Einstein theorized, that upon hitting the metal surface by a photon, the entire photon's energy is then transferred to the electron. This energy than devides in energy that is used for releasing the electron from the metal atom's grasp and in a kinetic energy that is given to the electron [8].

This can be written mathematically as follows:

$$E_f = A + E_k \quad (2)$$

$$h * f = A + \frac{1}{2} * m * v^2 \quad (3)$$

where	E_f [J]	energy of photon
	A [eV]	electron output work (energy required to eject electron)
	E_k [J]	kinetic work of electron

In order for a successfull photoelectric effect, the energy of an incident photon must be minimally equal to the electron output work. This energy of an incident photon is know as ionizing energy. The amount of ionizing energy needed for releasing the electron is called a photoelectric barrier and it's value depends on a material of the substance [7,8].

For overcoming photoelectric barrier, photon needs to have a sufficient amount of energy. That means sufficiently big frequency f or a sufficiently small wavelength λ.

Also from the equation (3) we can derive, that the energy of a released electron depends only on the frequency of the incident light, not on its intensity. On its intensity depends only the amount of released electrons. With higher intensity, the amount of released electrons is higher [7,8].

The threshold frequency can be determined from the equation for the occurence of the photoeffect, then it will look as follows:

$$f_0 = \frac{A}{h} \tag{4}$$

Photoelectric effect can be divided into an internal and external photoelectric effect. External photoelectric effect occurs, when an incident photon releases the electron out of the surface outside the substance. By these released electrons a so called photocurrent occurs. This phenomenon is being used in noctovisors and photodetectors [9].

On the other hand internal photoelectric effect occurs, when the released electron stays inside the conductor and increases its conductivity. This phenomena is mostly being used in semiconductors, where electrons are released in this way. The function of a photovoltaic cell is based on this phenomena [9].

8 Principle of a photovoltaic cell

Photovoltaic cell is the basic unit of the system where the photovoltaic effect is used for electricity production from light energy. The most frequently utilized semiconductor material for constructing the photovoltaic cell is silicon. The silicon atom has four valence electrons. In a normal state, each silicon atom shares his four valence electrons with other neighboring atoms, hence creating covalent bonds between them [10].

If the intensity of an incident light is strong enough, sufficient number of photons is absorbed, and these photons release some of the electrons in covalent bonds. These released electrons then can migrate from valence band to a conduction band. As the electrons migrate to a conduction band, a hole in the covalent bond is left behind them. These electrons are called free electrons and they move freely in the silicon structure. These free electrons and holes left behind them are crucial for creating electricity in photovoltaic cell. We call these particles light-generated electrons and holes. But for producing electricity in the silicon crystal, we need to add some pentavalent impurity such for instance phosphorus [10].

When a pentavalent phosphorus is added to a quadrivalent silicon crystal, the fifth valence electron does not get any chance to create a covalent bond. This extra electron then shares a relatively loose bound with its parent atom. When this fifth electron is being released from its parent phosphorus atom, the phosphorus atom immobile positive ions. Upon freeing itself, this electron becomes free but does not have any incomplete bond to bond with. Although there is plenty of free electrons, the substance remains electrically neutral, just because the amount of positive phosphorus ions locked inside the structure is exactly the same as the number of free electrons coming out of them. We call dopants these added impurities and the whole process is called doping. Pentavalent dopants are then known as donors. Doped semiconductors are known as n-type (negative type) semiconductors [10].

If instead of a pentavalent impurity a trivalent impurity such as boron is added to a semiconductor silicon, a conductor of an opposite type will be created. In this case all three valence electrons of boron will be paired with the neighboring electrons of silicon to create three complete covalent bonds. So, there will be one silicon covalent electron, which will be unable to create fourth complete covalent bond. Hence this electron will behave like an incomplete bond. And an incomplete bond always attracts other electrons to fulfill this lack. As such, there is a vacancy for the electron to sit [10].

This free space for electron is called positive hole. When is a semiconductor doped with a trivalent impurity, a significant number of incomplete covalent bonds is being completed by breaking other covalent bonds. Upon completing the bond, the hole disappears. On the other side when one bond is broken, one hole is created. In this way, when one hole appears, the other neighboring hole disappears. We can see such an action as a movement. After that we can proclaim, that holes can also move freely as electrons inside the semiconductor crystal. Trivalent impurities are known as acceptor dopants and the semiconductors doped with acceptor dopants are known as p-type or positive type semiconductors [10].

The main carriers of a negative charge in n-type semiconductor are free electrons. Holes are on the other hand the main carriers of a positive charge in a p-type semiconductor [10].

We can always find a potential barrier between p-type and n-type semiconductors. When both types of semiconductors are in a close contact with each other, the free electrons near to the contact surface recombine with the adjacent holes in a p-type semiconductor. Because even valence electrons are able to recombine with positive holes, many covalent bonds in n-type semiconductor are being broken and thus begins the creation of positive holes in n-type semiconductor. This phenomenon appears as a migration of holes from p-type semiconductor to n-type semiconductor. This process of migrating electrons and holes is very fast but doesn't last forever. After some time, there will appear a layer of positive charge in n-type semiconductor and a layer of a negative charge in p-type semiconductor. After reaching particular value of thickness of these layers, all the migration will be stopped. Due to the positively and negatively charged layers, there will appear an electric field across the region named depletion layer [10].

Now when a light shine on the crystal, a certain amount of the light is absorbed by the crystal and some valence electrons are excited from the covalent bonds, thus creating free electron-holes pairs. Light-generated electrons in n-type semiconductor are unable to cross the potential barrier (depletion layer) and migrate to the p-type semiconductor. Due to the attraction of electric field of depletion layer, the light-generated holes cross the barrier and recombine with electrons. The lack of electrons here is compensated by valence electrons from p-region. When light-generated holes cross the barrier and enter p-type semiconductor, they are trapped here due to the potential barrier. As the negative light-generated electrons and positive light-generated holes are trapped in opposite sides, a potential difference will appear [10].

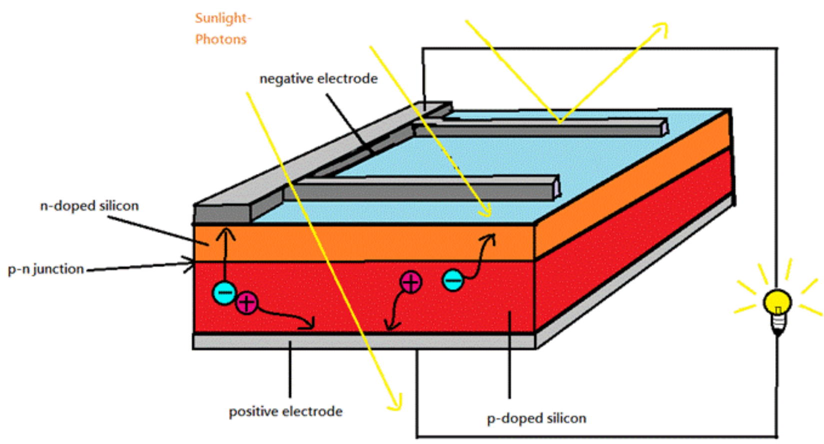


Figure 3 - photovoltaic effect in a solar cell [11]

9 Photovoltaic module performance characteristics

We can define photovoltaic module's characteristics by an I-V curve, which describes a current dependence on voltage during the given lighting of the cell. The threshold values on a I-V curve are the short circuit I_{sc} and open-circuit voltage V_{oc}.

The I-V curve can be seen on a figure 4. The curve itself shows the voltage and current at different operating conditions. The highest current is naturally a short circuit current, when the value of voltage equals to zero. The highest voltage occurs at open-circuit conditions.

The knee of the I-V curve represents the operating conditions when the values of current and voltage are the highest, thus resulting in the maximum power point (MPP) [12].

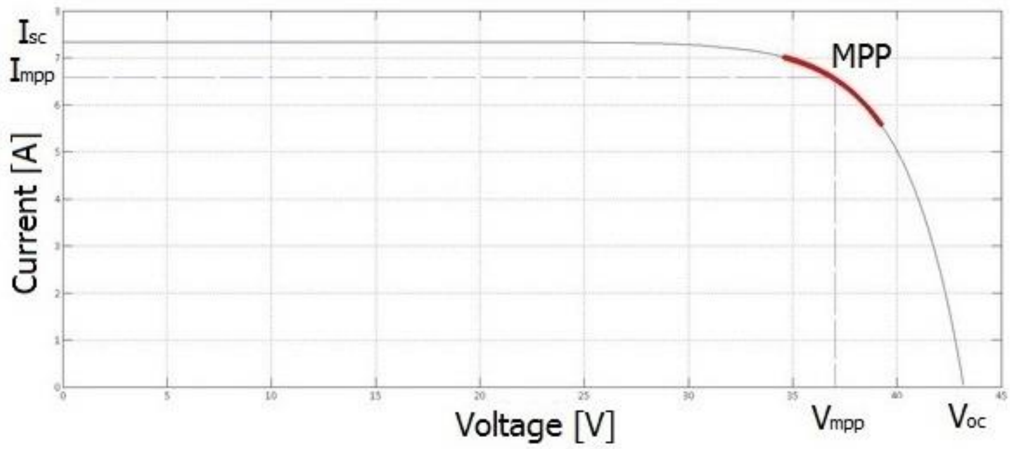


Figure 4 - The I-V curve of a photovoltaic module [12]

Another way how to describe photovoltaic module’s characteristics is using a P-V characteristic. This curve shows a dependency between power and voltage. As it was in I-V curve, the highest voltage occurs during the open-circuit condition while the current is zero. Since the active power is here just a multiplication of voltage and current, the active power during open and short circuit equals to zero. It is due to the fact, that during these conditions, either current or voltage equals to zero.

In order to work with the highest efficiency and with the biggest output power, we should try to work in the range of MPP.

The P-V curve can be seen on a figure 5. This characteristic is being used, because here is much easier to see the maximum obtainable output power, often referred as a maximum power point MPP [12].

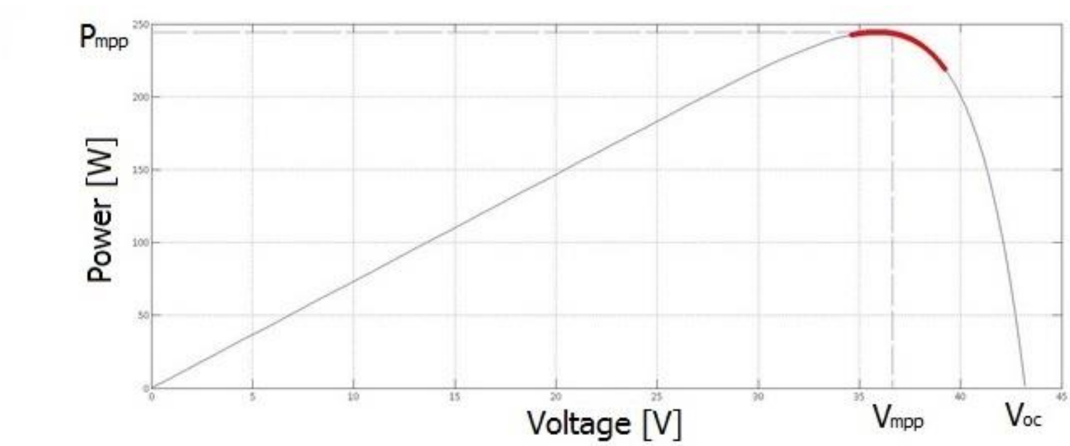


Figure 5 - the P-V curve of a photovoltaic module [12]

For better understanding, we will define the most important characteristics of a photovoltaic module.

Maximum power point – M_{pp}

Maximum power point of a photovoltaic module is a point on its I-V or P-V characteristic, in which respected photovoltaic module has at given sunlight the highest output power. The M_{pp} point lays on I-V curve on an I_{mpp} and U_{mpp} coordinates [12].

Voltage of a maximum power point – U_{mpp} [V]

Voltage of a maximum power point is a voltage during the maximum power point P_{mpp} in a point M_{pp} [12].

Current of a maximum power point – I_{mpp} [A]

Current of a maximum power point is a current during the maximum power point P_{mpp} in a point M_{pp} [12].

Maximum power – P_{mpp} [Wp]

Power of a photovoltaic panel depends on solar intensity radiation, cell light and the spectrum of incident light. Maximum power is calculated as a product of current and voltage at maximum power [12].

$$P_{mpp} = U_{mpp} * I_{mpp} \ [Wp] \qquad (5)$$

Fill factor – FF [-]

Fill factor is one of the ways, how to judge the quality of a solar panel. The bigger the value of a fill factor, the better solar panel we have. With an availability to produce higher power. Fill factor is defined as a ratio between maximum power and power given by the product of open-circuit voltage and short-circuit current [12].

$$FF = \frac{U_{mpp} * I_{mpp}}{U_{oc} * I_{sc}} \ [-] \qquad (6)$$

Efficiency of a photovoltaic panel – η [-]

Efficiency of a photovoltaic panel tells us, how well can a photovoltaic panel convert solar energy to an electric energy. The efficiency of a photovoltaic cell is defined as the ratio of the maximum cell power at the MPP point to the total output of incident solar radiation on the PV cell [12].

$$\eta = \frac{U_{mpp} * I_{mpp}}{P_{in}} = \frac{U_{mpp} * I_{mpp}}{E * A_c} \ [-] \qquad (7)$$

Where E [W/m^2] intensity of solar radiation

A [m^2] photovoltaic cell area

10 Temperature influence on photovoltaic cell parameters

Like all other semiconductor devices, solar cells are sensitive to temperature. Band gap of a semiconductor is dependent on temperature. Thus, increase in temperature effects most of the semiconductor material parameters. With the temperature increase, the band gap decreases, which can be viewed as increasing the energy of electrons in the material. Therefore, lower energy is needed for breaking the bond [13].

The most effected parameter in a solar cell by the temperature increase is the open-circuit voltage. The effect of temperature increase can be seen in the figure below.

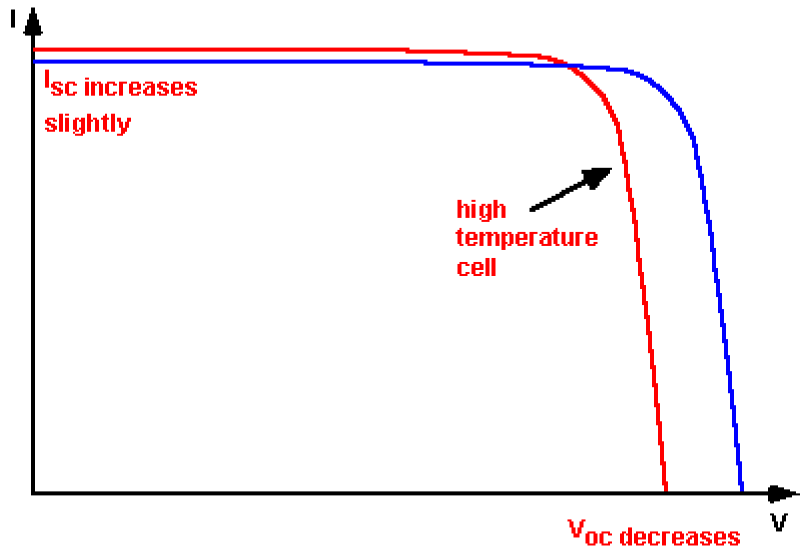


Figure 6 - The effect of temperature on solar cell [13]

If the cooling conditions of the solar panel deteriorates, for example it is a windless, sunny hot day, long lasting solar radiation might heat up the photovoltaic cell to high temperatures. As is shown in figure 6, during these high temperatures electrical parameters change. Change of these parameters has effect on reducing load characteristics to lower voltages and hence reducing the delivered voltage power [13].

For example, for a crystalline silicon photovoltaic cell, the drop of U_{oc} is around 0,4 %/K and the drop-in efficiency is around 0,5 %/K [13].

Magnitude of solar and parallel resistance also influences the efficiency of a solar cell. For small serial resistance with the solar radiation increase, the increase in efficiency follows. On the contrary, for high series resistance its efficiency decreases with increasing radiation intensity [13].

11 Development generations of photovoltaic cells

Photovoltaic cells and solar panels have been researched now for many years. The main focus of the research is to achieve higher efficiency of a photovoltaic cell and at the same time reduce usage of expensive materials needed for their construction. We can divide photovoltaic cells into three main categories.

11.1 First generation photovoltaic cells

Their PN junction is mostly made from monocrystalline silicon wafers. This type of junction is nowadays the most widespread on today's markets. They are known for good durability and efficiency stability. Their efficiency is usually between 14 and 22 %.

Their main disadvantage is demand for a big amount of very clear crystalline silicon. That was the reason for inventing new types of solar cells with lesser demand for crystalline silicon [14, 15].

11.2 Second generation photovoltaic cells

As was indicated in the previous article, second generation of photovoltaic cells aims at reducing the amount of pure silicon crystalline. In order to push the initial costs down, monocrystalline silicon is being replaced by polycrystalline and amorphous silicon. Wafers of this generation can be one hundred times thinner than wafers of the previous generation. This leads to lowering the demand for silicon, reduction of the overall weight and improvement of the mechanical properties, especially flexibility. The downside of silicon savings is, that the efficiency is reduced roughly to a value of 16 %. Photovoltaic panels from these cells are used in practice in the form of photovoltaic films for reconstruction roofs with simultaneous production of electricity [14, 15].

11.3 Third generation photovoltaic cells

There is still an ongoing research on this generation. The research is aimed at maximizing the usage of incident photons and the full usage of solar spectrum. These photovoltaic cells try to use other methods that PN junctions, like using multiple thin film transitions, photoelectrochemical cells or the usage of nanostructures in the form of carbon rods and tubes. Main advantages of these cells are their targeted influence on electrical properties [14, 15].

12 Dependency of solar energy

The potential of solar energy is not diminished only by light scattering losses. There are also other factors, that play the role. That is why following chapters will be devoted to advantages and disadvantages predetermining the use of solar systems.

12.1 The latitude dependence

Even though solar energy is practically obtainable across the whole globe, variability of conditions across the globe causes considerable variation in the possibilities of its use. We can see this phenomenon in the next figure. This figure shows the difference in annual solar radiation doses across the Europe. If we will compare Prague and Madrid, we can see, that the total irradiation in Madrid almost doubles the irradiation in Prague. Dependence on latitude becomes apparent already in areas in Czech Republic.

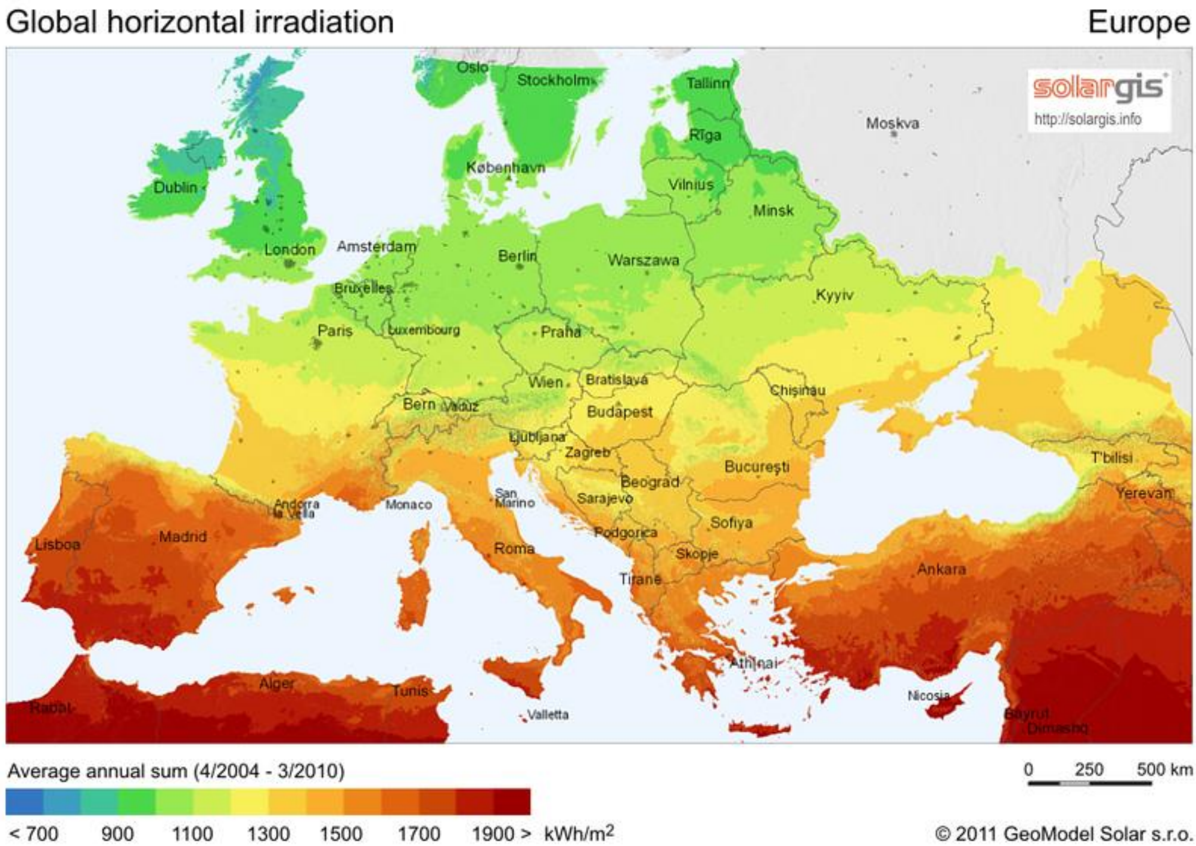


Figure 7 - Global horizontal irradiation [16]

As we can see from the map, in Czech Republic we do not have such a high potential of solar energy usage as they have in Spain, but solar energy is still a valuable and renewable source of energy.

12.2 Advantages of solar energy

Possibly one of the biggest advantages is the fact, that solar energy is fundamentally pollution free, renewable and causes no greenhouse gases after installation. Hence, we can take this source as practically limitless. Here is necessary to add, that only production of solar energy is pollution free. Building and making of solar panels is still a highly polluted industry [17].

Also, a non-negligible fact is, that this energy is practically everywhere, obtainable mostly anytime and is free. And due to frequent and easily obtainable subsidies, its acquisition value isn't as high, as it used to be [17].

In combination with batteries, rightly modeled and constructed solar system gives us an opportunity to live completely off-grid, giving us a chance to be electrically independent. If we decide to be connected to the grid, we can sell our electrical excesses back to grid [17].

Because of solar energy and renewable sources in general are nowadays considered as a future way of generating energy, we can witness and presume a big technological and economic progress in this area. This concretely means inventing cheaper, more durable and more effective solar panels with a wider variety of installation possibilities [17].

12.3 Disadvantages of solar energy

Even though what was written in the previous paragraph about numerous subsidies, the initial cost of solar panels is still relatively high. With this fact is connected second disadvantage, which is long return of investment [17].

Efficiency of solar panels is dependable on their location. Not only that, their production capability is dependent on weather and part of the year. Also due to their lower efficiency, they can take a lot of free space.

But arguably the biggest disadvantage is, that it is a non-influenceable source of energy. Generating of energy is completely dependent on the Sun. Because of that, solar panels produce most of the energy in the middle of a sunny day and no energy during the night [17].

13 Types of photovoltaic systems

Based on the connection of the system, we divide photovoltaic systems into three main categories. These are grid-off systems, grid-on systems and hybrid.

13.1 Grid-off photovoltaic system

Grid-off systems, sometimes called autonomous systems, are characterized by not being connected to the grid. They are mostly being used at places, where the public electric grid is not available.

These systems usually consist of photovoltaic panels, inverters, batteries and protective circuits that protect batteries from possible overcharging. Batteries in these systems are needed because the energy from the solar panels is not usually available during highest peak demands [18].

In these systems we can connect DC appliances (usually 12 or 24 V) and AC appliances (230 V, 50 Hz).

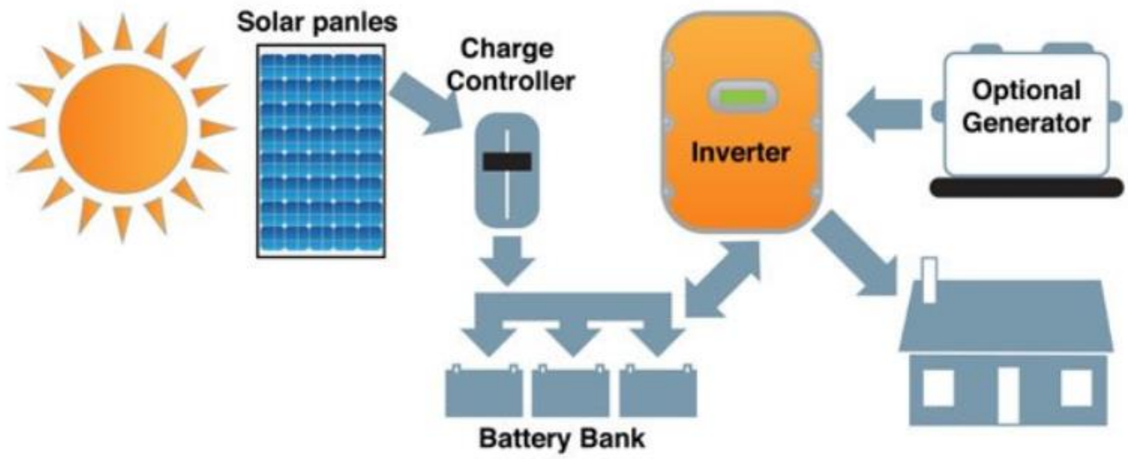


Figure 8 - grid-off system [18]

13.2 Grid-on photovoltaic system

Grid-on systems are characterized by the fact, that they are connected to the public electric grid. Connecting the photovoltaic plant and the network is realized through an electricity meter. In case the system produces more electricity, the excess of energy is supplied to the grid.

Grid-on systems usually consist of photovoltaic panels, voltage converters, measuring control and line protection devices. In these systems one phase inverters are often used, because their installed power does not usually exceed 4 kW. After exceeding this limit, the usage of three phase inverter is recommended [18].

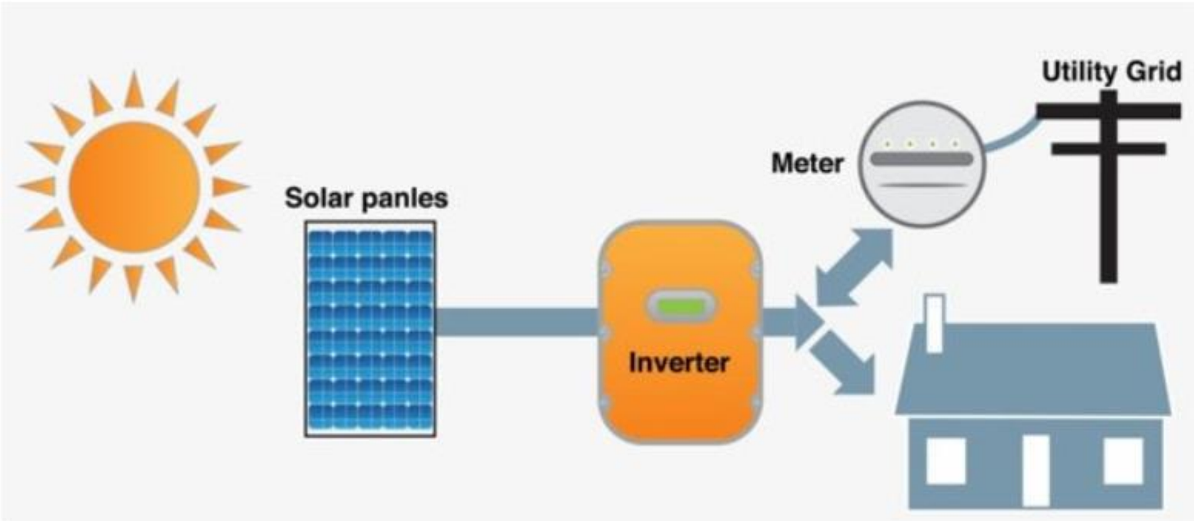


Figure 9 - grid-on system [18]

13.3 Hybrid photovoltaic system

Hybrid photovoltaic system can be understood as a certain connection between grid-on and grid-off systems. This system does not need to unnecessarily supply excess energy to the distribution network, as this energy is used directly at the place of production, for instance as hot water heating, additional heating, air conditioning or other predetermined appliances [18].

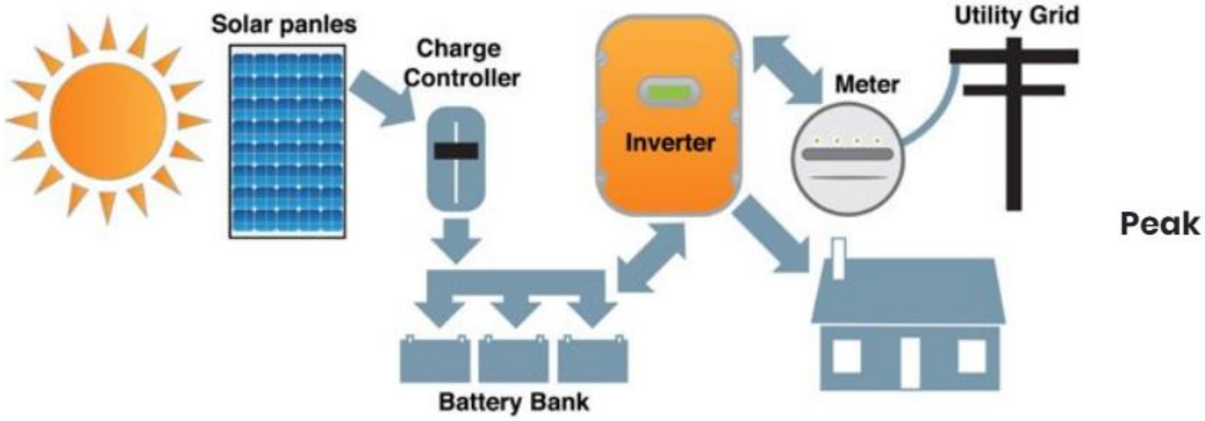


Figure 10 - hybrid photovoltaic system [18]

14 Main components of every photovoltaic system

Photovoltaic system consists of several components and devices. Probably the most important components of photovoltaic systems are solar panels, invertors and supporting structure. Every photovoltaic system that is situated outside should be protected against overvoltage and lightning strikes. These protective components should be placed on a DC side in front of the invertor, so as on an AC side behind the invertor. In these following chapters we will take a look at these main components of the solar system.

14.1 Solar panels

A solar cell on its own has a very small usage due to its low output voltage and power. That is why solar cells are being suitably connected to a series or parallel combination. In this way connected photovoltaic cells are called photovoltaic modules. It is necessary to hermetically sealed these modules, in order to protect them from outside influences and to guarantee a long service life [19].

That is why photovoltaic modules are being covered by an ethyl vinyl acetate film. Further, the front side of a module is provided with highly transparent and specially toughened glass. At the same time, this glass also contains an antireflective layer, reducing its reflectivity [19,20].

Back side of a module is provided with a multilayer protective film or protective film glass. This module is then sealed in an enclosed aluminium frame. This aluminium frame is then used for attaching the module to a supporting structure [19].

In the middle is usually situated a p-n junction made out of p and n wafers. Their principle of function was in detail described in previous chapters.

In the next figure, we can visually see what was stated in previous paragraphs.

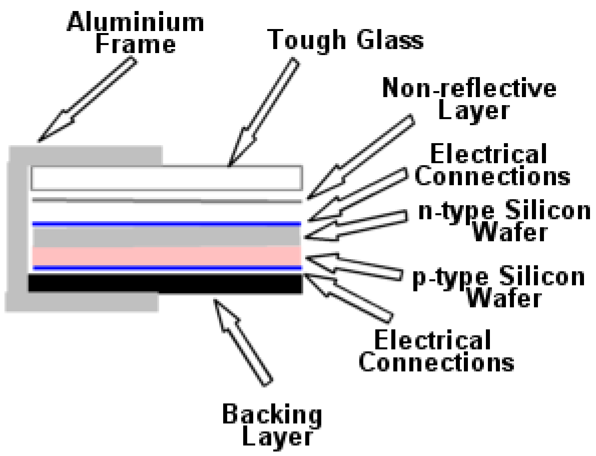


Figure 11 - Photovoltaic panel construction [19]

In order to achieve maximal output power in conditions of Czech Republic, we should maintain the slope equal to 33°. The panel should also be ideally oriented towards south.

14.2 Inverters

An inverter can be called the heart of every photovoltaic system. Its main function is transformation of the input DC voltage that is being produced by photovoltaic system to an AC output voltage with electrical parameters of the distribution network, which is 230 V and 50 Hz.

In this time, inverters also usually have other additional functions, like measuring the amount of produced electricity. They also have a user interface for easy connection to personal computers. Very high technical and economical demands are applied to inverters. The inverter must be able to deliver the highest possible power with minimum losses, i.e. with very high conversion efficiency [21].

The maximum efficiency of today's inverters ranges between 93 and 98 %. But very high efficiency does not always mean high energy gains, because this efficiency is measured under ideal conditions that are almost unreachable in normal operating life. Therefore, the emphasis is placed on keeping the conversion efficiency high during fast climate changes and temperatures [21].

This requirement is fulfilled using the MPP tracker in an inverter, which is an electronic device, that monitors the current maximum power point (MPP) of the photovoltaic modules and by changing the input resistance sets up the appropriate operating point of the inverter [21, 22].

For protecting the inverter, it is often being used wiring with an internal transformer that forms a galvanic isolation of DC and AC sides. However, the presence of a transformer reduces the efficiency of the inverter by about 2 %. This decline is caused by heat losses on the transformer [21, 22]

14.3 Bearing and construction elements, cabling

In order to successfully install photovoltaic powerplant, bearing and construction elements are needed. Construction elements can be divided into four groups by their usage:

- Construction for gabled roofs
- Construction for flat roofs
- Open space constructions
- Adjustable structures

Because of our photovoltaic panels will be situated on a gabled roof of a family house, the construction for gabled roofs will be used. These types of constructions are suitable for small installations on family houses with the roof slope around 35 ° and south or south-west orientation. The supporting element are here aluminium profiles, which are fastened to the roof with special hooks. Then, the photovoltaic panels are attached to aluminium profiles [23].

Installation of these constructions is very simple and is characterized by low purchase price.

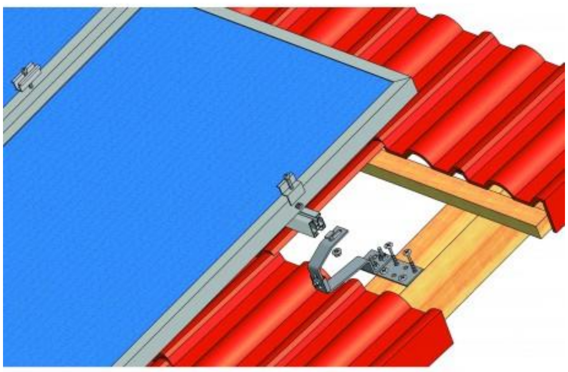


Figure 12 - Construction for gabled roofs [23]

Other components of photovoltaic systems are certainly connectors and cables. Cabling ensures a suitable connection of photovoltaic modules and inverter.

15 Legislation

In this chapter I analyze the current legislative situation for the construction and operation of small photovoltaic power plants. In this chapter I will also include the topic of support for photovoltaics in the Czech Republic, which means the program of the Ministry of Environment called Green New Savings.

15.1 Current legislative situation in Czech Republic

On the family house will be placed a photovoltaic plant with installed power probably in the range 2-5 kWp. Our photovoltaic plant will be classified as a micro-source. This term includes small photovoltaic plants with the maximum installed power not greater than 10 kWp. Since 1.1.2016 the operation of small photovoltaic plants is not considered to be a business according to Energy Act No. 91/2005 Coll [24].

The operation of small photovoltaic plants is not anymore restricted by the necessity to obtain a license from Energy Regulatory Office. With these facts other obligations are not needed to be met. The operator of the photovoltaic plant no longer has to be a self-employed person in order to own a plant. Therefore, he does not need to pay social and health insurance [24].

For operating photovoltaic plant with installed power exceeding 10 kWp, the necessity to obtain a license still stands according to Energy Regulatory Office. On 03.03.2016, the so-called tax advantage for operators of small photovoltaic power plants up to 10 kWp was authorized. Now the yearly income from the photovoltaic plant operation up to 1 174 $ is now considered as other income pursuant to Section 10 of the Income Tax Act [24].

15.2 Support of photovoltaics in Czech Republic

In the past, support for the production of energy from photovoltaics was supported by a guaranteed purchase price of electricity and so-called Green bonus. Mentioned support of a guaranteed purchase price consists of the fact, that Energy Regulatory Office (ERO) set a fixed feed-in tariff when commissioning a new photovoltaic plant for which the distributor was forced to buy all the electricity produced.

On the other hand, the Green Bonus is a cash bonus, which is paid for generated electricity from photovoltaic plant. For this subsidy option, the bonus is paid both for electricity supplied to the grid, but also for electricity consumed directly at the production site.

Both of these variants of support for the production of electricity from photovoltaic plant have been cancelled in 2014 and they are no longer valid [24].

15.2.1 New Green savings

In the present moment, subsidies from the program New Green Savings can be used. New Green Savings is the program of Ministry of Environment, administrated by the State Environmental Fund of the Czech Republic, which:" *supports energy-efficient reconstructions of family houses and apartment buildings, replacement of inadequate sources for heating and usage of renewable energy sources*" [24].

New Green Savings program has started receiving first applications on 22 October 2015 and planned termination of the project is set on 31. December 2021 [24].

Czech Republic obtained financial resources for this program by selling so-called EUA emission allowances and its financing is provided through the state budget of Czech Republic.

New Green Savings consists of several sub-programs. Because of the topic of this diploma thesis, I will focus on subsidies in family houses sub-program. This sub-program offers subsidies in three following areas:

- Reducing the energy consumption of existing family houses.
- Construction of family houses with very low energy consumption.
- Efficient use of energy sources.

We will be interested in the last area, which means efficient use of energy sources, which also includes subsidies for installation of solar thermal and photovoltaic systems. In this work I will focus on a category: photovoltaic system with a minimal usage income 1700 kWh/year, for which the obtainable subsidy equals to 2 345,40 $ [24]. The requirements for obtaining the subsidy are as follows:

- The subsidy cannot be higher than 50 % of total installation costs.
- The energy source has to fulfill the ekodesign requirements.

Because we fulfill all the requirements, we can apply for a subsidy and we will obtain it.

16 Evaluation of economic efficiency of investments

The basic prerequisite for investment evaluation is the choice of the right valuation method to match the purpose and objective of the investment. Time value of the money and the incapability of predicting all the future influences play an important role in economic evaluation of any investment. Both methods used, net present value (NPV) and internal rate of return (IRR) are one of the most used methods while evaluating investments, that take these factors into account. For calculating both methods it is necessary to know cash flow (CF) in individual years of the project, their estimation may not always be simple and accurate. The assessment therefore depends on a number of future events.

16.1 Net present value (NPV)

Net present value represents the sum of cash flows in individual years over the period of the assessment investments that are discounted to their present value. These cash flows represent the sum of capital expenses and investments incomes.

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t} = \sum_{t=0}^{T} DCF_t \tag{8}$$

Where	CF	cash flow
	DCF	discounted cash flow
	T	project lifetime
	r	discount rate
	t	year of a project

NPV is the amount of money that investor receives in addition to the amount invested. The investment is profitable considering the chosen discount, if NPV ≥ 0. It he value of NPV is lower, the investment does not reach the required profitability [25, 26].

The discount rate or interest rate represents the amount of the required investment return taking into account the opportunity cost and the risk level of the investment. Risk is the uncertainty of the future investment returns. In general, the higher the uncertainty, the higher the yield is required.

16.2 Internal rate of return (IRR)

The IRR indicates the relative rate of return of investment over its useful life with consideration of time value of money. It is therefore a discount rate at which NPV equals zero.

$$\sum_{t=0}^{T} \frac{CF_t}{(1+IRR)^t} = 0 \tag{9}$$

When determining the profitability of the investment by the IRR method it is necessary to compare the result with the required one yield. For the acceptance of an investment, the internal rate of return of the investment should be the same or preferably higher than alternative required yield.

However, in some cases, the investment brings non-cash benefits. So, it can be accepted even if the above conditions are not met. The same applies to the condition adoption of the NPV indicator [25, 26].

16.3 NPV and IRR comparison

Both methods have the same starting point, so it is not possible for them to make different decisions for a particular investment with regard to its acceptance or rejection. When comparing multiple investments, each method may indicate different order of investment profitability. This means that the investments preferred by the NPV method are more advantageous in terms of absolute benefits and IRR-preferred investment in terms of benefits relative. When comparing multiple investments, it is therefore appropriate to use both methods simultaneously.

16.4 Risks of using these methods

The greatest risk in using the above-mentioned indicators lies mainly in the correct identification of future cash flows from the investment. These are often difficult to predict in appearance to unexpected events that may occur in the future. Another pitfall may be correct determination of investment evaluation time and discount value, especially risk assessment.

16.5 Sensitivity analysis

For input parameters of economic evaluation that are burdened with uncertainty, it is appropriate to do sensitivity analysis of dependence of change of economic indicators on change of given parameter. Instead of the concrete value of an input parameter, a range of acceptable values is selected when performing sensitivity analysis.

17 Description of a family house

In this part of the work, I will focus on presenting, calculating and modeling a usable photovoltaic system for a chosen family house.

The family house is a two-floor building situated in Czech Republic. The village in which the house is situated is called Odolena Voda. It is a small village nearby Prague. The house is inhabited by 4 people. Two parents and two children. They represent a classic Czech family. Electricity is used only for household appliances and lighting. Problem of heating and hot water is solved by gas.

The roof of the house is a classical gabled roof. With the direction of one of its sides oriented to southeast with a 23° offset from the south and a 39° gradient, which is almost ideal gradient, which is 34°.

The roof area that can be used for placing photovoltaic modules equals to 45 m^2, which was calculated from the project documentation. So, there should be more than sufficient area for placement the photovoltaic modules.

17.1 Electricity consumption

As was stated in previous chapter, the problem of heating and hot water is solved by a gas. Electricity is used only for household appliances and lighting. In the next table we can see the consumption of electricity through the years and for particular months. This data was obtained thanks to my father, who has been collecting them through the years.

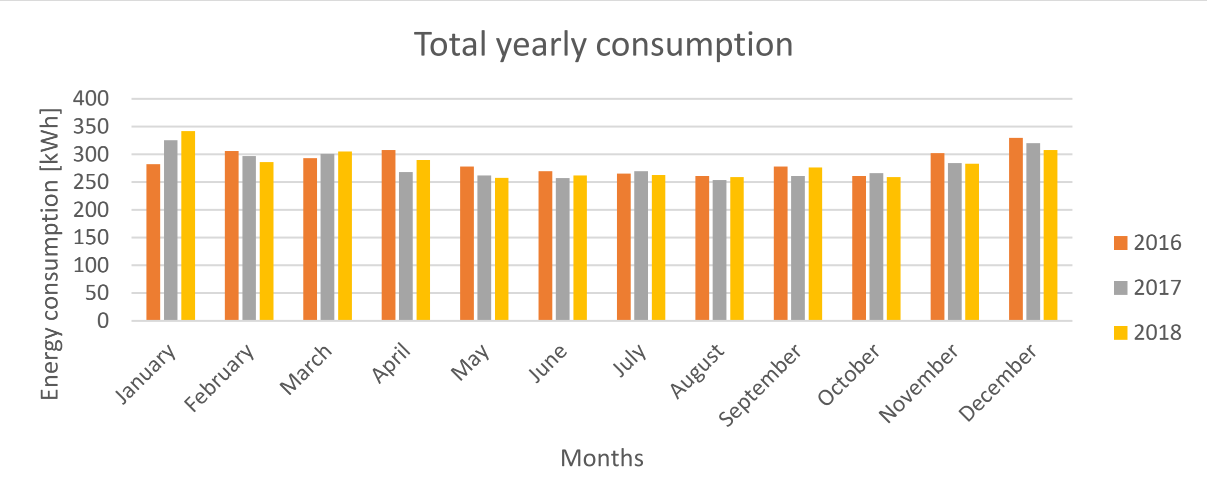
Table 1 - electricity consumption through the years

year	2016		2017		2018	
months	consumption [kWh]		consumption [kWh]		consumption [kWh]	
	per month[kWh]	per day [kWh]	per month[kWh]	per day [kWh]	per month[kWh]	per day [kWh]
January	282	9,10	325	10,48	342	11,03
February	306	10,93	297	10,61	286	10,21
March	293	9,45	301	9,71	305	9,84
April	308	10,27	268	8,93	290	9,67
May	278	8,97	262	8,45	258	8,32
June	269	8,97	257	8,57	262	8,73
July	265	8,55	269	8,68	263	8,48
August	261	8,42	254	8,19	259	8,35
September	278	9,27	261	8,70	276	9,20
October	261	8,42	266	8,58	259	8,35
November	302	10,07	284	9,47	283	9,43
December	330	10,65	320	10,32	308	9,94
Total [kWh]	3433		3364		3391	

Amount of electricity consumption per day was obtained by dividing the amount consumed during the month by the number of days in that month. Which means, it is only an average value, not taking into consideration different consumption during weekends and working days.

Also, in the last row of the table we can see the total consumption throughout the year. From the data we can see, that the consumed amount stays relatively the same. Or at least does not show any increasing or decreasing prediction.

In the next graph, we see a graphical representation of previous table. From this figure, we can better see comparison of consumption through separate months. The situation with months is similar as the situation with the yearly consumption. It stays relatively same as in previous years.



Graph 1 - Electricity consumption through the years

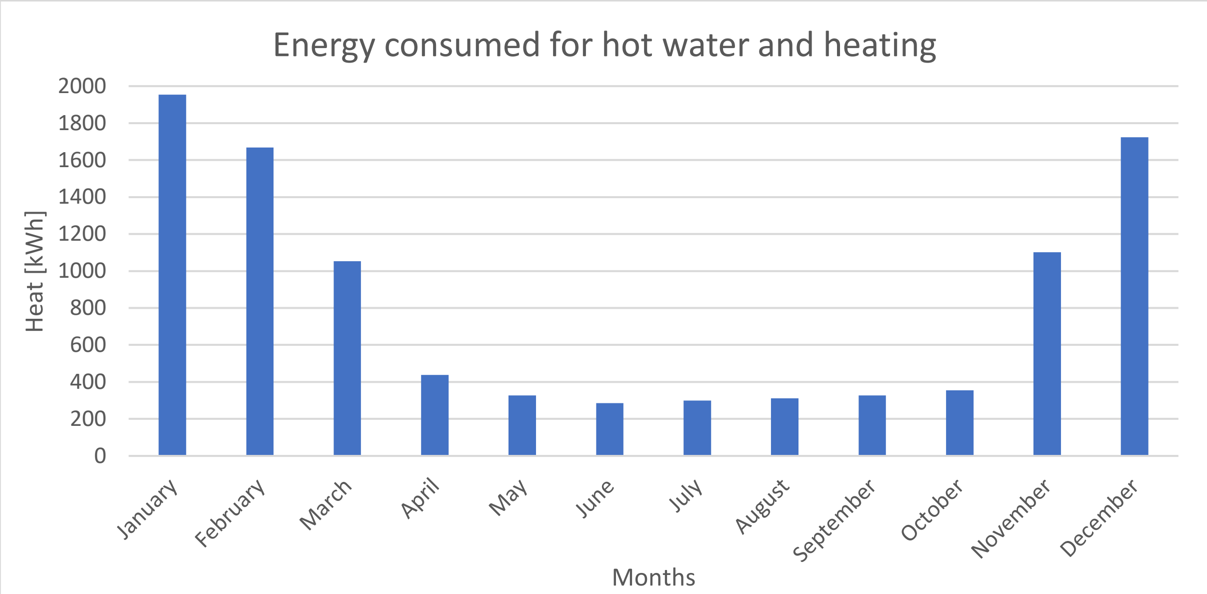
17.2 Gas consumption

As was stated previously, in this household gas is used for hot water and heating. In the next table, we can see the gas consumption for one particular year. The data were again obtained by my father.

Table 2 - gas consumption

Months	Gas [m^3]	Gas/day [m^3/day]	Heat energy [kWh]	Heat energy /day [kWh/day]
January	185	5,97	1954	63,03
February	158	5,65	1668	59,57
March	100	3,22	1053	33,97
April	42	1,38	438	14,60
May	31	1,00	327	10,56
June	27	0,90	285	9,50
July	28	0,92	300	9,66
August	30	0,95	312	10,08
September	31	1,03	327	10,90
October	34	1,08	355	11,44
November	104	3,48	1102	36,74
December	163	5,27	1724	55,61
Total	933		9845	

In the table we can see the household consumption of gas, recalculated in energy units. The data are displayed for a month and for a day. The graphical representation of energy consumed during a month for heating and hot water can be seen in the next graph.



Graph 2 - Energy consumed for hot water and heating

17.3 Load schedule diagram of a family house

In order to successfully estimate a load schedule diagram, we firstly need to define all the household appliances, where the electric energy is being consumed. All this information can be found in the next table.

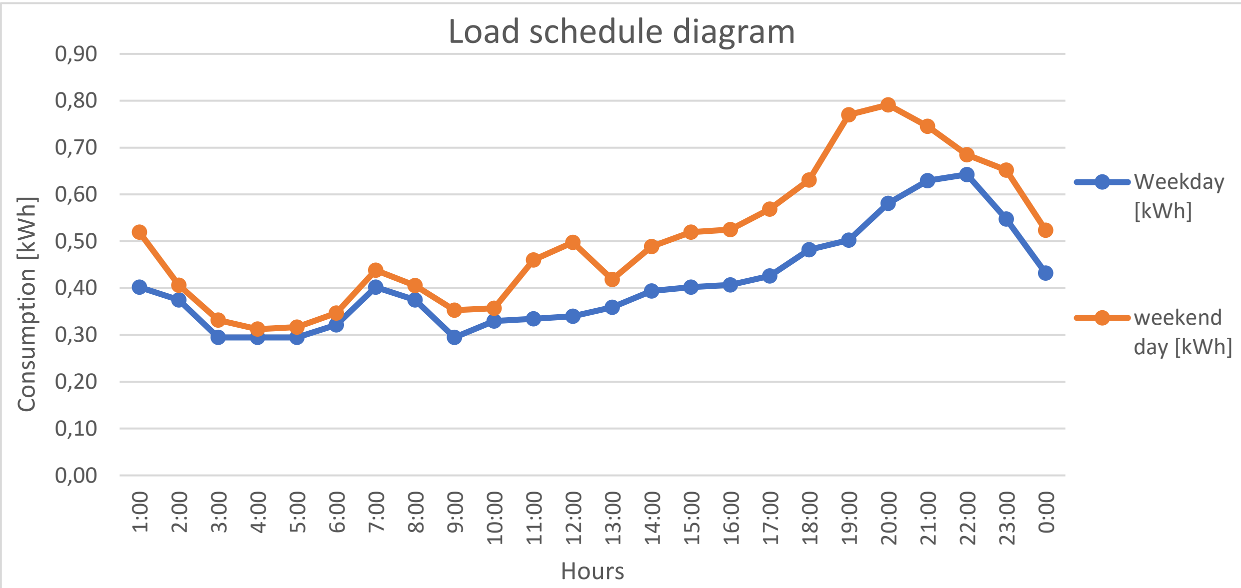
In the table are firstly listed all devices consuming electricity in the house, together with their rated input power. In the next columns is estimated their usage during weekends and working days separately. The estimation was based upon discussion with my parents. Lastly from their input power and their usage, the total consumed energy was calculated.

Table 3 - electricity consumption of household appliances

Electrical appliance	Input power [w]	Usage per weekday [h]	Usage per weekend day [h]	Consumption per weekday [kWh]	Consumption per weekend day [kWh]
Combined refrigerator	40	24	24	0,96	0,96
Washing machine	820	1,5	1,5	1,23	1,23
Dishwasher	1550	1	1	1,55	1,55
Electric oven	950	0	1,5	0,00	1,43
Microwave	1430	0,33	0	0,47	0,00
Coffee maker	350	0,33	0,16	0,12	0,06
LED television	74	3,5	9	0,26	0,67
Audio speakers	55	0,5	1	0,03	0,06
Notebooks	45	2	4	0,09	0,18
Computer	120	3	1	0,36	0,12
Iron	1150	1	1	1,15	1,15
Small induction hob	1400	0,5	0	0,70	0,00
Big induction hob	2300	0	0,5	0,00	1,15
Lighting	60	6	7	0,36	0,42
Wifi-router	8	24	24	0,19	0,19
Vacuum cleaner	750	0	0,5	0,00	0,38
Kettle	1900	0,33	0,33	0,63	0,63
Toaster	750	0,16	0,33	0,12	0,25
Stand-by regime	68,75	24	24	1,65	1,65
Total [kWh]				9,86	12,06

Here, the different season is not taken into consideration. It is due to the fact, that since we are using electricity only for appliances and not for heating, the yearly consumption does not change that much with a season. We can see this in previous graph. That is why, the consumption is divided only on working day and weekend day.

In the next figure, we can see load schedule diagram for a classic working and weekend day. The diagram was constructed accordingly to previous table and a basic knowledge of load diagrams for a classic family house. In the graph we can see the energy demand spikes during breakfast, lunch and dinner. The absence of higher spike during working day dinner is due to the fact, that we often eat cold dinner during these days.



Graph 3 - load schedule diagram

18 Voltage battery photovoltaic system

When designing a photovoltaic plant, we will be interested in how much electricity it is able to produce in real terms. Production of electric energy depends on the intensity of the solar radiation and on the total installed power of the photovoltaic modules.

Information bearing data on the intensity of incident solar radiation and overall electricity production can be found out from computer programs that work on the basis of long-term climatic averages, according to entered coordinates, roof pitch and azimuth.

In my work I will use the program called PVGIS, in which I entered data about our family house. This input data has been described in previous chapters.

In terms of dimensioning photovoltaic system, I must declare, that we are not dimensioning classical photovoltaic plant. We are dimensioning and calculating a relatively new product on Czech market, called Virtual battery. It is a product offered only by one Czech company, called EON. The principle of this product is as follows. The excess of energy produced by solar system is send to the grid. The amount is measured by a bi-directional energy meter. In the events of deficiency of energy, we can take the same amount previously stored from the grid for free.

The downside is the fact, that the solar plant must be built by EON solar company and part of the construction must be covered by subsidies. The total installed power and their prices for constructing the system can be found in the next table. In addition to that, in the same table are shown savings per year and per kWp of installed power. Based on that is calculated the raw rentability of the system.

Table 4 - raw rentability of the system

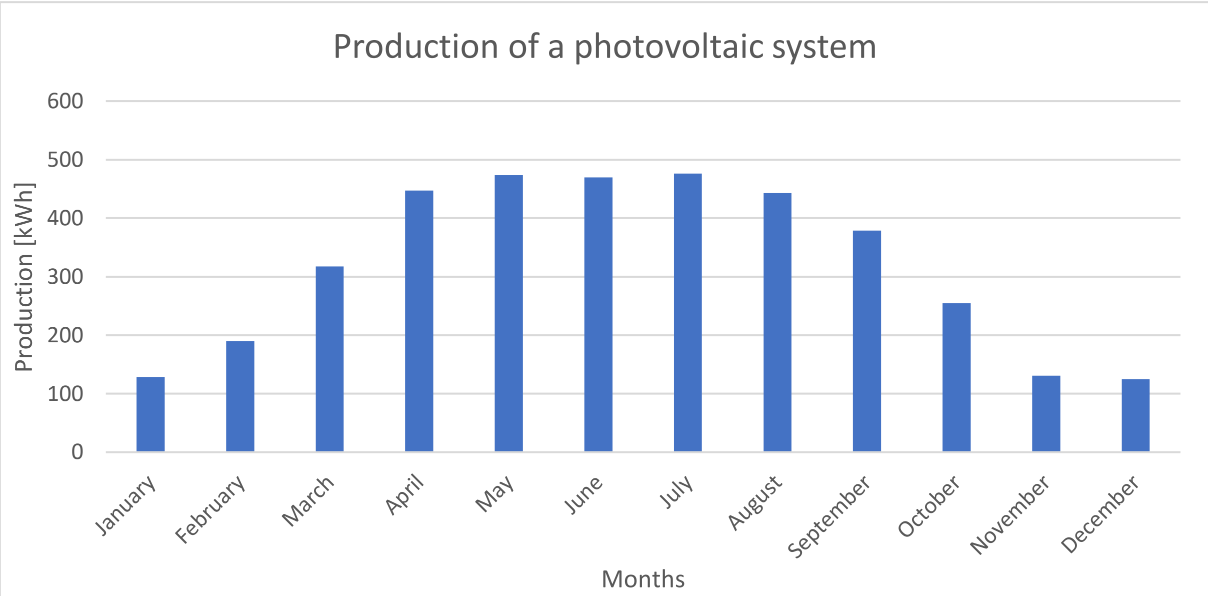
Installed power [kWp]	Initial investment [$]	Savings [$/year]	Savings [$/kWp]	Raw rentability [years]
0,66	$3 220	$108	$163	30
1,32	$4 476	$202	$153	22
1,98	$5 329	$266	$135	20
2,64	$5 974	$319	$121	19
3,3	$6 601	$367	$111	18
3,64	$6 200	$391	$107	16
4,1	$6 596	$397	$97	17
4,62	$9 676	$401	$87	24
5,28	$13 240	$405	$77	33

Due to the length and complexity of savings calculations, in the table is shown only the result. The complete calculations can be found in the attached excel document. And we know, that parameter raw rentability is not the best economical parameter, but we do not need an exact number of profitability. This will be calculated in economic part of this work.

From the table we see, the 3,64 kWp installed power seems like the most rentable option. Of course, from this parameter we cannot say what will happen after the rentability period, we do not take into consideration discount and many more. But as was previously stated, we do not need to know that now.

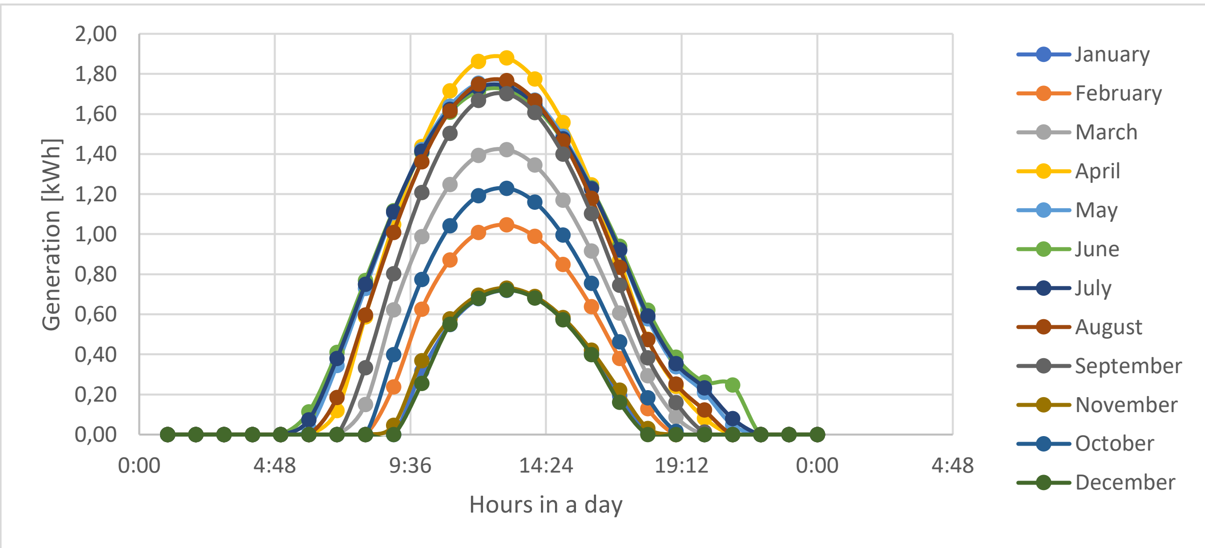
18.1 Energy production of a Voltage battery photovoltaic system

As was stated above, we chose to install a photovoltaic system with 3,64 kWp. Its monthly production we can see in the next figure. The production data were obtained from a program called PVGIS for our set of input data.



Graph 4 - production of a photovoltaic system

As a next step, we will determine the energy production of a system in separate hours throughout the day. These data cannot be obtained directly from the program PVGIS. From PVGIS can be obtained hourly irradiation data for every month. With the knowledge of total average energy production in a day, we can construct an hourly energy production. The result can be seen in the next figure.



Graph 5 - Hourly energy generation of a photovoltaic system

In the figure is represented an average day for each month. With the knowledge of load schedule diagram and the hourly energy generation, we can determine how much energy is being used immediately and how much energy is being stored into a grid. We will take a closer look at this in the following chapters. But firstly, we will also take a closer look at the components of the photovoltaic system.

18.2 Devices of our photovoltaic system

In the next chapters we will take a closer look at main components of our photovoltaic system. Firstly, there will be briefly introduction of the devices. Which means quick description of the type of a device followed by its main technical parameters.

Description and schemes of the whole system will be in the following chapters.

18.2.1Solar panels

In order to reach 3,64 kWp of installed power, we will use eleven polycrystalline solar panels with the output power 330 kWp. We will use solar panels from a company called Axitec. It is a company with a long tradition, great reviews and mainly offers quality product. They also guarantee 12 years warranty, highest performance due to specifically selected technologies and materials, positive power tolerance, maximum 2400 Pa snow load, 100 % electroluminescence inspection and high-quality junction box and connector systems. But these solar panels are mainly chosen for one and only reason. It is because the company which provides this product Virtual battery, uses solar panels from the same company Axitec. The complete datasheet of these solar panels can be found in appendix of this thesis.

Due to the current restriction on the input side of inverter, we will connect the solar panels in parallel. The nominal voltage of the whole panel system will be 414,7 V and open circuit voltage will be 504,13 V, where nominal voltage of one panel is 37,7 V. Nominal output current of the solar panel is 8,76 A and short circuit current 9,27 A.

18.2.2 Inverter

As an inverter we chose inverter Sunny Boy 4. It is once again a reliable, top quality piece of device from SMA company. Its company also promises valuable auxiliary services, such as automatic inverter monitoring, proactive communication in the event of faults, replacement service and performance service.

With a 600 V maximum input voltage and 15 A maximum input current this inverter fulfills the requirements in connection with solar panels. More information about the inverter and complete datasheet can be found in appendix of this thesis.

18.2.3 Watt router

As a watt router we will use a watt router M SSR from a company called SOLAR controls. We are dealing with a very sophisticated programmed controller for optimizing self-consumption for objects with installed photovoltaic or wind power plants.

Current measuring range is 3x20 A, continuous load 3x40 A. After proper installation and setup, the controller perfectly optimizes the use of excess energy produced by your photovoltaic plant. More information about it and complete datasheet can be found in appendix of this thesis.

18.2.4 Safety devices

In order to guarantee safety and proper functioning of the system, we have to use a set if safety devices. This set will consist of fuses and circuit breakers. Their exact position in the system will be seen in the next chapters, where schemes and one-line diagram will be introduced.

Fuses between solar panels and solar controller will be cylindrical DC fuses from a company called Onesto. They have 1000 V maximum rated voltage and 12 A maximum current and 25 kA rated breaking capacity. More information about these fuses can be found in appendix of this thesis.

As another used safety device are circuit breakers. We will use NDB2T-63(UL489) circuit breaker, with 1-63 A rated operating current. More technical information about this type can be found in appendix of this thesis.

18.2.5 Bi-directional energy meter

As a bi-directional energy meter, we will use meter from a company called SMA ENERGY. It is a flexible, easy to use high-performance measurement solution for intelligent energy management in photovoltaic systems. Technical information about this device can be found in appendix of this thesis.

18.2.6 Connecting and bearing constructions

In order to successfully construct the solar system, we also need cables, connectors and roof constructions. As connectors we will use type MC4 from a company called SunPulse. For connecting solar panels and inverter we will use DC cables from a company called KEI. With a 120 mm2 cross-section they provide 1,5 kV rated DC voltage and 416 Amps in single cable. For connecting the inverter and the rest of the system, we will use AC cables type NYY-O from company called Helukabel. More technical information can be found in the appendix of the work.

18.2.7Complete list of devices

Now that we have defined all our devices separately, we can showcase them together in one table. And exactly this we can see in the next table. Used devices, their types and the amount of them used.

Table 5 - devices of the photovoltaic system

Device	Type	Amount
Inverter	SMA SunnyBoy 4	1
Solar panels	Axitec Axipower AC 330 Wp	11
bi-directional energy meter	SMA ENERGY Meter 20	1
watt router	M SSR	1
switchboard	DC switchboard with protection and overvoltage protection up to 15A	1
Cables	BS EN 50618, NYY-O	50
Connector	Connector MC4 SunPulse	11
Roof construction	Schletter roof construction	6

18.2.8Connection of the system

The system of itself is very identical with classical net metering system. Example of such a system can be seen in the next figure.

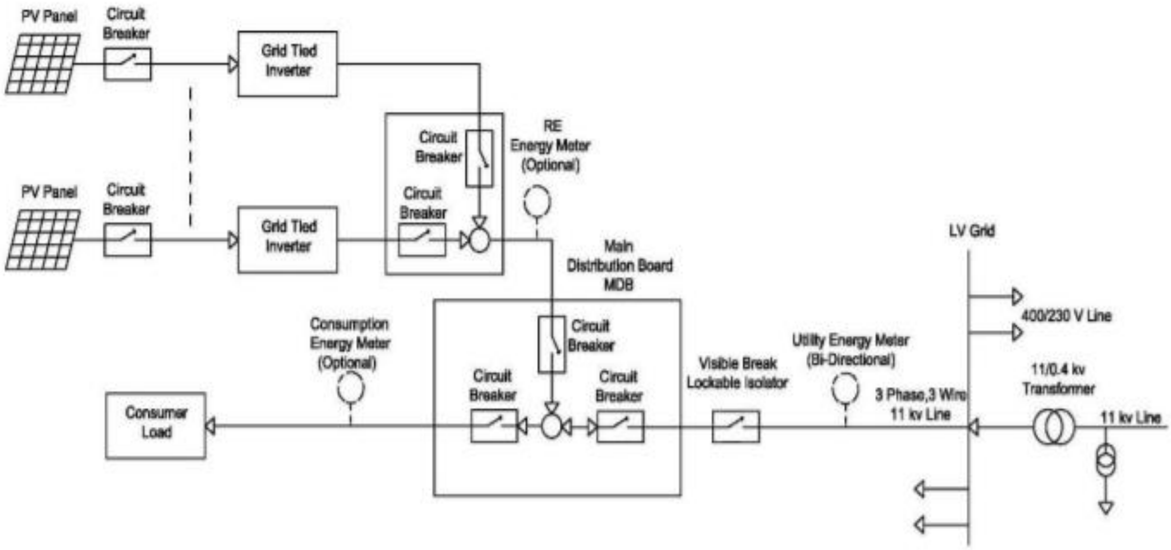


Figure 13 - Net metering connection [27]

In the figure we can see a common setup similar to a normal photovoltaic power plant. The only difference is, that between photovoltaic plant and a grid is placed bi-directional energy meter. This meter measures and calculates energy flows in both directions. This information is later used by a distributing company, in our case EON, for calculating how much energy we have stored in a grid and thus how much energy we can withdraw from a grid. More detailed description of the meter can be found in previous chapter.

But this scheme is a generic scheme and does not apply directly to our example. That is why in the next figure, we can see one-line diagram of our power plant.

The specific representation of our system can be seen in the next figure. It is a one-line diagram of our setup. Used devices are the one mentioned in previous chapters.

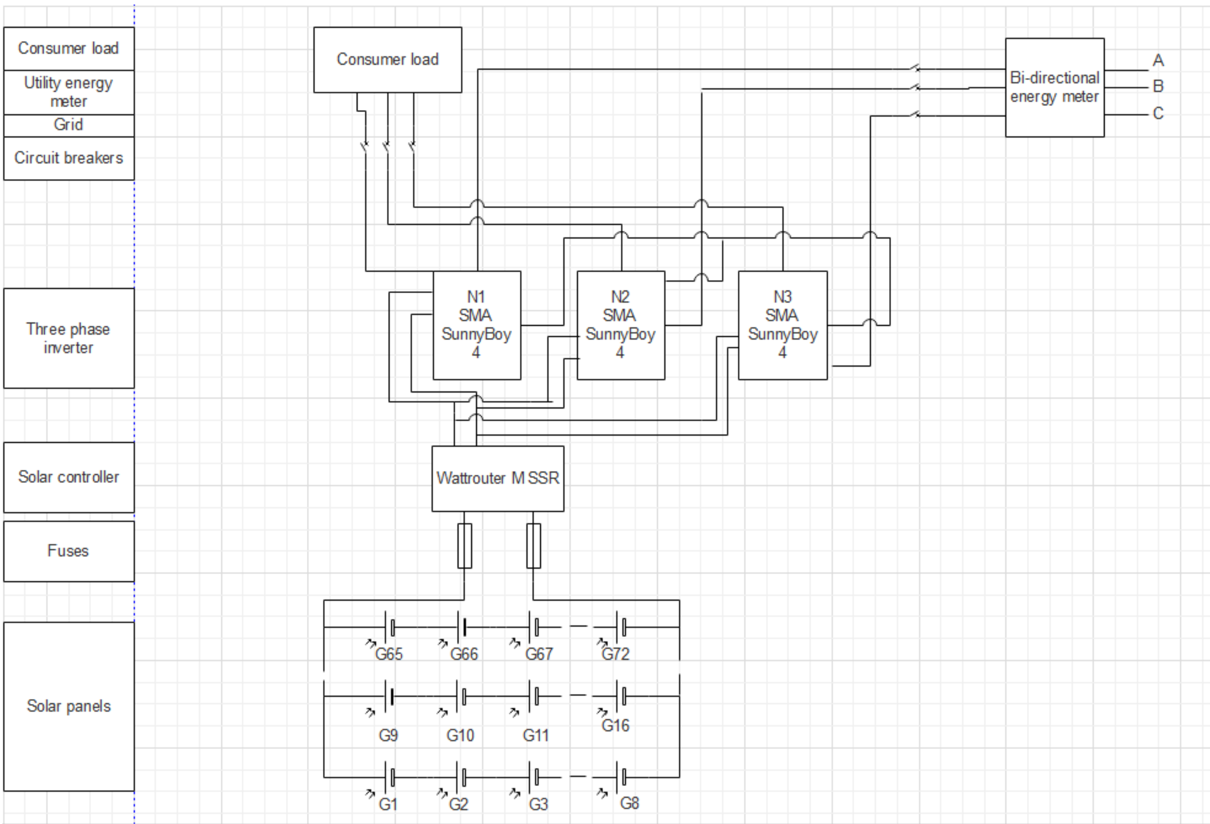


Figure 14 - one-line diagram of our system

In the middle is a basic scheme of connection of our system and on the left side, we can see for better understanding a short specification of devices.

18.3 Usage of a virtual battery

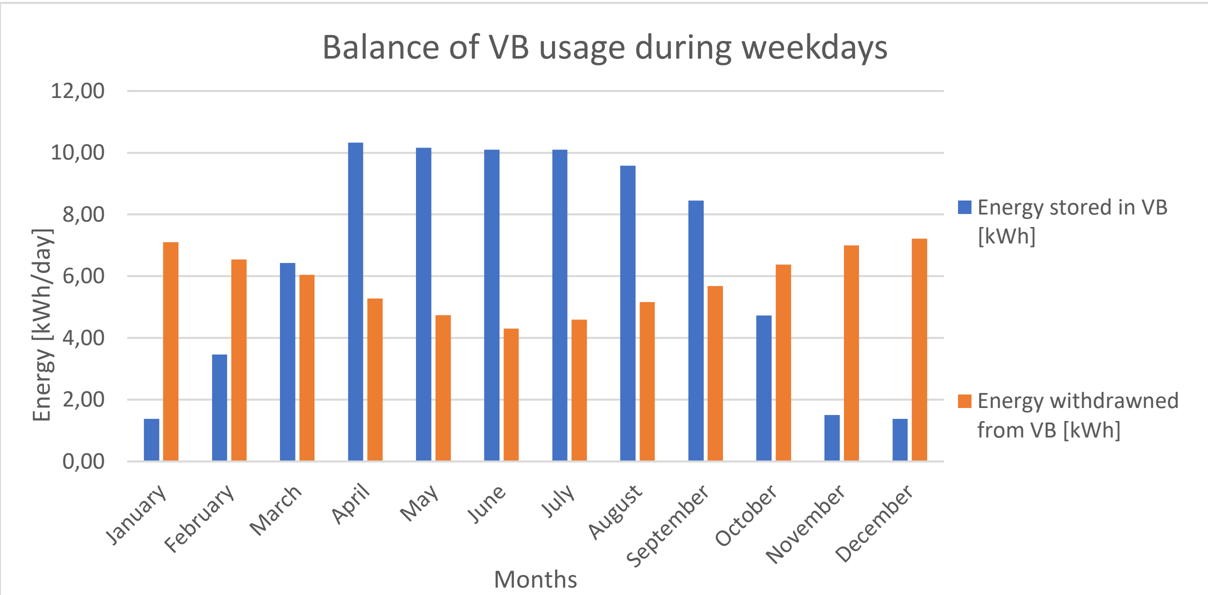
Now that we have defined and modeled our house, its load schedule diagram, our photovoltaic system, its energy generation, devices etc. we can finally proceed and calculate the total usage of virtual battery.

Which means how much energy we store into a grid and how much energy we withdraw from a grid daily. Since our generation and consumption of energy is calculated hourly with differentiation in weekends and working days, our calculations should be sufficiently accurate.

18.3.1 Usage of virtual battery during working days

The logic behind these calculations is straight forward. If we have excess of energy, we store this energy into a grid. If we have on the other hand a shortage of energy, we withdraw the energy from a grid. If there is a shortage of energy without any energy stored in a grid, we simply withdraw the energy from a grid for the payments according to our tariff. The complete calculations can be seen in attached excel document.

In the next graph, there can be seen a result of these calculations.



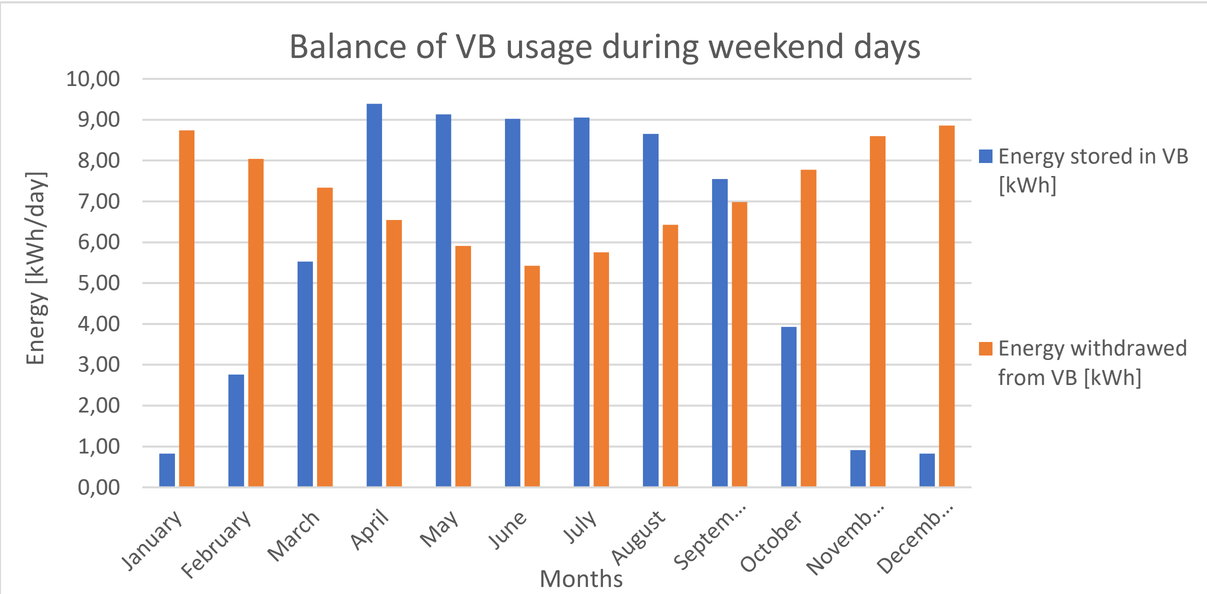
Graph 6 - usage of virtual battery during working days

The data in the graph are for one day from a month. Which means, that in the graph is displayed one average working day, from each month of a year.

The graph itself looks as would be expected. During summer months, when generation of solar energy is high, we store most of the energy. On the other hand, during winter months, when generation of solar energy is low, we withdraw most of the energy from the grid.

18.3.2 Usage of virtual battery during weekend days

The principle of calculations is the same as calculations for virtual battery usage during working days. The complete calculations can be also found in attached excel document. The result of calculations can be seen in next graph.



Graph 7 - usage of virtual battery during weekend days

As in the previous graph, here we see an average weekend day from each month. Results are as could be expected. During summer months, we again generate more energy than we consume, thus we store this energy. And during winter months we generate minimal amount of energy, thus most of the energy we withdraw from the grid. The difference here is, that the electricity consumption is overall higher than during working days. It is mainly due to the fact, that the family spends more time home.

18.3.3 Yearly usage of virtual battery

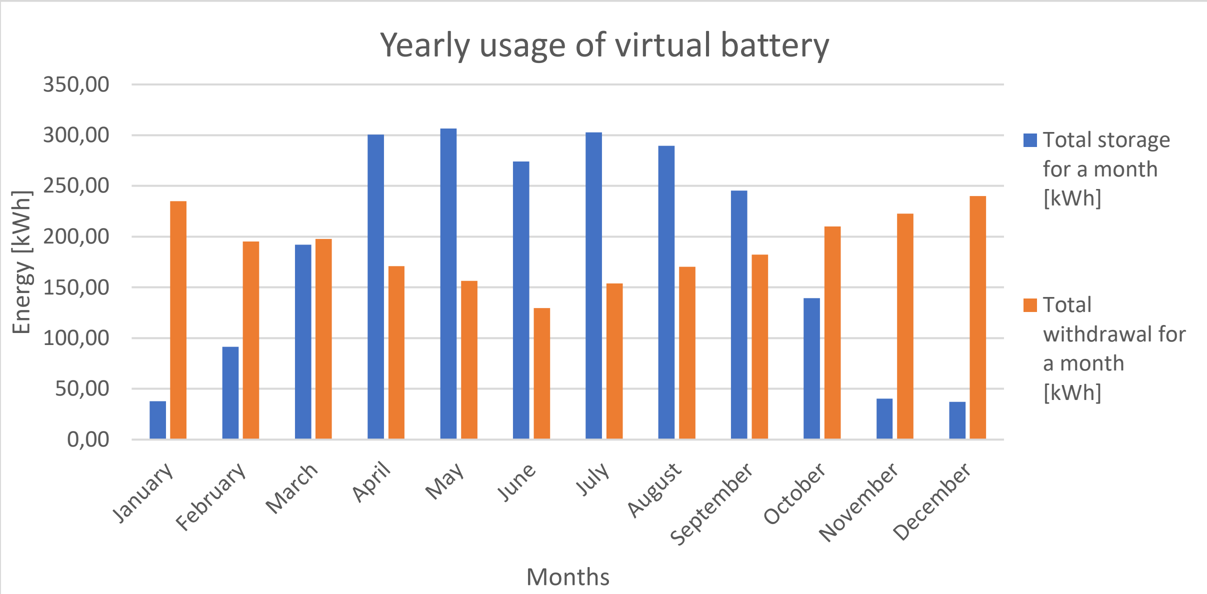
Since from previous chapters we know the virtual battery usage in different days, we can simply calculate the usage for a year. Again, detailed information can be found in attached excel document. Here will be displayed only result of the calculations. And that can be seen in the following table.

Table 4 - yearly usage of virtual battery

Month	Number of weekdays	Number of weekend days	Total storage in weekdays [kWh]	Total storage in weekend days [kWh]	Total storage for a month [kWh]	Total withdrawal in weekdays [kWh]	Total withdrawal in weekend days [kWh]	Total withdrawal for a month [kWh]
January	22	9	30,38	7,41	37,79	156,17	78,68	234,85
February	20	8	69,28	22,11	91,38	130,92	64,37	195,29
March	23	8	147,83	44,20	192,03	138,96	58,72	197,68
April	20	10	206,50	93,93	300,43	105,57	65,47	171,04
May	23	8	233,68	73,05	306,73	109,06	47,31	156,37
June	20	8	202,07	72,18	274,24	86,15	43,42	129,56
July	21	10	212,07	90,56	302,63	96,50	57,53	154,04
August	23	8	220,44	69,22	289,66	118,76	51,45	170,21
September	21	9	177,51	67,96	245,46	119,36	62,84	182,20
October	22	9	103,97	35,37	139,34	140,20	69,99	210,19
November	22	8	33,11	7,27	40,38	153,90	68,79	222,69
December	21	10	28,91	8,22	37,13	151,50	88,61	240,11
Total[kWh]			1665,75	591,46	2257,21	1507,04	757,19	2264,23

In the table we can basically see a previous data-for one day, multiplied by according number of days in that month. As a result, we obtain the total withdrawal or storage for that month.

Graphic representation can be seen in the next graph.



Graph 8 - yearly usage of virtual battery

The result is similar as it was for single days. During summer months, we have an excess an energy which we store in a grid. During winter months we have a lack of energy, so we withdraw this energy from a grid.

19 Input assumptions

In these chapters we will take a closer look at the most important parameters while calculating net present value and IRR of our investment.

19.1 Inflation

The value of inflation in our calculations was set at 2 %. This value was selected, because it is long-term inflation goal of a Czech National bank. And since Czech National bank has ways how to influence inflation, we will believe, that this value will be maintained even in the future [28].

19.2 Discount

The price of a real discount rate was set as a profitability of an alternative investment. If we would not have invested in solar system, the money would still be on a savings account.

Discount rate was then set as an average value of top five rated savings accounts [29]. In this thesis the value of a real discount is then 1,33 %. On the basis of real discount and value of inflation, we set up the value of nominal discount at 3,36 %.

19.3 Degradation of solar panels

The Axitec solar company guarantees a warranty, that the decrease in power output in 25 years will be only 15 %. That is why, every year the power output will be lowered by 0,6 % in first 25 years.

Because of solar panels will be on the roof even after 25 years, we predict an increase in efficiency decrease after 25 years. In these years, the yearly efficiency decrease will be set at 2 %.

19.4 Revisions

Revisions are made every third year by EON company and they do not charge the owner for any payment. That is why, we will not be calculating with them in our example.

19.5 Recycling costs

According to the Waste Act No. 185/2001 Coll. For recycling the panels that were placed on the market after 1 January 2013, the manufacturer is responsible [30].

The recycling fee is therefore automatically included in the price of the panel. For this reason, we do not include this item in our calculations.

19.6 Service life of devices

We realize that the lifetime of individual components does not always match with the lifetime of the entire system. For this reason, we counted the lifetime and therefore the forced replacement of the inverter after 15 years.

This exchange will be reflected in the calculations.

19.7 Insurance and maintenance of the system

In the annual operating costs insurance of the plant is included in the amount of 0,1 % of the initial costs of the power plant itself and maintenance and possible minor repairs in the amount of 0,5 % cost of power plant.

These costs are cumulated primarily to cover the unexpected costs and also include maintenance costs, for example in the form of cleaning the panels with a jet of water for preventing unwanted losses.

19.8 Electricity price prediction

The largest share of the total price of electricity is the price for energy, the price for distribution and payment for renewable energy sources. The decline in the price of electricity has been caused in recent years mainly by a decrease in emission prices allowances, a decline in coal and gas prices and a rise in the share of renewable energy sources on electricity production. The price of emission allowances can be expected to increase in the future and a further increase in the share of renewable energy sources in electricity generation, the assumption is that the influence of renewable energy sources will prevail, and the price of power electricity will drop slightly. The effect of the growing share of renewable energy sources on the decline in the price of electricity is caused by non-market funding of these resources through various forms of support. The cost will thus gradually move from the market price of electricity to the contribution to renewable energy sources. Distribution costs will continue to increase based on the assumption of increased costs for distributors associated with the development of decentralized sources.

From this thought results, that the price of electricity will decrease due to the increase in the share of renewable energy sources in production offset by an increase in off-market support for these resources in the form of a contribution to renewable energy sources.

Overall, the price of electricity will rise due to an increase in the price of distribution and due to rising prices of emission allowances, the question is the future development of coal and gas prices. Necessary replacement of the aging portfolio of power plants in the Czech Republic is another factor that will contribute to the increase in electricity prices.

Given the increasing profitability of investment with the rising price of electricity is due to conservation of conservative approach chosen only a slight 0,5 % year-on-year increase in electricity prices. The effect of the change of this parameter on the investment evaluation is given in chapters Sensitivity analysis.

19.9 Gas price prediction

The development of gas prices tends to be smooth and there are no visible year-on-year jumps during the year, as it is with electricity prices. The resulting price of natural gas depends on the current state of filling of gas storage facilities and failures of natural gas production in the world.

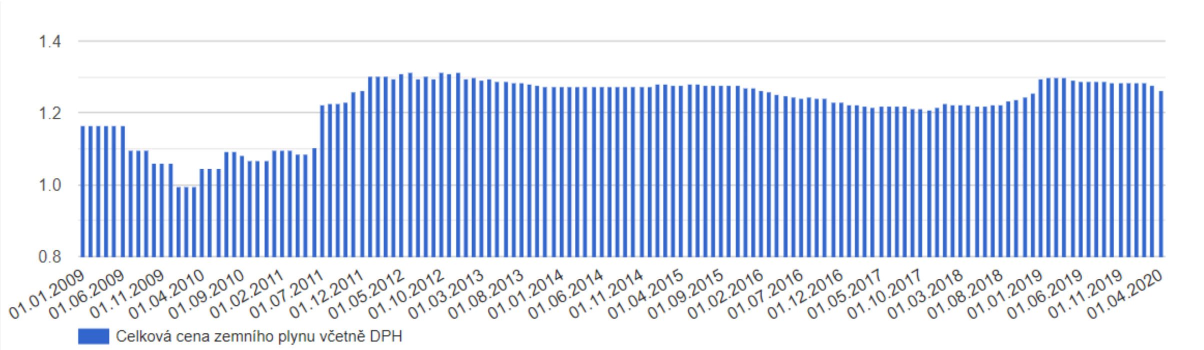


Figure 15 - prices for gas in Kč/kWh in Czech Republic [31]

From the figure we can see that until year 2013 the total price of natural gas has been variable over the years, with a gradual upward trend. Since 2013, changes in the total price of natural gas have stabilized due to the huge increase in the number of fixed-price product lines. The future is however, it is very unlikely that prices will fall further, as is the case with electricity. It will be rather a slow rise as fixed-price tariffs will no longer be added. As a prediction of price development, I would again choose the value of 2 % year-on-year growth.

19.10 Initial investment

As was stated previously in this thesis, in order to be entitled to obtain a product called Virtual battery, the solar power plant must be constructed by EON company, which is the same company, which offers Virtual battery. They explain this by the fact, that since they are responsible for deviations in network and they are the ones paying fees if it occurs, they need to make sure, that the whole system is constructed, plugged and installed correctly.

The price they charge for a 3,64 kWp solar system is 6 200 $. And that is the exact price, that will be used in future calculations.

19.11 Economical profitability of a virtual battery

Now that we know the usage of virtual battery energy wise and we have already predicted our input parameters, we can calculate profitability of virtual battery. In order to do that, we will calculate net present value, internal rate of return and raw and discounted rentability of our investment.

Considering the input parameters as were stated previously, we can easily calculate the main evaluation methods. Due to the velocity of calculations, these will not be displayed in this thesis. But they can be easily found in the attached excel document. In the next table, only final results are displayed.

Table 5 - results of economical evaluation

NPV 25	-909 $
NPV 35	826 $
IRR 25	2,02%
IRR 35	4,17%
Raw rentability	21 years
Discounted rentability	30 years

These results were obtained taking into consideration inflation, discount, solar panels degradation, insurance and maintenance, lifelong of an inverter and annual electricity growth price.

From the table we can see, that if we would be operating our solar plant only for 25 years, according to expected lifelong of solar panels, our investment would not be rentable. Only with the assumption of keeping our solar panels on the roof for another 10 years, our investment becomes profitable. In these 10 years the solar panels degradation is increased, but the higher probability of malfunctioning or even complete destruction of some device is not here simulated in any way.

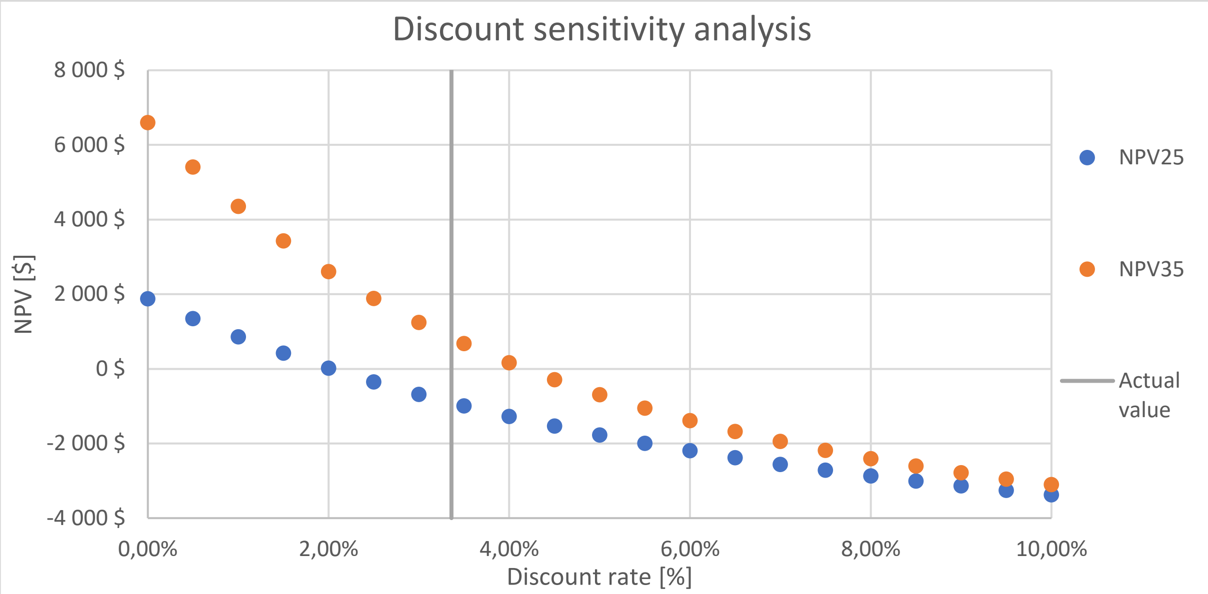
Not surprisingly our second evaluation method-internal rate of return gives us the same results as net present value. Because our IRR for 25 years is less than predicted nominal discount, the investment appears to be non-profitable. The opposite is considering the lifelong of investment for 35 years. Then the investment appears to be profitable, as was with NPV evaluation.

In the final results is also displayed another evaluation method and this method is rentability. Which means in how many years our investment will be paid back. We can see, that if we take into account discount our rentability is 30 years. Without discount the rentability is 21 years. In both cases, the rentability is too long.

19.12 Sensitivity analysis of Virtual battery

Since we have been estimating numerous parameters 35 years in the future, doing sensitivity analysis on their value would be a wise decision. And that is exactly what we will do in next chapters. We will do four sensitivity analysis on the four most influential input parameters.

In the next graph we can see a sensitivity analysis done on a discount.

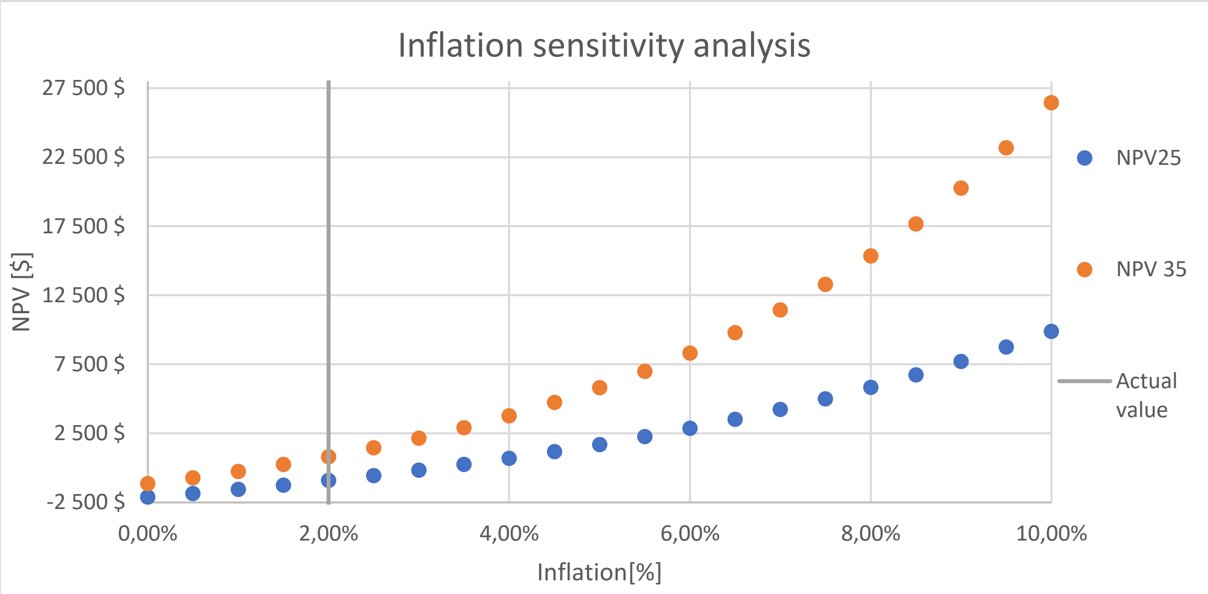


Graph 9 - discount sensitivity analysis

In the graph we can see the analysis done for both considered life longs. These are 25 and 35 years. We can basically see dependence of our main valuation method NPV on a discount variability. Plus, there is displayed an actual value of discount used in calculations.

From the graph we can see, that if our discount rate would reach higher values, our investment in Virtual battery would be less and less profitable. And since are discount prediction was modest, we can expect higher values of discount. So, from this sensitivity analysis we can see another reason, why not put in motion this investment.

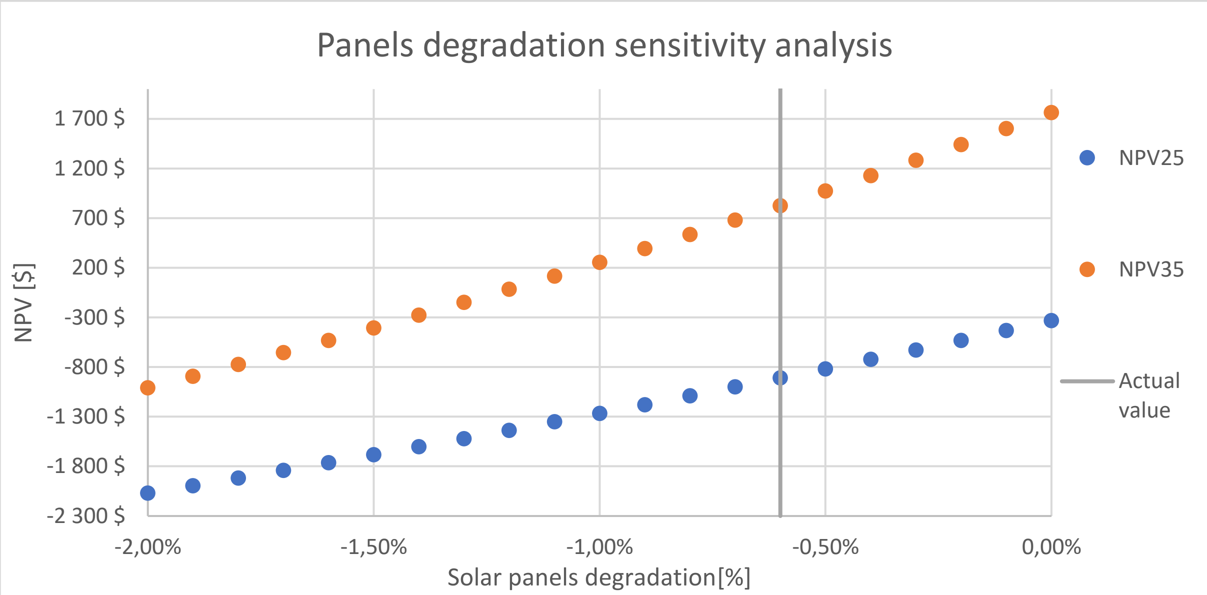
As a second most influential parameter was chosen inflation. The dependence of NPV on variable inflation can be seen in the next graph.



Graph 10 - inflation sensitivity analysis

With the grey color is marked an actual used value of inflation in calculations. From the graph we can see, that with increasing inflation the net present value also increases. But because the value of inflation has been steadily around 2 % throughout the last years, we do not expect its dramatic increase in the future.

As a next chosen parameter is a solar panel efficiency degradation. The result of this sensitivity analysis can be seen in the next graph.

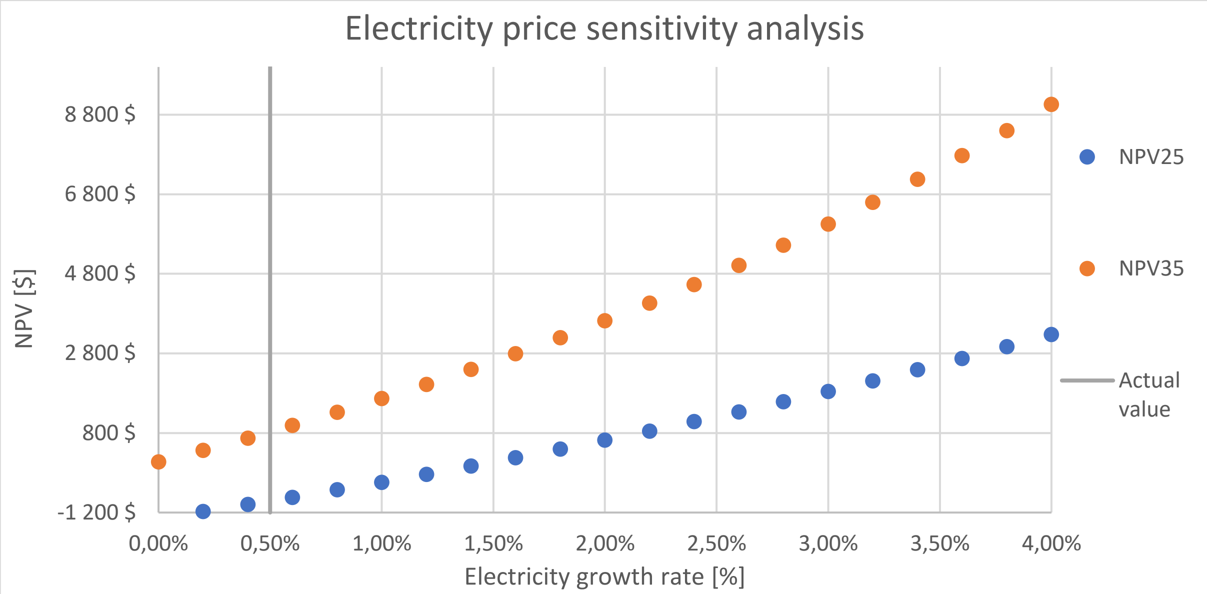


Graph 11 - solar panel efficiency degradation

With a solar panel degradation is meant a yearly decrease in its efficiency of producing electrical energy. Even though value 0,6 % is guaranteed by the developer of solar panels, something might happen, and the efficiency might drop. With the grey color is again marked an actual value of panel degradation used in calculations.

From the graph we can see, that even if we would have a zero decrease in efficiency, we would not reach a positive net present value in first 25 years.

And as a last most influential parameter an annual electricity price growth was chosen. The graphic result of this analysis can be seen in the next graph.



Graph 12 - Electricity price sensitivity analysis

With the grey color is displayed an actual value of electricity growth rate used in our calculations. From the graph is clearly seen, that with increasing electricity price, the profitability of our solar system will also be increasing.

And with the effort to fully use clean energy from renewable sources, the scenario of electricity price increasing might be more than expected.

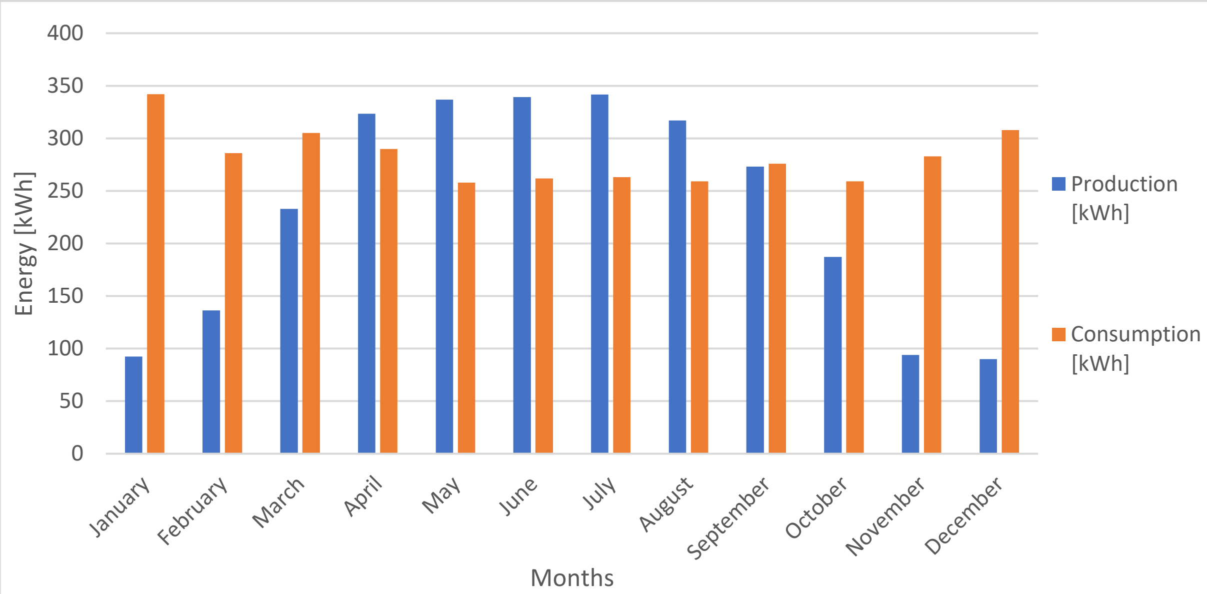
20 Photovoltaic system with the excess used for heating

As was stated in the introduction to this diploma thesis, the main idea of this work is to compare a new product on the market, which is Virtual battery, with a more traditional photovoltaic system. The conclusion should be a decision, whether this new product is more profitable than other available products.

As a comparing product, I chose the most common system, which is a photovoltaic system used for power electric equipment and using the excess of energy for hot water and heating. In order to make the comparison as truthful as possible, we will try to change as few parameters as we can. Which means we use the same house, with the same electricity and gas consumption and with the same load diagram. We will assume the same solar irradiation and the same input economical parameters. There will be only two big differences. The first one is the amount of installed power. Because we are utilizing a different system, we will have to dimension the system accordingly to it. The second big difference derives from the first one. And that is the fact, that we will have to dimension and use different devices.

20.1 Dimensioning of the system

The system will have an installed power equaled to 2,64 kWp, consisting of 8 solar panels from the same company as last time-Axitec. The energy generation throughout the year in a comparison with its consumption can be seen in the next graph.



Graph 13 - energy generation and consumption comparison

In the attached excel document, there is calculated a generation and consumption of electric energy by an hour of a day during the months. From this data, we can quite precisely determine, how much energy will be used immediately as electricity and how much energy will be stored in the form of heat.

The results can be seen in the next table.

Table 6 - results for a solar system with heating

Month	Number of weekdays	Number of weekend days	Solar energy used for electricity in working day [kWh]	Solar energy used for electricity in weekend day [kWh]	Solar energy used for heating and hot water in working day [kWh]	Solar energy used for heating and hot water in weekend day [kWh]	monthly used solar energy for electricity [kWh]	monthly used solar energy for heating and hot water [kWh]
January	22	9	2,50	2,88	0,48	0,10	80,91	11,49
February	20	8	3,10	3,74	1,77	1,13	91,93	44,36
March	23	8	3,68	4,45	3,84	3,06	120,16	112,75
April	20	10	4,33	5,26	6,45	5,52	139,08	184,21
May	23	8	4,77	5,70	6,10	5,17	155,18	181,72
June	20	8	5,13	6,07	6,18	5,25	151,22	165,56
July	21	10	4,89	5,82	6,13	5,20	160,89	180,77
August	23	8	4,40	5,33	5,83	4,90	143,91	173,21
September	21	9	3,93	4,80	5,17	4,30	125,62	147,33
October	22	9	3,35	4,05	2,69	1,99	110,02	76,97
November	22	8	2,61	3,02	0,52	0,11	81,51	12,36
December	21	10	2,42	2,80	0,48	0,11	78,71	11,21
Total	258	105	45,09	53,90	45,64	36,83	1439,14	1301,94

The consumption is divided into working days, weekend days and of course in months. We can determine the exact production and consumption in the hour of the day. The excess of energy is then stored as a heat in the water. In order to calculate the economical profitability, we firstly have to determine the initial investment of the system. In order to do that, we have to choose appropriate devices. We will do that in the next chapters.

20.2 Initial investment

As was stated previously, in order to determine the initial investment, we have to determine the used devices. The type of used devices will be the same as in the previous system, that is why I will not write them here separately again. But now there will be two big differences. The first one is, there will not be any necessity to use bi-directional energy meter. The second one is, that we will be able to construct the whole system by ourselves, which will greatly reduce our initial costs.

We will use the same solar panels, which means Axitec 330 Wp, but this time we will use only 8 of them. They will be again connected in series due to the input current limitations on the side of converter. This time, the converter will be different. It will be converter from the same company but designed for a lower power. We will use converter Sunny boy 2,5. Its exact technical information can be found in appendix of this work. We will use the same watt router though. Safety will be guaranteed with a set of fuses, circuit breakers and connectors. Its more precise description can be found in the attached excel document or in appendix. Luckily, we do not have to purchase a new boiler. Because the owner of the house was planning a photovoltaic system from its beginning, a sufficient boiler has already been installed in the house. It is a boiler with a 200 liters capacity from a Czech company called DZ Dražice, which enables a heating the water by a DC current.

Table 7 - Initial investment

Investment costs			
	Amount	**price/amount without VAT**	**final price with VAT 21 %**
SMA SunnyBoy 2,5	1	$769	$930
Axitec Axipower AC 330 Wp	8	$185	$1 791
Wattrouter M SSR	1	$347	$420
DC switchboard with protection and overvoltage protection up to 10A	1	$110	$133
Cabels 2x20m 4mm2	50	$1	$61
Connector MC4 SunPulse	8	$7	$68
Schletter roof construction	4	$88	$426
Installation and work	1	$600	$726
Transport	1	$400	$484
Expert consultation of the project	1	$264	$319
Final price with the VAT			**$5 358**
Final price after a subsidy			**$2 718**

Considering all the previously mentioned devices and with the assumption of obtaining a state subsidy, the initial investment will look accordingly.

From the table we can see, that we will be able to get a subsidy, which makes almost a half of the total investment. We can also see, that our initial investment is more than twice cheaper than with the previous system.

The block scheme of the system will look as follows.

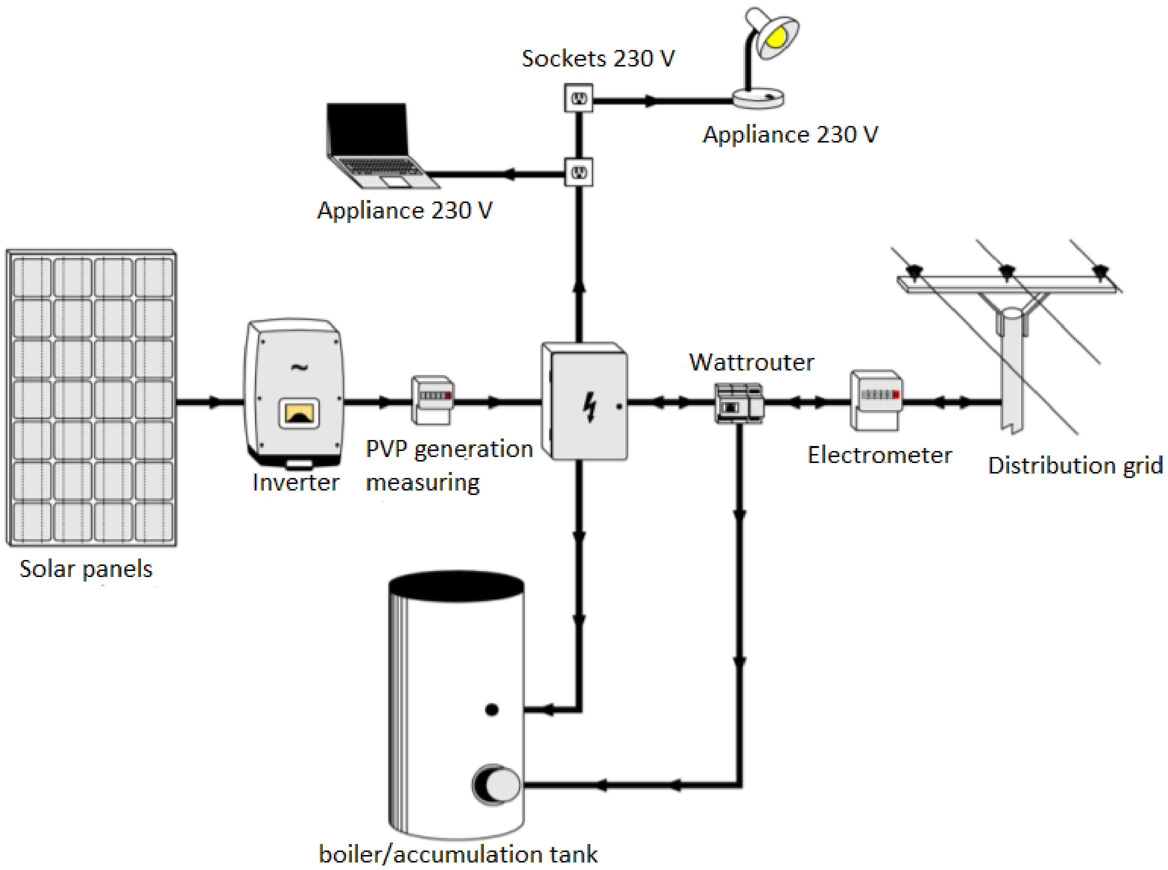


Figure 16 - block scheme of the system [32]

As was stated before, the energy generated by the solar panels will be converted to AC current, primarily used for powering household appliances and the excess of energy will be stored in the form of heat in boiler. Since the construction will be done by a professional company, one-line diagram is not necessary. For the basic understanding of the system block diagram is sufficient.

20.3 Economical evaluation of the system

With the presumption of same input data and with determining the value of initial investment, we can proceed and calculate NPV and IRR of the system. All the presumptions will be same as in the previous system in order to make the comparison as meaningful as possible. After calculating and modeling the system, we obtain following results.

Table 8 - economical evaluation of the investment

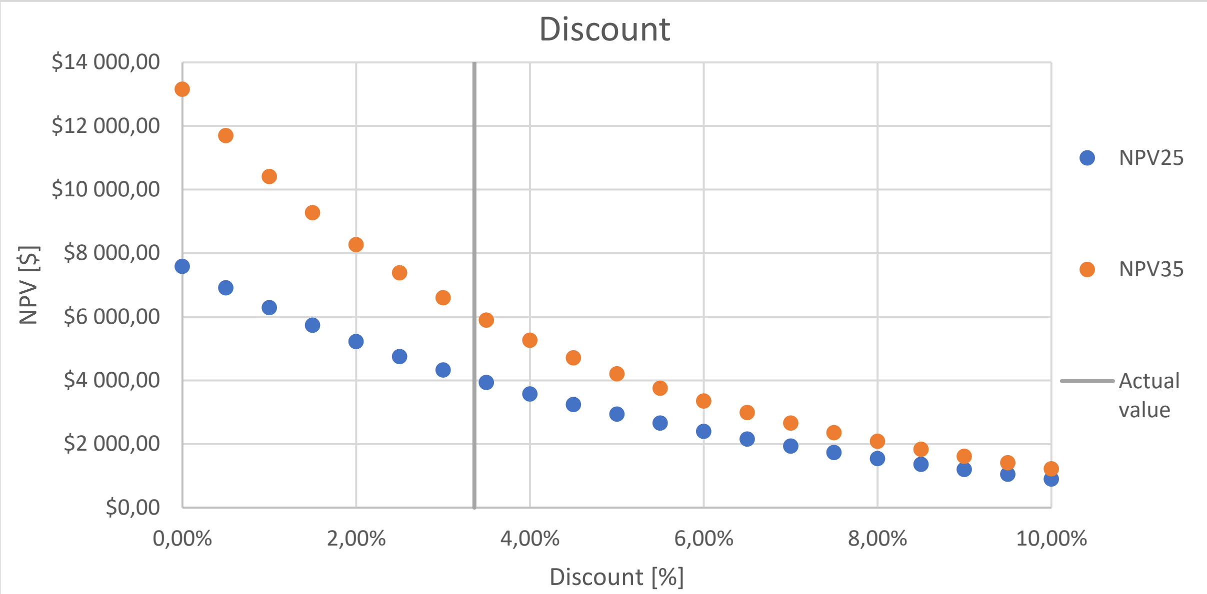
NPV25	$4 044,77
NPV35	$6 089,94
IRR25	14,30%
IRR35	14,87%
Raw rentability	8 years
Discounted rentability	9 years

From the above table we can see, that our investment is profitable whether we count the working life as 25 years or 35 years. This result is confirmed by both comparing criteria, NPV and also IRR. And from the rentability parameter we can see, that the rentability in both cases is below 10 years.

20.4 Sensitivity analysis

In this chapter, we will take a look at the most influential parameters and how they change the final results. As in the previous case, I chose discount rate, inflation rate, panels degradation, the growth of electricity price and as an addition the growth of a gas price.

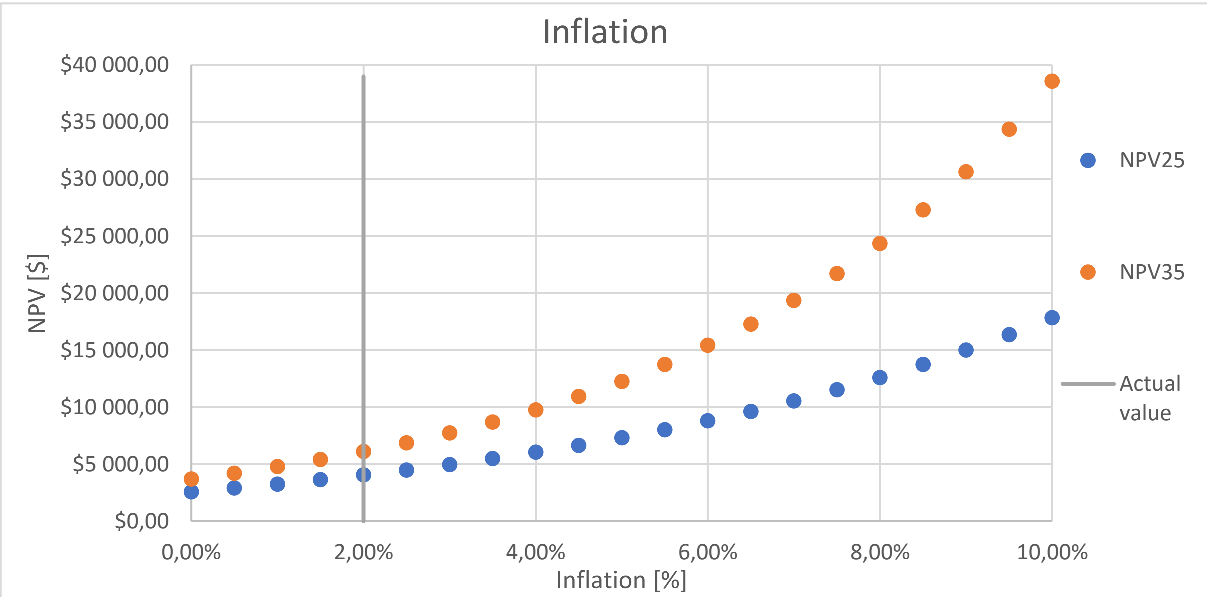
In the next graph we can see the change of discount rate.



Graph 14 - discount sensitivity analysis

From the graph we can see, that our investment will be profitable even if we will compare it with some other extremely profitable investment. So, the investment appears to be stable from this point of view.

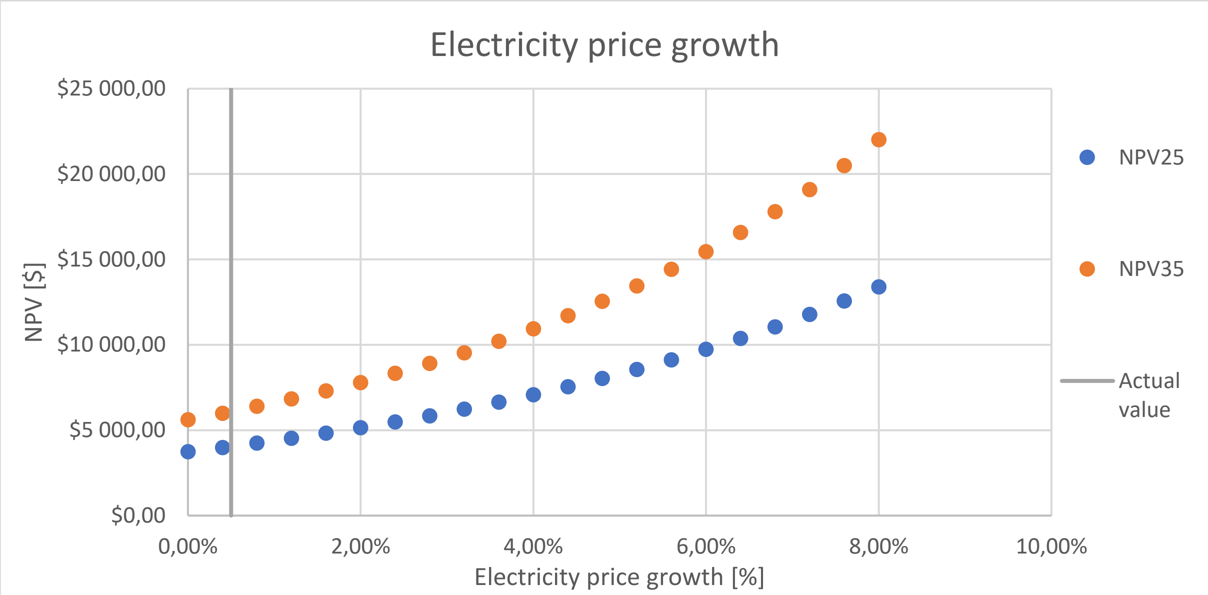
In the next graph, we can see the dependence on the inflation rate.



Graph 15 - Inflation sensitivity analysis

From the graph we can see, that with rising inflation rate, our investment is more profitable. And we do not expect lower inflation rate than 2 %. So, from this point of view, the investment should be also stable.

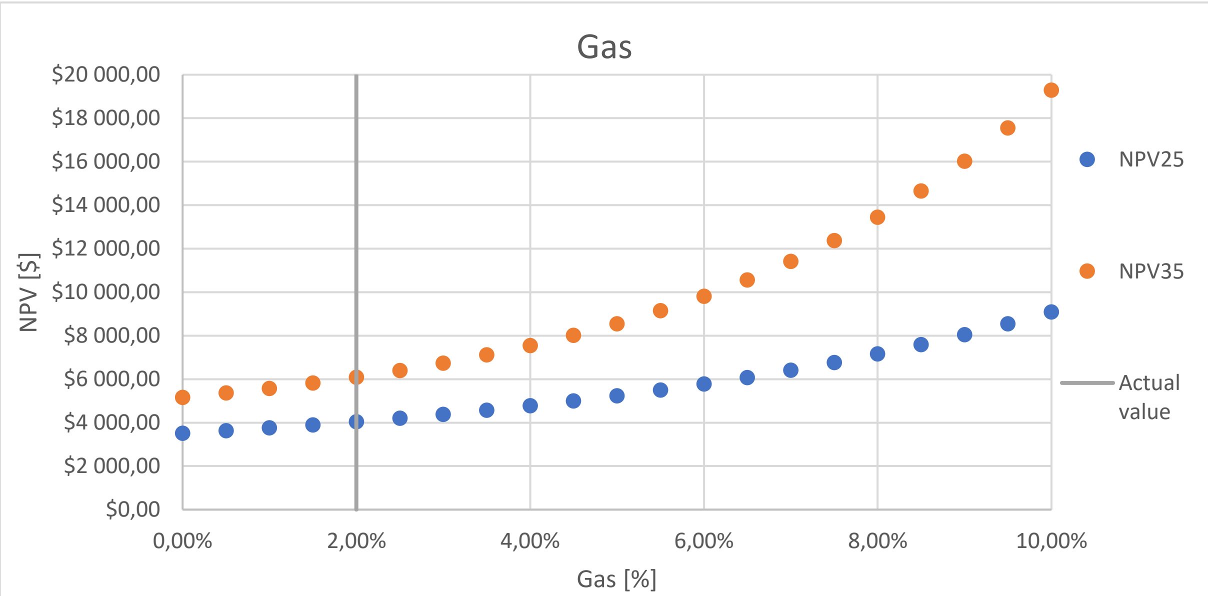
In the next graph we can see the dependence of the project on the growth of electricity price.



Graph 16 - Electricity price growth sensitivity analysis

From the graph we can see, that with increasing electricity price, our investment is more profitable. And we do not expect lower year-on-year electricity price growth rate than 0,5 %. So, from this point of view, the investment should be also stable.

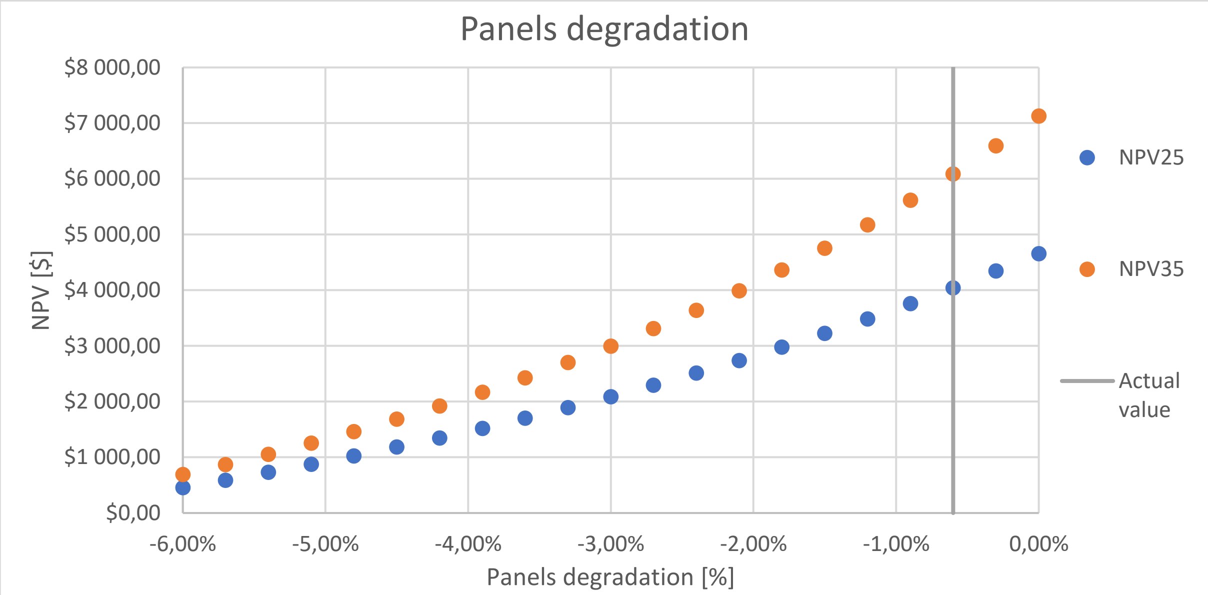
In the next graph we can see the dependence of the project on the year-on-year growth of gas price.



Graph 17 - growth of gas price

The conclusions for the gas price growth are same as for conclusion considering growth of electricity price.

In the last graph, we can see the dependence of profitability of the project on panel degradation.



Graph 18 - panels degradation sensitivity analysis

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