Interreg - IPA CBC
CCI 2014TC16I5CB006
EUROPEAN UNION

DECENTRALIZED ENERGY PRODUCTION OF ROOFTOP SOLAR SYSTEMS

A-Z INVESTMENT GUIDE FOR PUBLIC AUTHORITIES

EnerGAIN

PROMOTION OF DECENTRALIZED ENERGY PRODUCTION FROM RENEWABLE ENERGY SOURCES

This publication has been produced with the assistance of the European Union through the Interreg-IPA CBC Bulgaria-the former Yugoslav Republic of Macedonia Programme, CCI No 2014TC16I5CB006. The contents of this publication are the sole responsibility of the Foundation for Local and IT Development – Gevgelija and can in no way be taken to reflect the views of the European Union or the Managing Authority of the Programme.

Name of the document	Guide for investment in commercial-administrative buildings
The document is prepared within the project	Promotion of Decentralized Energy Production from Renewable Energy Sources, Ref. no. CB006.1.11.023 (EnerGAIN)
Financed by	INTERREG - IPA Cross-border cooperation Bulgaria – Macedonia 2014 - 2020
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DECENTRALIZED PRODUCTION OF PHOTOVOLTAIC SYSTEMS

Guide for Investment in commercial-administrative buildings

FOREWORD

In the tendencies for sustainable development, use of clear energy and lower bills for consumed electrical energy, the photovoltaic systems become more and more interesting. Due to high prices in the recent period the application of these systems was mainly reduced on supply of smaller consumers that are distant from the electrical grid. With the stimulation mechanisms in many countries, improvement of technologies and mass production in the last ten years the price of photovoltaic modules has been multiply decreased. With this, new areas of application are opened.

Decentralized production decreases the loss during transfer and distribution of electrical energy but what is also important is that smaller private investors can come up with own production capacity and decrease their bills for electrical energy. Production of electrical energy from photovoltaic systems is variable. The biggest production is realized during the day, around noon, and at night there is no production at all. In the daily hours the consumption at the commercial and administrative facilities is the biggest.

Because of this the photovoltaic systems are acceptable for covering of part of own consumption.

It is evident that there is great interest and enthusiasm in investing in photovoltaic systems. But there are also barriers for their wider use. Part are objective technical limitations, such as the limited capacity of the electro-distribution grid of the overall electro-energetic system. However, many of the barriers are of subjective nature: inertness of bureaucracy, lack of knowledge of new tendencies in technology, opportunism towards changes, etc. Because of this, the regulations changes very slow in favor of application of decentralized production units and photovoltaic systems.

Commercial and administrative buildings are ideal location for integration of photovoltaic modules on the facades and roofs. At the same time, instead of using classical or glass materials, photovoltaic modules can be applied that give a modern outlook of the building, produce electrical energy and because of the decreased prices of the investment also to save financial resources. Also, an image is created for a company that is aware of the protection of natural environment.

This guide has several goals. The main is, as simple as possible, to introduce the citizens with the technology of photovoltaic systems, giving ideas of possible potential places for installation, calculation of their cost-effectiveness. Of particular importance is the use of experiences from the Republic of Bulgaria and Republic of Macedonia for improvement of regulations as well as application of good practices from both countries.

The project is being implemented by: Foundation for local development and IT development – Gevgelija (FLORIT) and Association of eco energy producers – BG from Blagoevgrad (SPEE-BG), Republic of Bulgaria.

The preparation of the “Guide for investment in households” is made by the Center for Climate Changes – Gevgelija and the authors PhD Dimitar DImitrov and PhD Atanas Iliev. The Center for Climate Changes is a civil organization which main goal is protection and improvement of natural environment and alleviation of climate changes in Macedonia and the region.

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1. Introduction

1.1. Renewable energy sources

Our life without energy is unimaginable. It can be produced in classical electric plants (thermo-electrical, nuclear, gas turbines, etc.) but also from systems that use renewable energy sources (solar energy, wind energy, hydro energy, biomass energy, geothermal energy and others.)

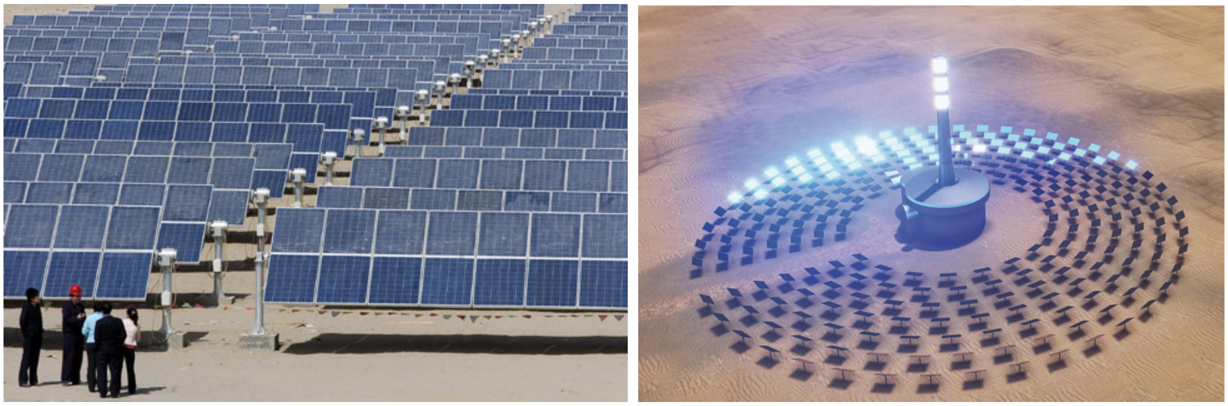
Renewable energy sources are sources that can be renewed and cannot be consumed. The use of renewable sources for production of electrical energy is in constant growth. According to the data of the IEA – International Energy Agency, in 2012, 13 % of the overall spent energy in the world is produced by renewable energy sources (including the big hydroelectric power plants). The expectations are that this percentage will rise up to 26 % by 2020. Some expectations point that by 2040 the share of the renewable energy sources compared to 2012 will be tripled.

These facts are known to everybody but it is of essential importance if we know how much energy can produce these sources, whether the received energy can be used at once and whether their use is cost-effective.

Pic. 1.1: Renewable energy sources

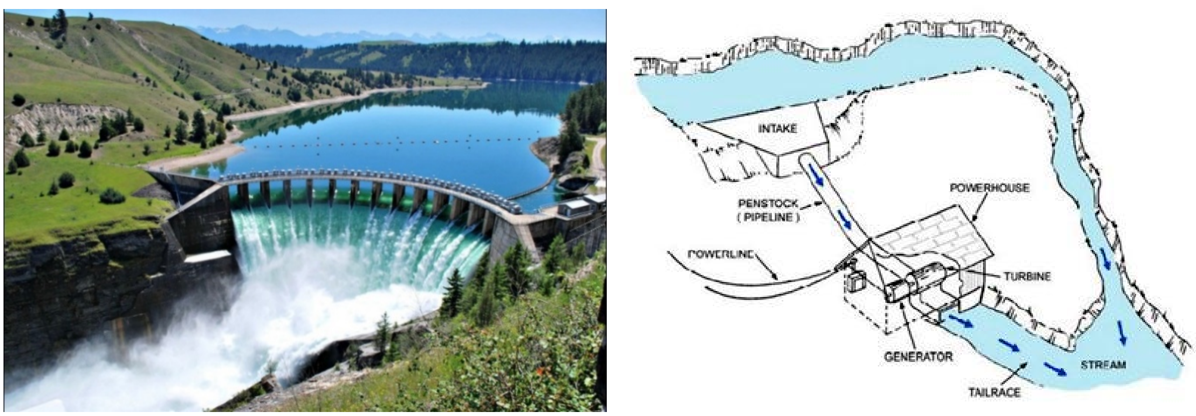
Beside the role in the protection of the natural environment, a great contribution in the use of renewable energy sources is the application of domestic resources and decrease of the import need, which at the same time means increase in the number of employments. On the other hand, the use of renewable energy sources is accompanied by high investments and usually the production price of the received energy is higher than the other sources. As a result of this, there are big investments in the improvement of technologies and efficiency, increase of the scope of their use in order to decrease the investments and achieve competitiveness with other (classical) sources of electrical energy.

The Solar Energy is result of the thermic reactions that happen in the Sun. On one hand, it is clear that this source will exhaust one day its fuel but on the other this will happen after several billions of years, which, from today's aspect is a very long period, so the solar energy is considered inexhaustible. It is most frequently used for acquisition of heat (hot water, steam) and electrical energy. The conversion of solar energy into electrical is exerted with photovoltaic systems, as well as with solar thermal plants with concentrators.



Pic. 1.2: Solar energy systems

Hydro electrical power plants use the energy of water movement. Generally hydro electrical plants are seeping and are placed by water flows (rivers, waterfalls, etc.) or accumulations beside ponds. Beside with the hydro electrical plants it is also possible to apply the water energy from oceans and seas through use of wave energy and water movement in the process of flux and reflux.

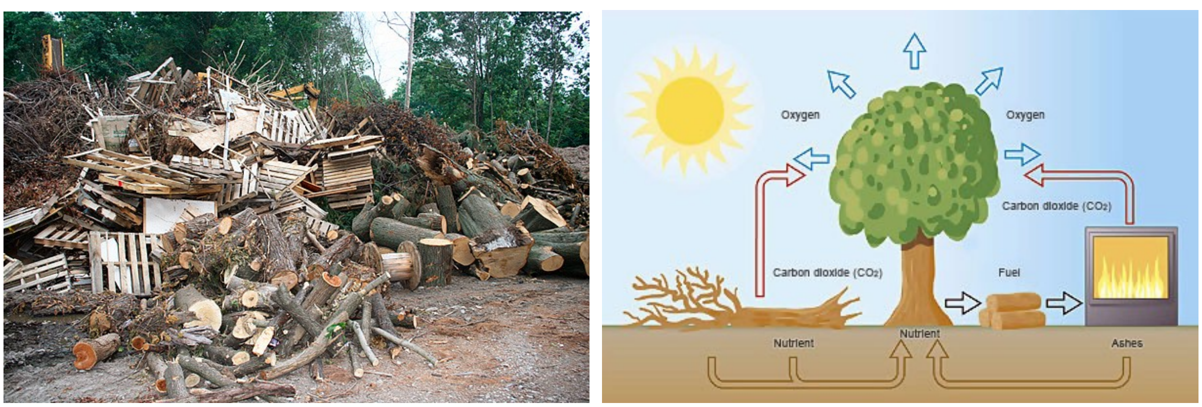


Pic. 1.3: Hydroelectric power plants

The energy of the movement of air masses – ***wind*** can be used for acquisition of electrical energy by use of wind generators. They can be set up on the land or out of land, on some water area (ocean or sea).

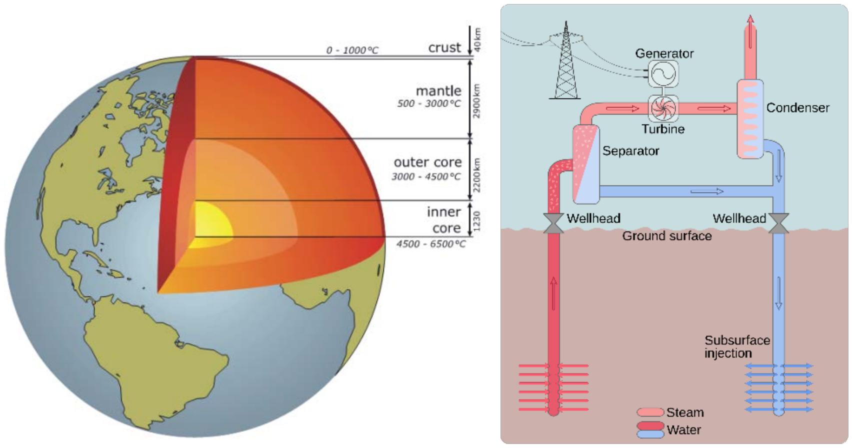
Pic. 1.4: Wind power plants

Biomass is an energy source contained in the biologically decomposing organic matters of plant and animal origin (forestry and agriculture residues, wooden and non-wooden plants purposely planted, farm waste, communal and industrial waste). There are several ways of biomass procession where we get solid, liquid or gas fuels. Then they burn in internal combustion engines, which move generators for production of electrical energy. Although in the process of biomass use there is combustion of fuel accompanied by gas emission that have negative impact on the environment, biomass (at plants for instance) previously absorbed more carbon dioxide. As a result it is considered that the overall impact on the environment is positive. Biomass is considered as a renewable energy source only if there is a balance between the consumption and planting.



Pic. 1.5: Utilization of biomass

Geothermal energy is heat energy from the interior of the Earth. This heat, in a type of steam or hot water at certain places spurts up on the very surface of the ground (geothermal springs, volcanic windows, gazers). With the use of steam-turbine plants this heat is transformed into electrical energy.

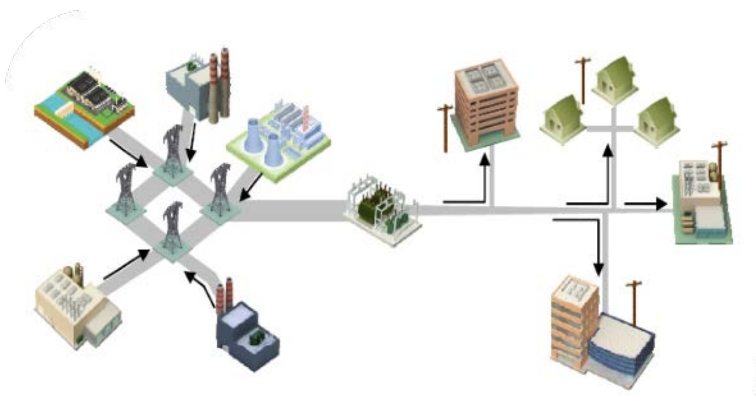


Pic. 1.6: Geothermal energy and plants for its exploitation

Beside the geothermal energy, accumulated energy in uranium and partially the energy received from the tide, all other types of energy in nature emerge from the solar energy.

1.2. Decentralized production of electrical energy

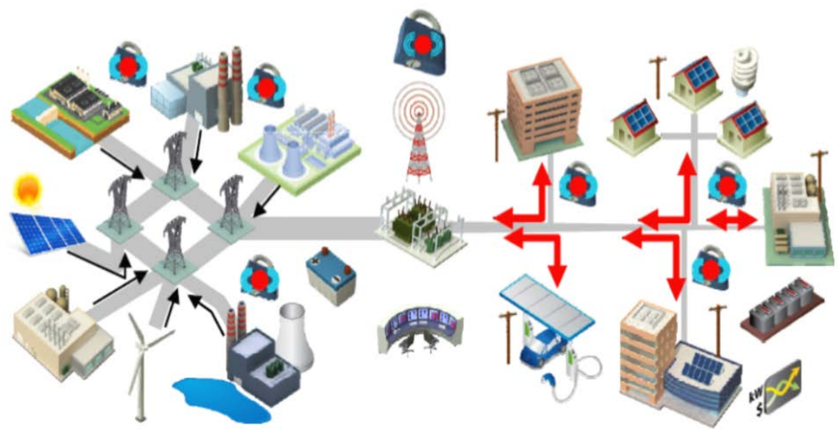
In the current electro energetic systems electrical energy is mainly generated in big electrical power stations, such as thermo electrical, nuclear, hydro electrical, plants on natural gas and other. Through the transmission and distributive network, electrical energy is transferred to customers.



Pic. 1.7: Centralized production of electrical energy

High confidence is achieved with the management of electrical networks during the transmission and distribution of electrical energy, with relatively acceptable price. However, the need for increased energy efficiency, continuity in the electrical energy supply and decrease of the negative impact on the environment, as well as deregulation of the market in this sector leads to change in the mentioned concept of the electro energetic system with big electrical power stations and big consumption centers. Thus, there are more small production units in the electro energetic system placed near the consumers, i.e., there is an ongoing process of decentralization of the production of electrical energy.

Decentralized production differs in many aspects from the traditional centralized concept of the electro energetic system. In addition, big numbers of production units are connected to the system with lower power, which are right next to the electrical energy consumers. They produce heat at the same time very often, which local consumers use for heating and even cooling of premises. Systems that use renewable energy sources are compatible with this concept. They usually have lower power and are connected to the distributive network on middle or low voltage. In this case, electrical energy is produced to the very consumers, which decrease the loss during transmission and distribution of electrical energy. This way of production is called decentralized, dispersed or distributive production. In some cases, decentralized units, beside production can encompass also plants for energy accumulation and to adjust their power according to the current demand of the system. In this way the ultimate beneficiaries, beside the role of producers actively participate in the balancing of the network.



Pic. 1.8: Decentralized production of electricity

The application of the decentralized production has many advantages. The most obvious result is set up of decentralized production units in the vicinity of consumers. At the same time, the amount of energy that is transferred through the network is decreased which results in double profit. One is that it can significantly lower the loss during transfer of electrical energy. Also, in case of bigger number of consumers, due to the weak exhaustion, can help in avoiding the need for additional investments in the so called "bottlenecks" of the network. In the following chart are given the plants that are applied as decentralized plants.

		FOSSIL OR RENEWABLE							RENEWABLE					
		Steam- turbine plants with low power	Gas turbines	Micro turbines	Internal combustion engines	Stirling machines	Fuel cells - high temperature	Fuel cells - low temperature	PV systems	Small hydro power plants	Wind turbines on land	Wind turbines on the sea	Geothermal	Solar thermal
BASICS	Tipe fuel/ Source of energy	gas, coal, charcoal, biomass	gas	gas	diesel, oil, biofuel, gas	gas, solar energy	gas, водород	gas, hydrogen	Solar energy	Energy on water	Wind energy	Wind energy	Heat from the earth	Solar energy
	Power [MWe]	0.5 - 10+	0.5 - 10+	0.03 - 0.5	0.05 - 10+	<0.01 - 1+	1 - 10+	<0.1 - 3+	<0.001 - 5	0.05 - 1	0.5 - 6+	5 - 10+	0.5 - 3+	<0.001 - 2
	Status of tehnology	Commercial available	Comm. Available	Developing / comm. available	Commercial available	developing/ demo/ comm.	Developing / comm. available	Developing / comm. available	Developing / comm. available	Commercial available	Commercial available	Developing / comm. available	developing/ demo/ comm.	developing/ demo/ comm.
	Costs	€	€	€€	€	€€/€€€	€€€	€€€	€€€	€€€	€€€	€€€	€€	€€€
	Impact of the environment	☼/☼☼	☼/☼☼	☼☼	☼/☼☼☼	☼☼	☼☼/☼☼☼	☼☼/☼☼☼	☼☼☼	☼☼☼	☼☼☼	☼☼☼	☼☼☼	☼☼☼
	Public acceptability	•	••	••	•	••/•••	•••	•••	•••	•••	•••	•••	••	•••
	Degree of development	High	High	Small, on the rise	High	Small	Small	Small, on the rise	Small, in a rapid rise	Medium	Medium	Small, in a rapid rise	Small	Small
APPLICATION	In industry	***	***	*	***	*	***	**	*	**	**	-	-	-
	In commercial buildings	*	**	**	***	***	*	***	**	*	*	-	-	-
	In households	-	-	***	**	**/***	-	***	***	-	-	-	-	-
	Possibility of cogeneration	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes
COSTS	Investment [€/kW]	550-1250	500-1100	1000-2000	350-1000	1500-8000	3500-10000	2000-8000	4000-8000	1400-5000	800-2000	1200-3000	800-4000	1500-2000
	Installing [€/kW]	100-200	65-150	50-200	60-120	40-200	500-850	500-850	40-150	100-200	100-200	600-800	200-400	100-200
	Production price of EE [€ct/kWh]	3-7	3-5	8-15	4-7	9-15	15-35	10-25	20-40	6-14	6-10	8-15	NA	NA
	Lifetime	20	20	20	20	15	10	10	20	60	20	20	20	20

Table 1.1 – Characteristics of technologies for production of electrical energy

1.3. Innovative examples of use of decentralized production in other countries

1.3.1. Plant for decentralized production of electrical energy and heat in METRO market Dusseldorf, Germany

One of the measures for energy efficiency in METRO GROUP, minimizing the expenses and reduction of CO2 emissions, in one of the facility of METRO Market in Dusseldorf, Germany is installed plant for decentralized combined production of electrical energy and heat.

The plan in the future is to adjust the production with the distributed hybrid energy system set up on the facility, for which at moment receives preferential price.

DATA ABOUT THE PROJECT

- Investor: Metro Cash & Carry Deutschland GmbH
- Partner: E.ON Connecting Energies GmbH
- Location: Düsseldorf
- Type of plant: 2G Agenitor 306
- Power: 250 kWe, 265 kWth
- Start of operation: 7/2013
- Fuel: natural gas
- Production of EE: about 1 GWh/year
- Production of heat: околу 1,16 GWh/year
- Reduction of CO2 emissions: 280 t/year
- Investment: 475,000 EUR

1.3.2. Trigeneration plant in a storehouse in Essen, Germany

The company Logistic Services Essen for coolers supply spends great amounts of energy. The cooling is executed through lithium-bromide absorption chiller, which supplies with waste heat from two engines on internal combustion that produce electrical energy through generators.

DATA ABOUT THE PROJECT

- Investor: Logistic Services Essen GmbH & Co. KG
- Location: Essen
- Volume of the freezer: 196 500 m³
- Power: 1000 kWe, 1081 kWth
- Power of the chiller: 3600 kW
- Put into function: 6/2012
- Fuel: natural gas
- Production of EE: about 7,5 GWh/year
- Consumption for cooling: about 27,1 GWh/year
- Reduction of CO_2 emission: 848 t/year
- Investment: 2 300 000 EUR
- Period of investment return: 5,5 year

1.3.3. Plant in adapted mill in Wegberg, Germany

The plant is purposed for cogenerated production of heat and electrical energy in a restored facility – mill, adapted and conversed into a hotel with restaurant

DATA ABOUT THE PROJECT

■ Investor: GC Wärmedienste GmbH
■ Fuel supplier: PRIMAGAS Energie GmbH & Co. KG
■ Fuel: liquid gas
■ Location: Wegberg
■ Power of the cogenerated plant: 5.5 kWe, 12.5 kWth
■ Power of the condensing boiler: 60 kWth
■ Start of operation: 2013
■ Consumption of EE: около 100 000 kWh/year
■ Reduction of CO2 emissions: 30 t/year
■ Investment: approx. 50,000 euros

1.3.4. Cogeneration plant for supply in the restaurant Lippeschlösschen

More than 10 years the restaurant Lippeschlösschen provides its own needs with the help of three high-efficient cogeneration plants. Two thirds of the produced electrical energy is used for own needs and the remaining part is transferred to the electro distribution grid. The surplus of heat is accumulate in two water tanks of 500 liters. In 2014 a station for recharging of electrical bicycles was installed.

DATA ABOUT THE PROJECT

■ Investor: Restaurant Lippeschlösschen
■ Location: Wesel
■ Type of plant: 3x SenerTec Dachs HR 5.3l
■ Power of every cogeneration plant:
5,3 kWe, 10,5 kWth
■ Put in function: 2/2000, 10/2003, 1/2013
■ Fuel: oil
■ Production of EE: about 78 000 kWh/year
■ Production of heat: about 122 145 kWh/year
■ Total number of working hours: about 13 400 kWh/year
■ Oil consumption: about 24 000 lit/year
■ Capacity of the hot water tank: 2 x 500 lit

1.3.5. Micro gas turbine for production of electrical energy and heat in the technical college in Aachen

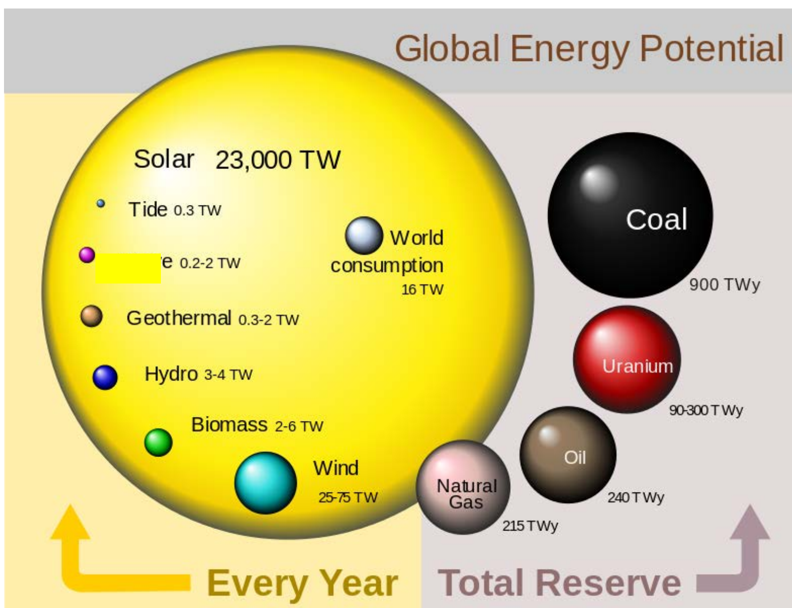
In the technical college in Aachen a plant was installed with micro gas turbine for supply of part of the needs for heat and electrical energy. As propellant is used liquid gas distributed with the help of a tank. The liquid gas is kept under pressure of 3-5 bars so there is no need for additional compression before it enters the combustion chamber, which increases the electrical efficiency for 2 %. It is estimated that the return time of the investment is 3,5 years.

DATA ABOUT THE PROJECT

- Investor: Propan Rheingas GmbH & Co. KG
- participants: Aachen technical college, department of energy technology, Institut Nowum-Energy
- Location: Brühl
- Power of the gas turbine: 30 kWe, 68 kWth
- Put in function: 5/2009
- Fuel: liquid gas
- Production of EE: 109 069 kWh/year
- Production of heat: 247 223 kWh/year
- Investment: 128 000 EUR

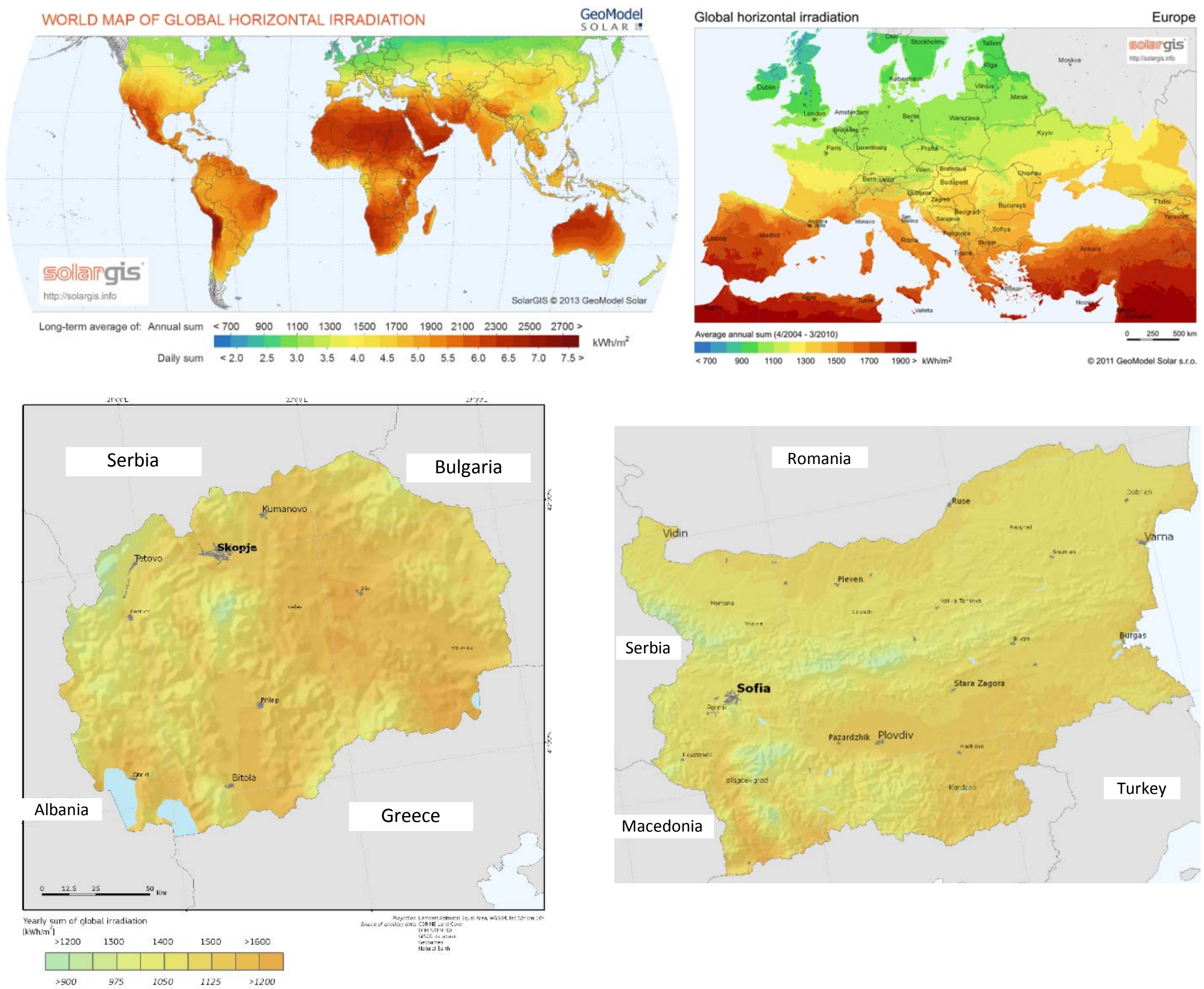
1.4. Energy from the solar radiation

The energy from the solar radiation is the biggest energy source on Earth. The energy that annually comes to the surface 10000 times bigger of the annual energy needs in the world. Beside geothermal and nuclear, all other types of energy come from the solar energy. In the picture are given energy sources on Earth and their amounts.



Pic 1.8: Amount of different types of energy in the world

The potential of the solar radiation on the Earth ground is biggest around the areas of Equator and lowest at the north and south pole. Beside this, solar radiation also depends on the altitude, micro location conditions, etc. In the Republic of Macedonia and Republic of Bulgaria, depending on the latitude and longitude, the energy of the global solar radiation which on annual basis falls on the horizontal area is about 1300 to 1550 kWh/m^2. This is about 30 % more from the solar radiation in the Central-European countries, Germany for instance.



Pic. 1.9: Energy of the solar radiation in the world, Europa, R. Macedonia and R. Bulgaria

2. Photovoltaic systems and components

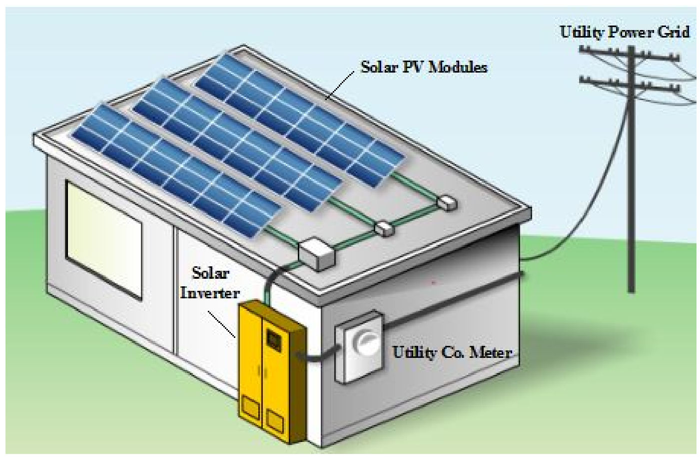
Photovoltaic (PV) systems are plants that make direct conversion of the solar radiation into electrical energy and adjust it for further application. In the following chart are given the advantages and disadvantages of the PV systems.

ADVANTAGES	DISADVANTAGES
• Ecologically accepted source of electrical energy • Decreased loss for transfer and distribution of electrical energy • Available technology • Low maintenance expenses	• Variability (day-night, winter-summer) • Incertitude (changing weather conditions) • Inability to sell the produced EE on a liberalized market according to satisfying prices • Administrative barriers

• Long exploitation period • Modularity • Lower price	

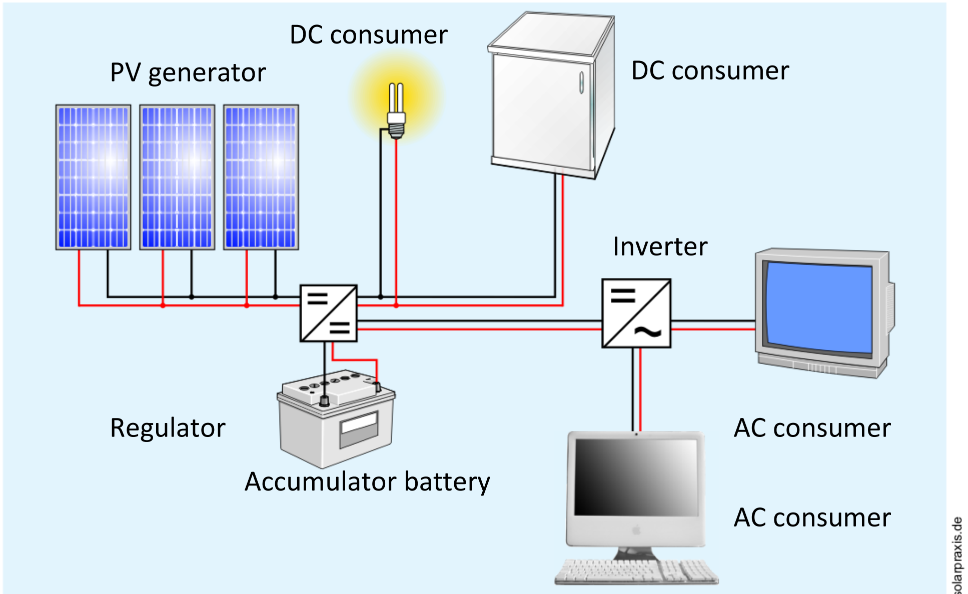
They are divided according to the type of ultimate beneficiaries, where we have: systems connected on networks and autonomous systems. The biggest number of installed PV systems are connected to the electro distributive network, as is case here and abroad.

In case where PV systems are connected to the network, we have big photovoltaic plants (power of several tens of Kws to several hundreds of MW) that installed in a field and smaller PV systems (up to 10 kW), which are frequently integrated in facilities.



Pic 2.1: Photovoltaic system connected on the grid

The autonomous PV systems are purposed for electrical energy supply for consumers who are far from the network. Usually they are with lower power (up to several tens of kW) and in order to provide continuous supply of electrical energy the systems uses accumulator batteries. In the following picture is presented an autonomous system which supplies DC consumers and AC consumers. The main drawback of these systems is the need of accumulator battery, which is expensive and short-lasting.



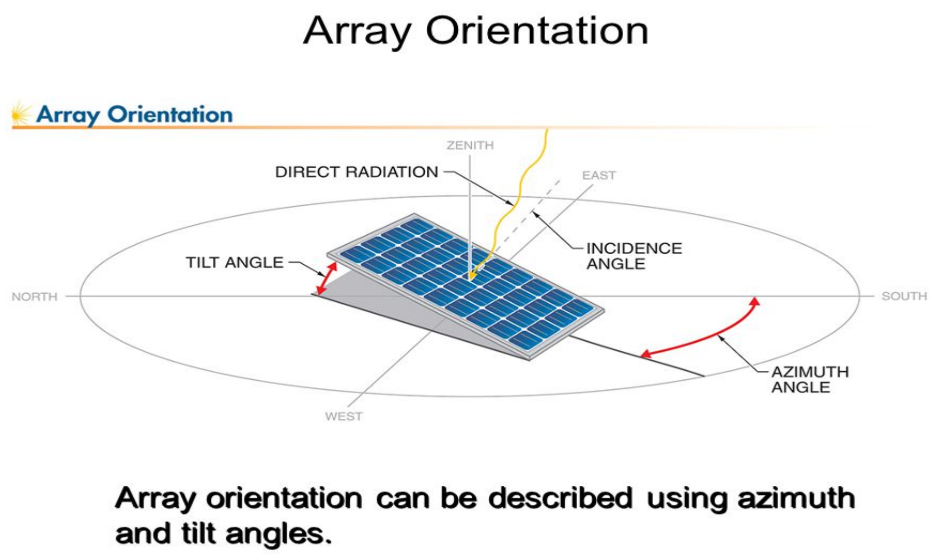
Pic.2.2: Autonomous photovoltaic system

2.1.1. Location and orientation of the photovoltaic panels

The production of electrical energy by the PV systems depends on the potential of the solar radiation on the location where they are set up. In order to increase the dropping solar radiation, PV modules are set up at a certain plane tilts, which for the locations of Macedonia and Bulgaria is best to be around 30° and 35°, with south Pane Azimuth.

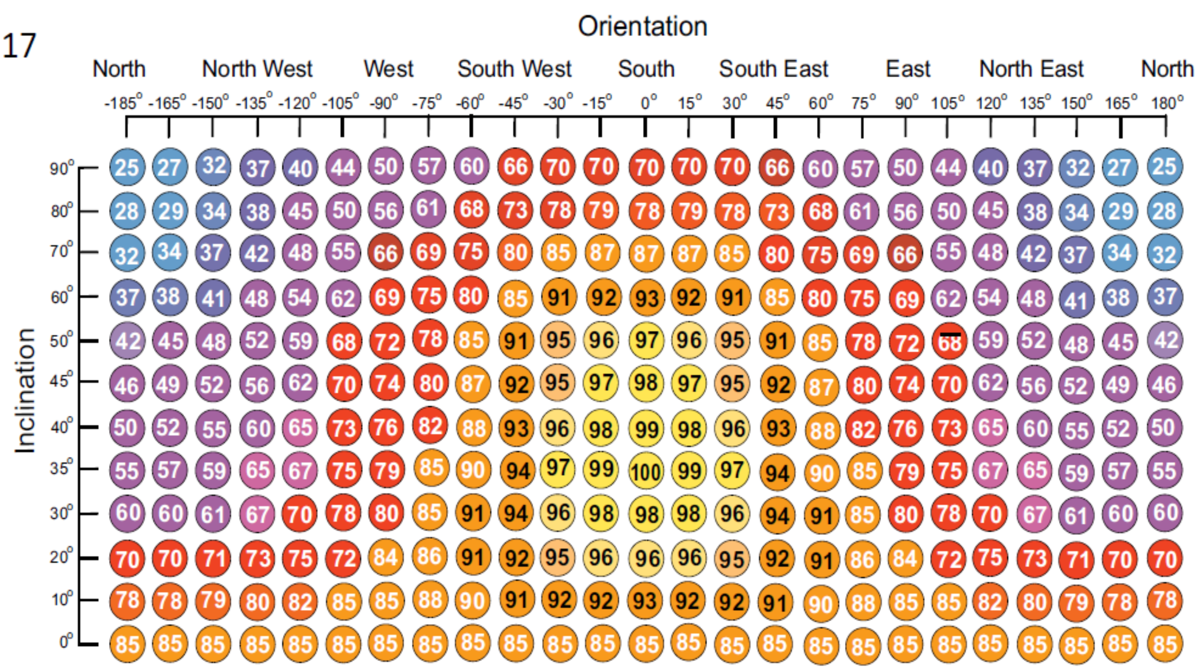
Large number of PV systems are placed on facilities where plane tilts and Pane Azimuth are dictated by the very facilities. This partially decreases the solar energy that falls on the modules. In the pictures we can see the results of the analyses of solar radiation for different Pane Azimuth and plane tilts. Azimuth has negative value towards east and positive towards south. For example, if the modules are to be placed on a vertical wall with orientation of 45° towards west, the falling energy during one year will be 66 % of the energy during optimal set up.

Pic 2.3: PV panels placed on roof with different pane azimuth and plane tilt



Pic. 2.4: Azimuth (orientation) and tilt angle

Fig 17

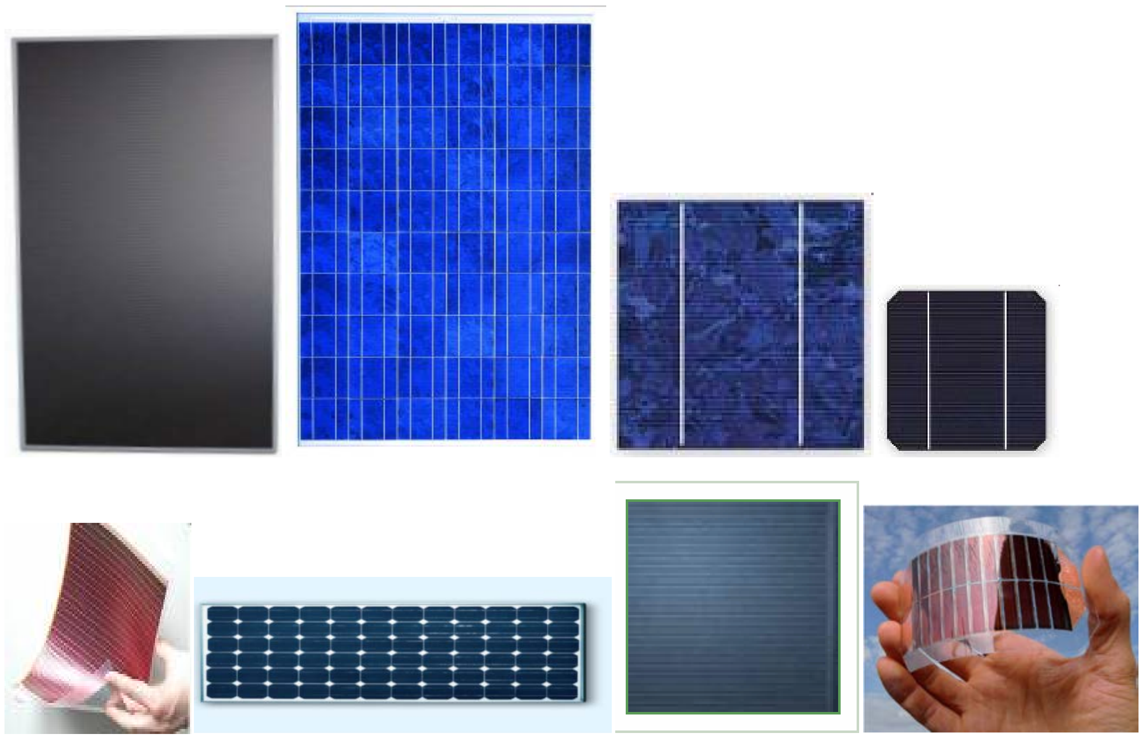


Pic. 2.5: Percentage of dropping energy in relation to energy at optimal set-up (on annual level)

2.2. Photovoltaic generator

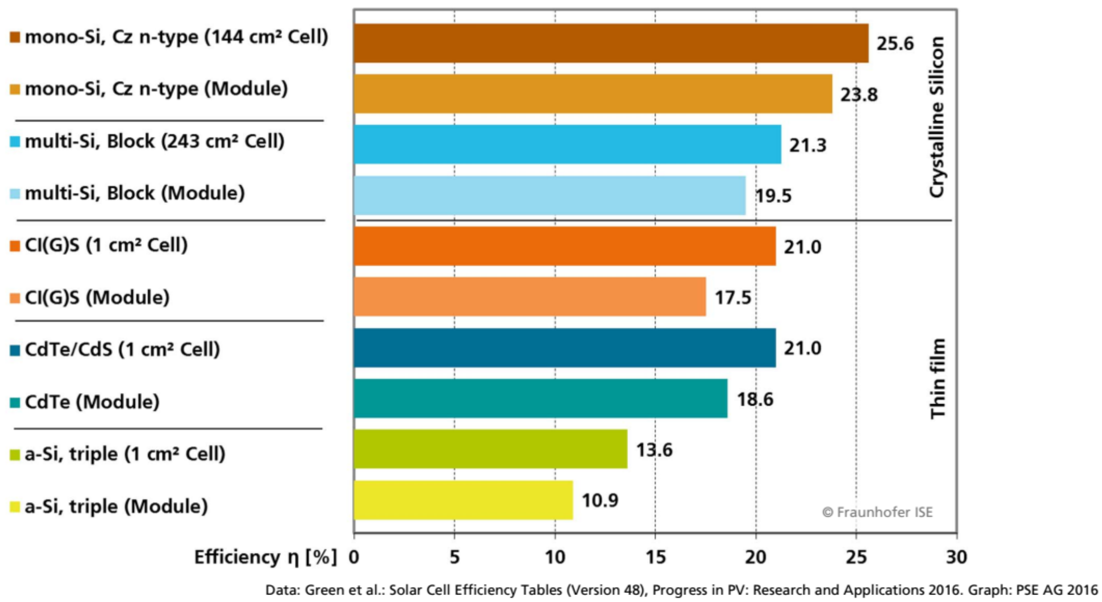
2.2.1. Types of solar cells

The solar cells are the core of the PV systems. They directly transform the solar radiation into electrical energy. The transformation is made without rotating parts, through complex quantum-dynamic processes. The cells are made of semiconducting material: monocrystaline and polycristaline silicon, amorphous silicon, gallium arsenide, cadmium telluride, copper indium diselenide, etc. Over 90 % of the PV cells on the market are monocrystalline and polycrystalline silicon.



Pic. 2.6: Outlook of PV modules with different cells technology

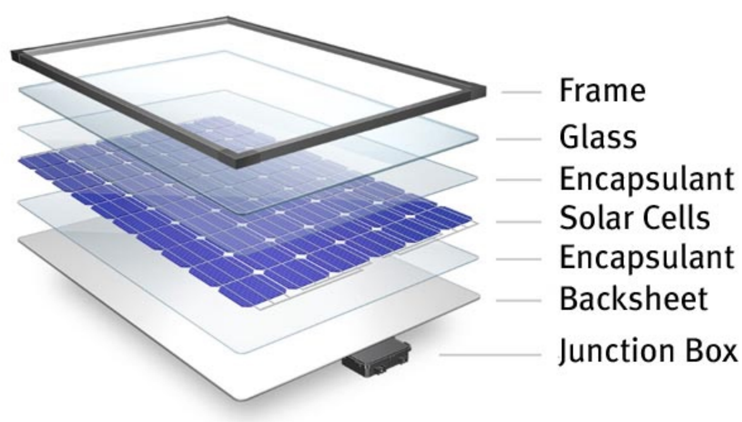
Cells of single crystal silicon have the highest efficiency, but their price is the highest. Cells of polycrystalline silicon had somewhat lower efficiency, lower cost and show better performance at higher temperatures relative to single crystals. Cells of amorphous silicon (from thin film) have the lowest price, but also lower efficiency. They have better performance during partial shading and cloudy time compared to others, their service life is lower and their performance is rapidly getting worse. The picture shows the achieved efficiency of commercially available photovoltaic cells.



Pic. 2.7: Efficiency of photovoltaic cells and modules made with different technologies and materials

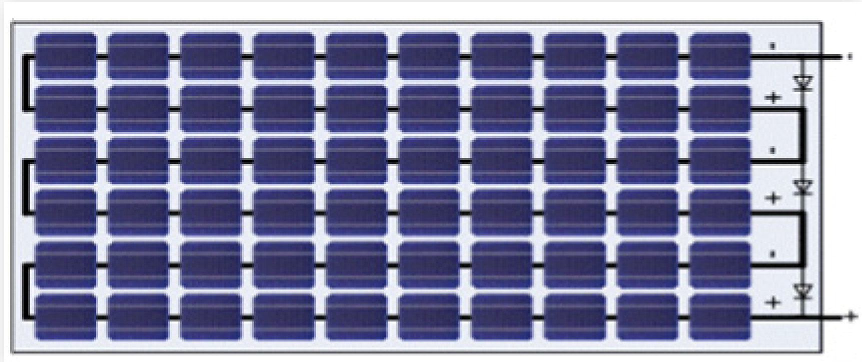
2.2.2. Characteristics of photovoltaic cells, modules and generators

The electrical power of a photovoltaic cell depends on the technology used and its area and totals 1-4 W. To get more power several cells are connected in a row. The cells are slim and are made of fragile material. As a result of this, for regular functioning they are placed on a base of special material (tedlar), protected by glass in advance and the whole construction is strengthened with aluminum profile. Thus, a photovoltaic module is formed.

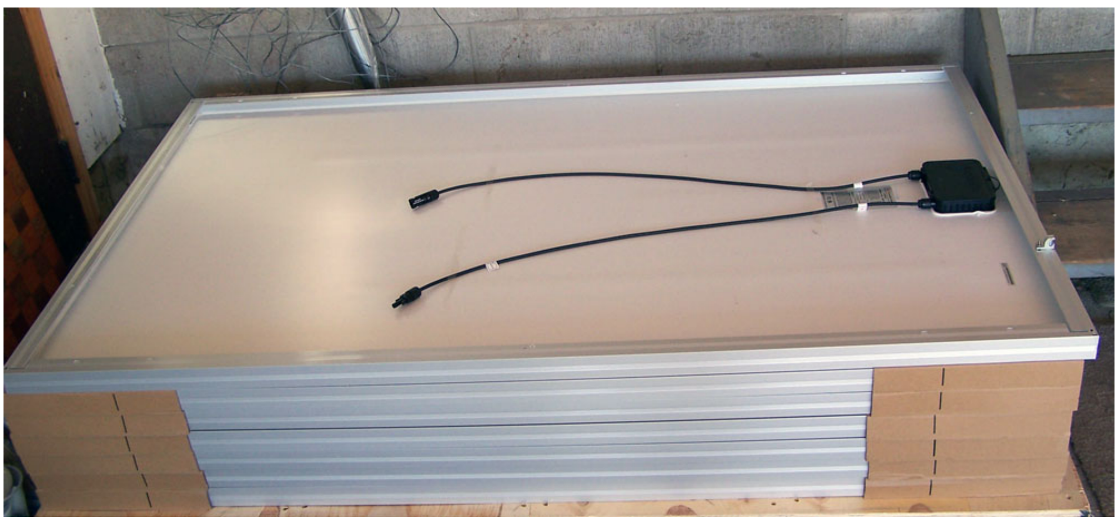


Pic. 2.8: Consisting components of photovoltaic module

All cells of the module are most frequently connected in a row. In parallel of every 15-20 cells a diode is placed which protects the module of extreme heating, which is result of shading and malfunctions in some of the cells. Electrical connection of the cells goes to distribution box placed on the back side of the modules. Two wires come out of the box at which ends there are connectors. Most frequently used connectors are of type MC-4, rarely Tuso.

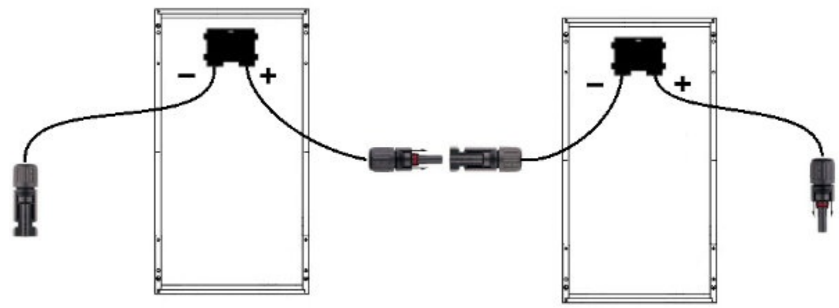


Pic. 2.9: Connection of cells in a photovoltaic module



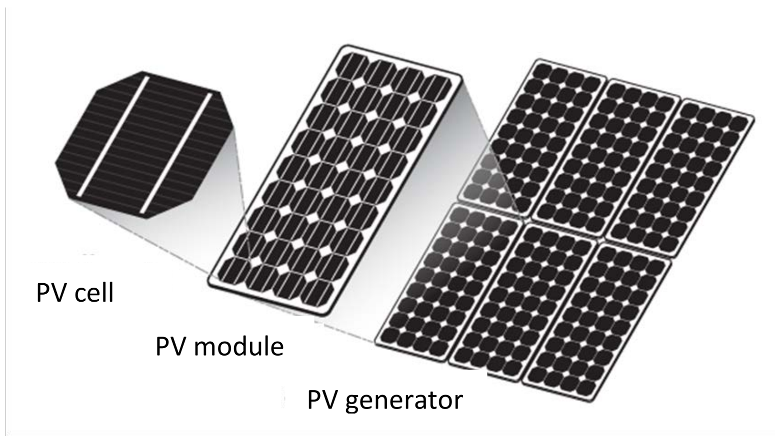
Pic. 2.10: Outlook of back side of a photovoltaic module

Bigger power can be achieved with a serial connection of the photovoltaic modules, made with suitable alignment of the connectors. In this way we have consecutive connected modules in a row – so called *string.* The number of serially connected modules in a one string is determined with special calculations and depends on the minimal and maximum value of the input voltage of the inverter and characteristics of modules.



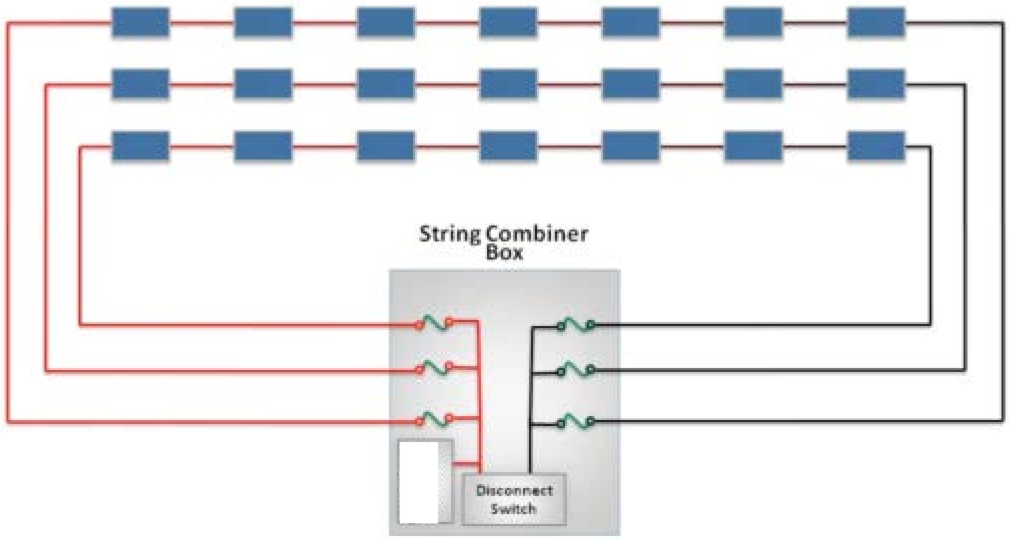
Pic. 2.11: Connection of photovoltaic modules

The strings can be connected in parallel and this is most often performed in the so called string boxes. Beside the connections, in the string boxes are placed elements for over-electrical and over-voltage protection and in certain cases a clutch for switching off of the circuit. A PV system is created in this way.

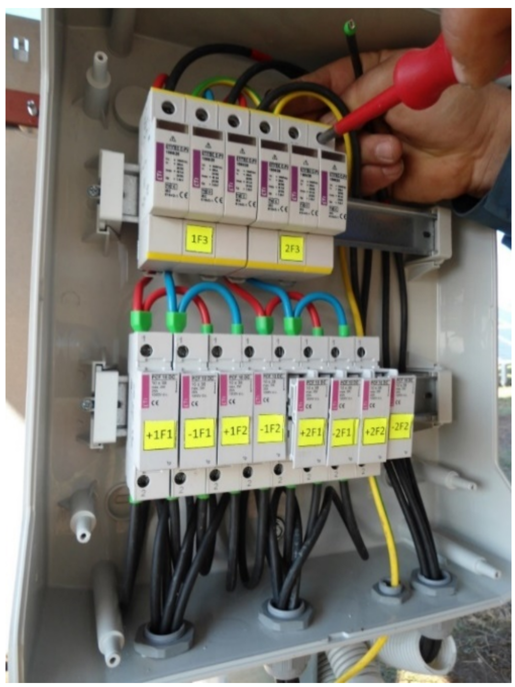


Pic. 2.12: Names of consisting components of photovoltaic generator

Pic. 2.13: Photovoltaic panels



Pic. 2.14: Connection of photovoltaic generator

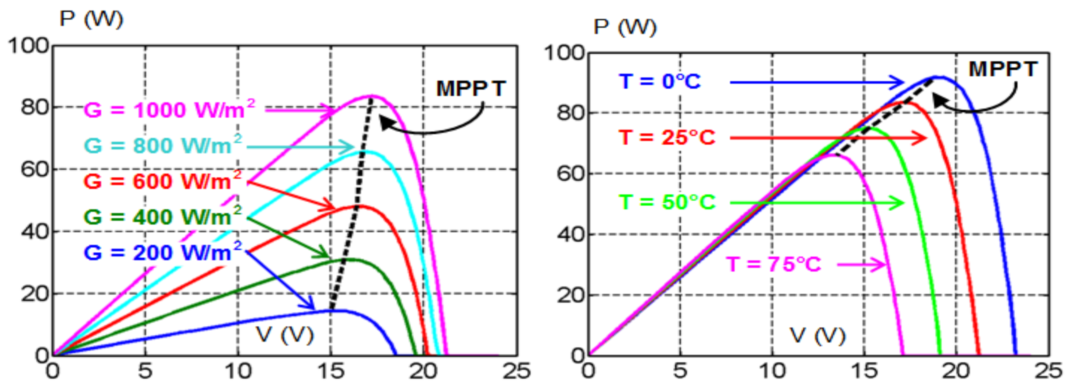


Pic. 2.15: String box

It is very important at a PV generator all modules to be from the same producer, same type and to have the same characteristics. Also, the number of modules in a string should be the same. Otherwise, the generator will not work efficiently and there is a possibility of damaging of modules.

The outlet of the PV generator depends on the intensity of the solar radiation that falls on the area of the modules and temperature of cells. If these two parameters do not change, the power of PV generator depending on the voltage and the reaction of the consumer connected to its ends, the power changes from zero to some maximum value P_{mp}, where the generator works most efficiently. For adjusting the generators to work in that point there are devices for looking the maximum power point tracking (MPP tracker), which are most frequently integrated in the inverters.

With the decrease of the solar radiation is decreased the maximum power that the PV generator can give. Opposite of this is the impact of the cells temperature. With the lower temperature rises the power and vice versa. In addition, for every °C of higher temperature of the cells, the power of the PV system falls from 0,35 – 0,5 %. On the picture is shown a model which power falls from 92 W at 0 °C to 65 W at 75 °C. Suitably, the decrease of power totals (92 – 65) x 100 / (92 x 75) = 0,391 %/°C



Pic. 2.16: Characteristics of power of photovoltaic module during application of solar radiation and change of cells temperature

Regarding the dependence of the power the PV generator from the intensity of the solar radiation and cells temperature, modules are tested at exact determined conditions, called Standard Test Conditions (STC). The characteristic parameters that are received at these conditions are seen in catalogues for modules given by the producers.

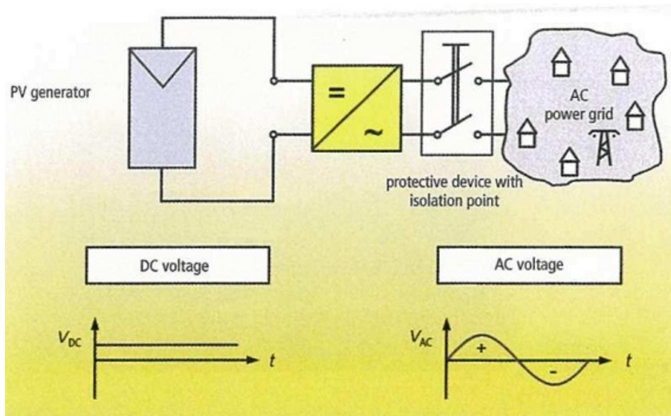
The cells temperature depends on the air temperature and intensity of solar radiation. Unlike the air temperature, the temperature of the cells can hardly be measured and therefore it should be calculated. In order to enable the calculation, modules are tested also at other conditions that can be really expected. They are called *normal working operation conditions*, where their temperature of the cells is measured (NOCT – Normal Operation Cell Temperature). Normally the NOCT is 45 – 50 °C.

Standard Test Conditions – STC	
Solar radiation	1000 W/m²
Cell temperature	25 °C
Spectrum of solar radiation	AM1.5

Normal operation cell temperature - NOCT	
Solar radiation	800 W/m²
Air temperature	20 °C
Wind speed	1 m/s

2.3. Inverters as components of PV systems

PV generators make conversion of solar radiation into electrical energy. The generated energy is with one-way parameters (voltage and electricity). (230 V, 50 Hz). The electro distribution grid and the biggest number of consumers work on alternating voltage. For conversion of one-way voltages and currents into alternating (with suitable values of the voltage) inverters are used.



Pic. 2.17: Purpose of inverter in a photovoltaic system

Modern inverters beside conversion of one-way voltages and currents into alternating integrate many other functions such as: adjustment to the working point of the PV generator to work in a regime of maximum power point tracking (MPPT), control of reactive energy, protection, monitoring, etc.

At autonomous PV systems the inverter has the role to maintain the constant frequency and effective value of the consumers' voltage. In contrast to this, at the systems connected to the grid, the inverter adapts to the frequency and voltage of the grid.

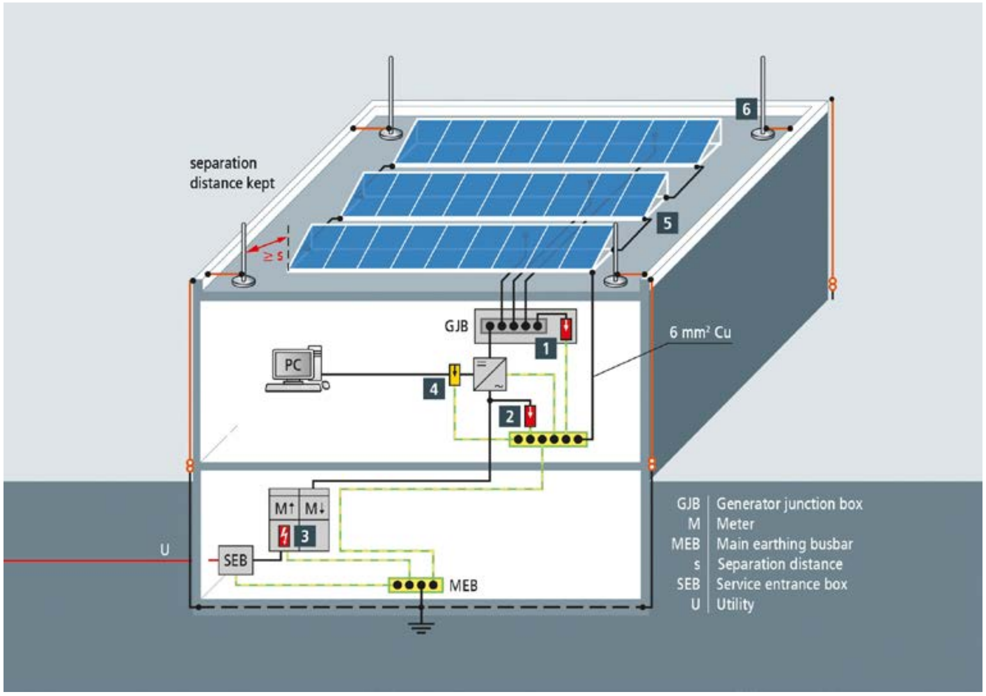
Inverters can have transformers and in that case there is a process of galvanic separation of the grid from the generator, which enabled the overvoltage of the grid to be transferred towards the generator but their efficiency is lower. Inverters without transformers have high efficiency (over 98 %).

At dimensioning of PV systems what is important is the range of the voltage of one-way side of inverter. It depends on it the number of PV modules in one string.

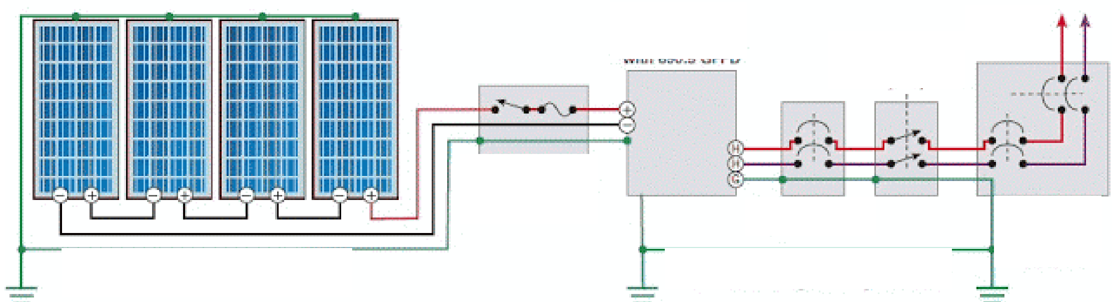
2.4. Other components of PV systems

For regular functioning of PV systems, beside PV modules and inverters, other components can be found in PV system such as wiring, components for over-current and overvoltage protection, lightning protection, grounding, monitoring devices, etc.

The wiring is consisted of electrical cables that connect the components. The section of the wiring cables is chosen so that not in a single point the loss of voltage is not bigger than several percent.



Pic. 2.18: Lightning protection in a photovoltaic system placed in a facility



Pic. 2.19: Diagram with over-current protection of a photovoltaic system (fuse)

2.5. Configurations of PV

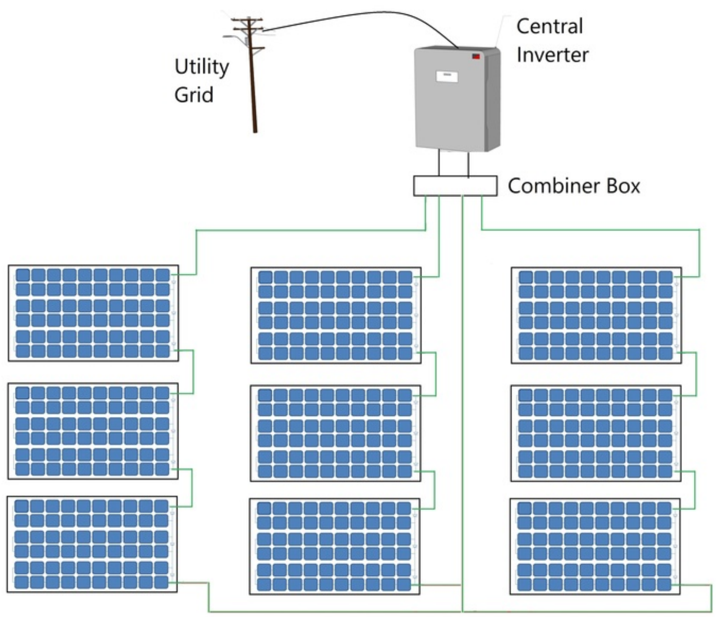
2.5.1. Connection of PV generators and inverters

In practice there are several ways of connecting (topologies, configurations) of PV generator with the inverter. There are configurations with:

- Central inverter (with power of several ten of kilowatts up to 100 megawatts)
- String inverters (with power of several hundred watts up to several ten of kilowatts)
- Multi-string inverters (with power of several hundred up to several ten of kilowatts)

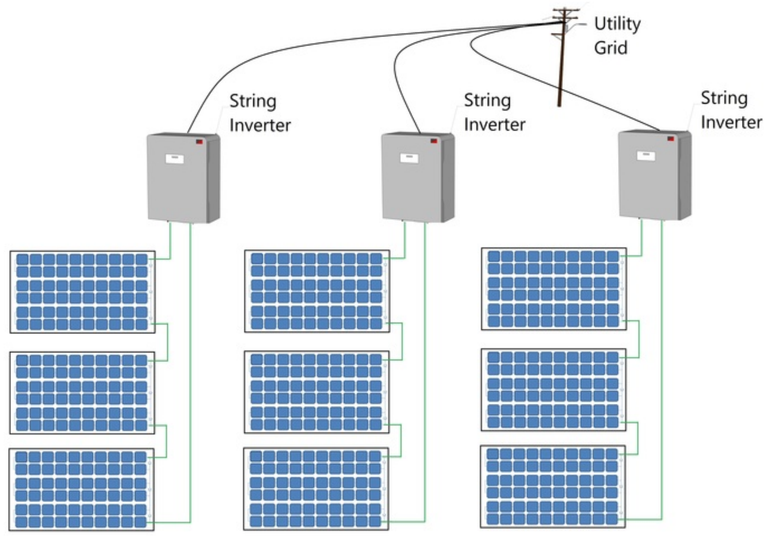
- Micro-inverters (with power of 50 W to 500 W)

In the configuration with central inverter the system is consisted of one inverter, which means that its power can be very big. This configuration is with the lowest price for the same power, it is simple for projecting and performance. What is deficient about this is that the whole plant is connected to one MPPT device and the system at partial shading has significant smaller power. They have smaller confidentiality because during malfunctions the whole plant is out of function. In smaller countries it is difficult to provide authorized servicing of the inverter in a short period.



Pic. 2.20: Configuration of photovoltaic system with central inverter

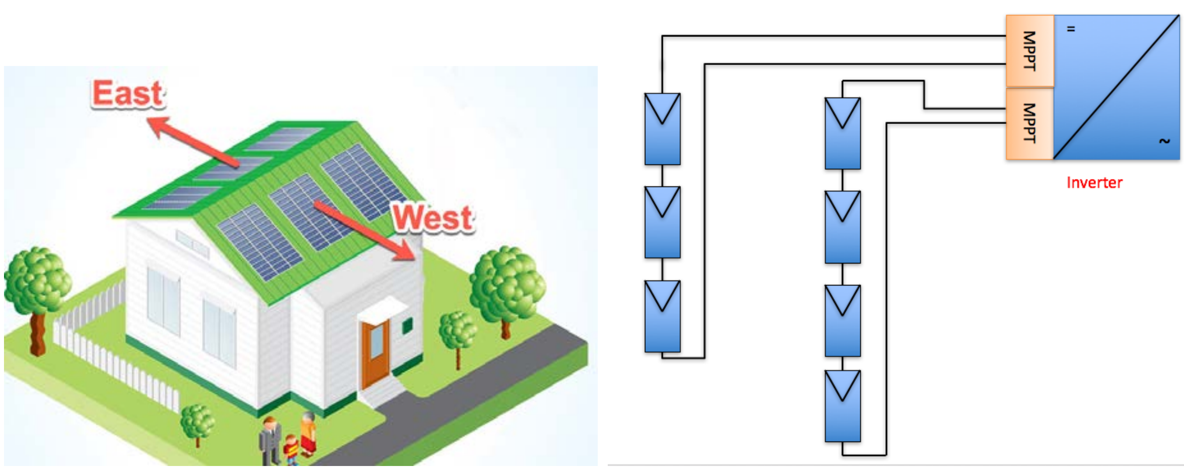
In the configuration with string inverters, every inverter is connected to one or more alongside connected strings in the one-way side of the inverters. At the systems with bigger power, more string inverters are connected in parallel. In case of more connected strings, the configuration is similar as in the case with the central inverter, but the power here is much smaller.



Pic. 2.21: Configuration of photovoltaic system with string inverters

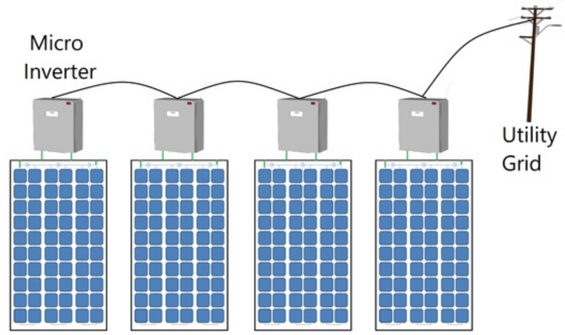
The advantages of string inverters are: smaller dimensions in regard to the central inverters, separate MPPT for smaller parts of PV generator, possibility to make a monitoring on every string, bigger confidentiality, possibility for keeping spare inverters. Disadvantage is the higher price and same power with the central inverters.

Special type of string inverters are the so called multi-string inverters. They contain (most frequently) two or three MPPT devices. In the two devices the number of strings can be differentiated, even the number of modules per string. These inverters are used in case when parts of the PV generator are under different conditions, for example, different shading, roof areas with different orientation and azimuth.



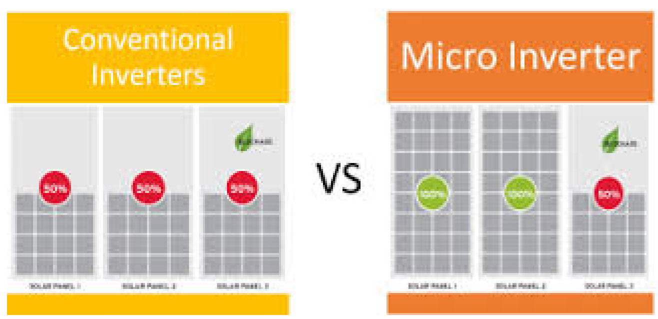
Pic. 2.22: Application of multi-string inverter at PV generator placed on a house roof on both sides

Micro inverters are very often called module inverters because for every PV module there is a separate inverter. Micro inverters are connected with other inverters on the alternating side.



Pic. 2.23: Configuration of photovoltaic system with micro inverters

The advantage of configurations with micro-inverters is better behavior at partial shading of PV generator because the existence of MPPT device for every inverter optimizes the output of every PV module separately. With a monitoring system the behavior of every PV module can be followed. Disadvantage is the highest price for same power, high maintenance expenses, difficult approach for maintenance of PV generators set on the roof.

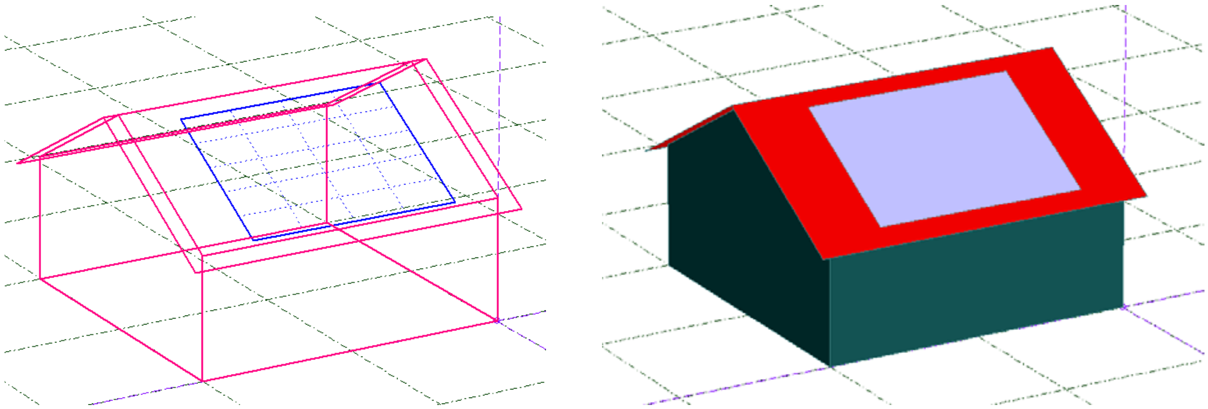


Pic. 2.24: Shading impact at conventional and micro inverter

2.5.2. Dimensioning of components of PV systems

Before starting with planning of PV system it is necessary to know the location of the of the system set up, its purpose and financial resources that can be spent for provision and installation of the equipment for PV system. Also it is essential to determine the closer and more distant facilities that can shade the PV modules, volume, shape, plane tilts and pane azimouth of the roof or other area where the modules should be placed and possibilities for their attachment.

The data about the solar radiation are necessary for determination of the energy that should be received from the PV system for a period of one year. Nowadays, for dimensioning of PV systems are used specialized software tools (PVSYST, PV*SOL, SAM, PV Designer). These tools offer possibilities for detailed creation of the scene (near and far objects, height of the horizon), exact location, plane tilt and pane azimouth of the modules, etc. They integrate large number of databases with components that are regularly updating and databases about solar radiation.



Pic. 2.25: CAD design of PV system placed on a roof house (simulation with software too PVSYST)

TABLE 2.1 – Performance of PV system connected to the grid with power of 5 kWp – energy balance

	GlobHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	EffArrR	EffSysR
	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	%	%
Jan	58,6	-1,3	102,6	91,7	438,1	421,8	13,01	12,52
Feb	76,2	0,3	115,3	104	500,6	482,4	13,22	12,74
Mar	116,9	4,8	150,2	140,3	655,5	631,9	13,29	12,81
Apr	136,5	10,4	146,8	139,3	646	622,1	13,4	12,9
May	170,8	16,1	168,7	159,5	719,5	692,8	12,99	12,51
Jun	195,9	20,4	184,4	174,6	767,6	738,7	12,67	12,19
Jul	207,1	22,9	200,6	190,5	823,5	792,9	12,5	12,03
Aug	184,1	22,7	194,4	185,4	799,3	769,8	12,52	12,06
Sep	137,4	18,1	168,3	159,3	698,5	673,5	12,63	12,18
Oct	89,9	11,9	126,5	116	528	508,6	12,71	12,24
Nov	57	5	93,7	83,6	391,7	376,7	12,73	12,24
Dec	46,5	-0,3	82,6	73,8	350	336,1	12,9	12,39
Year	1476,9	10,98	1734,2	1617,9	7318,2	7047,6	12,85	12,37

Also, the inverter producers offer software tools for simulation, which usually have limited possibilities but can be used for determination of the number of PV modules in strings as well as the number of parallel connected strings.

2.5.3. Set-up of photovoltaic modules on a roof

The way of setting up PV modules is of great significance for the investment, maintenance and performance of PV systems. In practice, at family houses, PV modules are placed on ground or curved roofs (see picture).

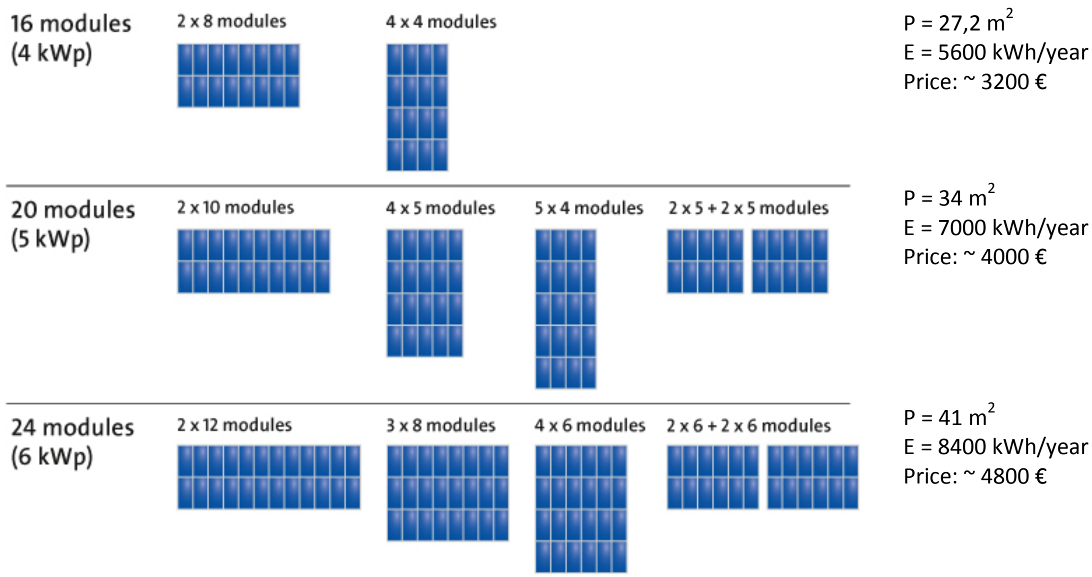
Pic. 2.26: Set up of PV modules on roof and ground

Pic. 2.27: Set up of PV modules on roof with special holders

The advantages during set up on the ground are: simpler mounting, possibilities for regular cleaning of the modules, lower temperature of the cells due to better conditions for heat transmission, multi-functionality (ex. parking shading) etc. The main obstacles are the higher price and the need to obtain a construction permit, which is a complex and expensive procedure.

For setting up PV modules on curved roofs there are special holders that are attached on the roof construction, which is an advantage due to the low price of the overall bearing construction. This is most frequently the crucial factor where the place the modules, where at family houses additional construction is rarely used for adaptation of the tilt angle and orientation of modules. During set up of modules on the roof only permission from the municipality is necessary for the mounting of the equipment, which is relatively easy to achieve. What can be a drawback is the more difficult mounting to the inaccessibility of the roof, lack of regular cleaning of the modules and weak ventilation of the back part of the modules, which leads to higher temperatures of the cells and weaker performances.

In the following diagrams are presented the possible ways of set up of modules on roof areas, together with the suitable installed power, estimated production of electrical energy and expected price.



Pic. 2.28: Number of modules, necessary area, power, annual production, price and way of set up of PV modules on a roof (dimension of one PV module 1 m x 1,7 m with power of 250 Wp)

2.6. Accumulation of energy

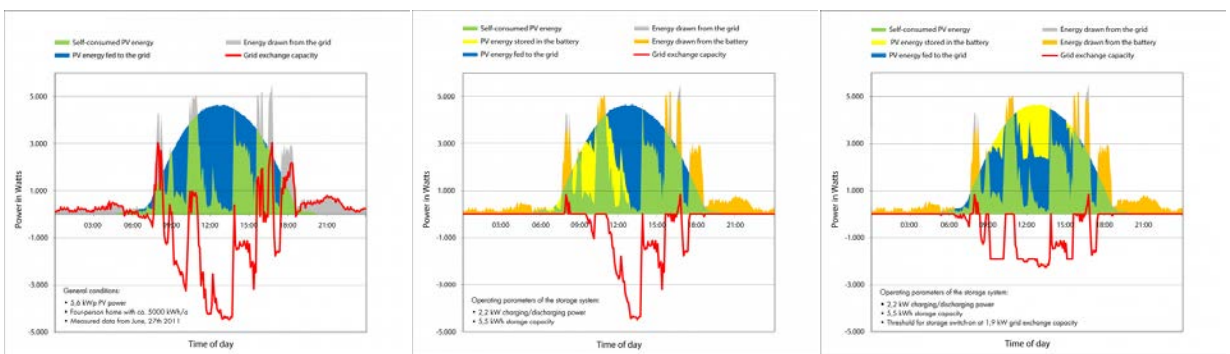
The solar radiation is present only during the day and with variable intensity per hours and additionally its intensity depends on the cloudiness. As a result of this, it is usually said about the production from the photovoltaic systems that It is of variable character. It is similar with some other systems that use renewable energy sources. In cases where the production units with variable character are connected to the electrical network, the deficit or surplus of energy of the produced energy should be balanced in the overall electro energetic system and distributive networks as well. This can be achieved with devices for temporary accumulation of the energy and management of consumption and production.

Decentralized production is the best solution for balancing. For instance, in Germany more than 70 % of the energy from the PV systems is produced with systems that are smaller and are connected to the low-voltage network, as well the biggest number of consumers. Decentralized balancing is the best way to implement this due to the vicinity of the production units, consumers and devices for accumulation of energy which decrease the loss during transmission and distribution of energy.

The batteries for accumulation of electrical energy have high specific price which is not lower for biggest capacities. From technical aspect, decentralized accumulation of energy offers more possibilities an advantages. In addition to this, with certain mechanisms for support big number of house owners and private investors can be stimulated to install batteries on electrical energy. This will increase the confidence in the network as well as the maximum capacity of PV systems that can be accepted in the distributive network.

The application of the batteries at PV systems aimed at covering own consumption decreases the energy that is transferred to the network, which is important from financial aspect, for the transferred energy we have lower price and is more cost-effective to accumulate that energy and use it later. Also, the burden on the network is alleviated, which leaves space for connection of more production units. To illustrate this, an analysis is presented for the consumption of one four member family which set up a photovoltaic system in their house with 5,6 kWp power. Three cases have been analyzed: with and without battery with accumulation capacity of 5,5 kWp without limit of transferred power and with limited transfer of power of 1,9 kW.

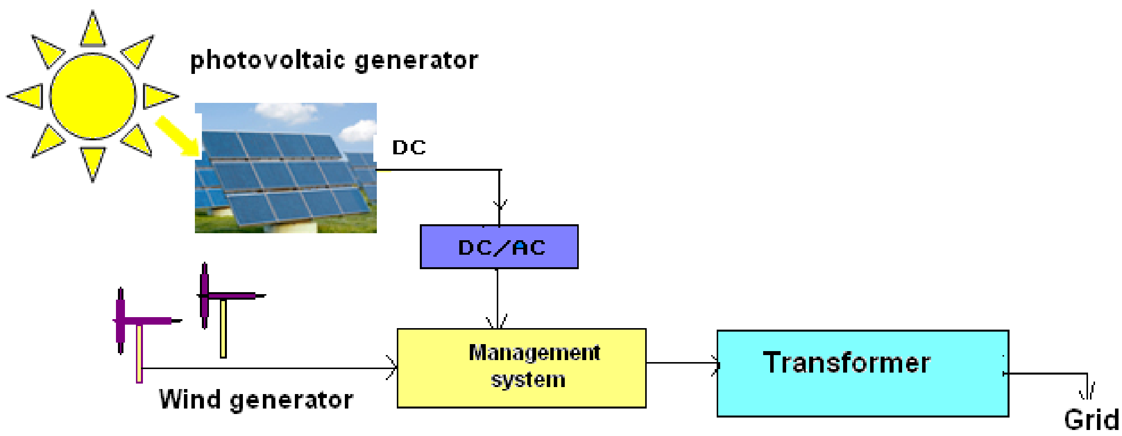
Between 9 and 10 o'clock the power of the PV system is about 3 kW, of which the consumers use 0,7 kW (own consumption). 1,9 kW of power is transferred to the network and the remaining part is accumulated in the battery. After 10 o'clock the consumption is bigger than the power of PV system. In addition, the shortage of power is received from the battery. Between 11.30 and 14.00 the transferred power is surpassed towards the network of 1,9 kW, because the power of the battery charging is limited to 2,2. After 14.00 o'clock the consumption grows so the transferred power on the network is not bigger than 1,9 kW even if there is no accumulation battery. Around 8.00 and 17.00 the consumption overpassed the production from the PV system and the power that the battery can received, so the shortage is restituted from the network.



Pic. 2.29: Diagrams of consumption of a household and production from PV system a) without battery b) with battery capacity of accumulation 5,5 kWh without limit of transferred power c) with battery capacity of accumulation 5,5 kWh with limit of transferred power of 1,9 kW

2.7. Distributed hybrid energy systems

The hybrid energy systems are systems that produce energy from two or more sources. For example, a hybrid photovoltaic system integrates in itself a wind generator or small hydro electrical plant and/or electrical plant on biogas or gas, etc.



Pic. 2.30: Configuration of hybrid photovoltaic system connected on the grid

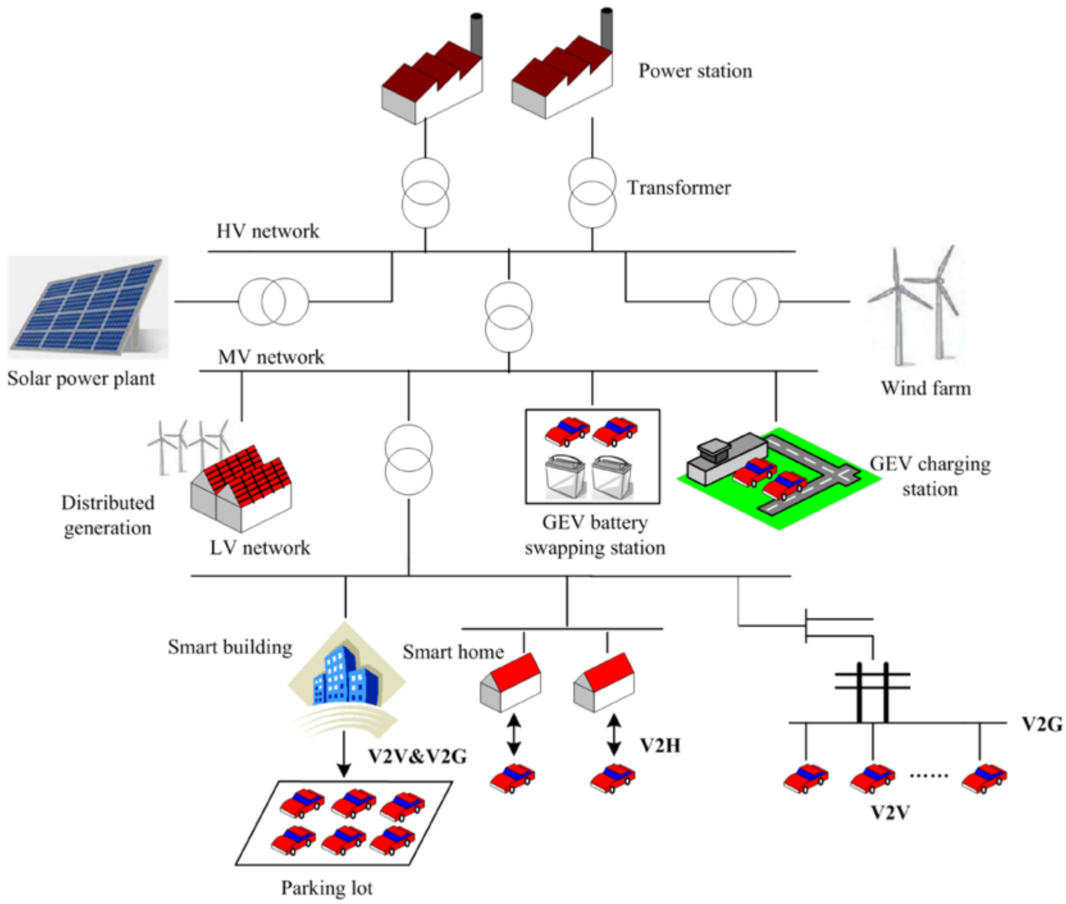
They integrate very often accumulator batteries. Hybrid energy systems find application in systems for autonomous supply with electrical energy where the production price of the electrical energy is lowered, the confidence is increased and there is smaller pollution. On the other hand, the hybrid systems can appear as connected to the electro energetic network most commonly as decentralized production units.

The basic reason for “hybridization” of the production unit connected to the electro energetic network is continuity in the production. Photovoltaic systems, as well as some other systems that use renewable energy systems (wind generators, small hydro electrical plants) have a variable character of production, which is a consequence of the variability of the energy received from the basic source of energy (sun, wind, water flow), which is characterized with regular and accidental changes. These energetic plants are characterized with high investment and very low expenses for regular work. This means that it is cost-effective if they work maximum use of the energy from the prime source.

On the other hand, the generators that use natural gas, biogas, oil or diesel fuel have lower investment, fuel and maintenance expenses are high. However, these production unit can be put into and out of function faster, or change their power without causing any additional expenses. These plants can be managed or dispatched.

In the hybrid photovoltaic systems the variable production or lack of production from the photovoltaic system can be restituted with production from dispatch able source. In this case the production can be adjusted to the needs of local consumers which is of great importance to the distributive network and from the aspect of decreased loss and improved voltage conditions and connecting new consumers to the network and new generators without need of additional investments.

The hybrid systems will be of particular importance in the near future when the expansion of electrical vehicles is expected. The vehicles will recharge their batteries with energy from the network. It is also predicted that there will be frequent occasions in certain period when they will return the accumulated energy in the network, so called regime “vehicle to grid” (v2g).



Pic. 2.31: Distribution grid with decentralized generating and connection of electrical vehicles

2.8. Good practices of application of photovoltaic systems at commercial and administrative users

2.8.1. PV system for shading of a parking space in Zografou, Athens, 19,95 kWp

Location: Athens, Zografou, Greece
Installed power of the PV generator: 19,95 kWp
Area per kW: 5,42 m^2
Type of cells: crystal silicon
Investment expenses: 120 000 EUR
Production of EE: 26 200 kWh/year

PV system is aimed at providing shading in the parking lot. A preferential tariff is obtained for the system of 0,46 €/kWh.

2.8.2. PV system at a shopping center in Athens Metro Mall, 51 kWp

location: Athens, Ag.Dimitrios, Greece
Installed power of the PV generator: 51 kWp
Area per kW: 7,72 m^2
Type of cells: crystal silicon
Investment expenses: 142 000 EUR
Production of EE: 39 900 kWh/year
Reduction of CO_2 emission: 23,94 t/year

The PV system is installed to save energy, money and protection of natural environment. PV modules are placed on the south side of the trade center with an area of 400 m^2. In this way 5 % of energy is saved. In this way 5 % of the energy is saved. A preferential tariff is obtained for the system of 0,394 €/kWh.

2.8.3. PV system in a primary school in Cavle, Croatia, 30 kWp

Location: Cavle, Gorski Kotar, Croatia
Installed power of the PV generator: 30 kWp
Type of cells: polycrystalline silicon
Investment expenses: 90 000 EUR
Production of EE: 34 032 kWh/year
Reduction of CO_2 emmission: 20 t/year

PV system is installed on a roof of the sports hall at the primary school in Cavle. PV modules follow the inclination of the roof. PV system is installed on a roof of a sports hall in a primary school in Cavle. PV modules follow the inclination of the roof. A preferential tariff is obtained for the system of 0,4 €/kWh.

3. Regulations and administrative procedures

3.1. Review of laws and regulations

- Law on energy (Official Gazette of RM no. 16/2011)
- Law on construction
- Law on ambient air quality (Official Gazette of RM no. 67/04 and 92/07)
- Law on protection of environmental noise (Official Gazette of RM no. 79/07)
- Decree on the limit values of the levels and types of polluting substances in the ambient air and alertthresholds, deadlines for limit values achievement, margins of tolerance for the limit values, targetvalues and long-term targets (Official Gazette of the. Republic of Macedonia No. 50/2005);
- Law on protection of cultural heritage (Official Gazette of RM no. 20/04 and 115/07)
- Decree determining the projectsand the criteria on the basis that will establish the need to implement the procedure for assessment ofenvironmental impact
- Regulation for preferential producers of electrical energy from renewable energy sources
- Regulation for licenses for performing energy activities (Official Gazette pf RM no. 143 from 15.10.2011)
- Rules of procedure of the Energy Regulatory Commission

3.2. Grid rules and decentralized production

The operator of the distributive grid is obliged to provide secure, quality and confident supply to all consumers in the system. The way this is realized is prescribed in the by-law act *Grid rules for distribution of electrical energy.* Decentralized generators are connected to the distributive grid according to grid rules, for which it is necessary to submit special request (BSP-2). Beside the general rules, during connection of electrical energy generators, the requests in the grid rules should be followed, which particularly refer to the dispersed generators.

During connection of generators in a given distribution grid it is essential to have a state analysis of the distribution grid during different regimes of work. So, for the grid is analyzed the connection of the generator. Special emphasis is put on the analyzes of the following typical states during:

- Minimal load of the grid and minimal production of electrical energy
- Minimal load and maximum production of electrical energy
- Maximum load and minimal production
- Maximum load and maximum production

In all typical states it is necessary the voltage in all knots of the grid not to overpass the allowed limits of deviation which are given in the grid rules. The maintenances of the voltage not only in the place where the generator is connected but throughout the whole grid can present a problem for the distribution operator. Depending on the type of plant that connects (directly connected generator or via inverter) estimations are made of the impact on the network from the aspect of appearing:

- flickers;
- higher harmonics;
- imbalance of phases;
- Injection of reactive power.

If the given conditions are fulfilled, operator of the distribution system gives the producer consent where the standards for the installed equipment are designated.

3.3. Procedures for obtaining construction permit

3.3.1. Procedure in the Republic of Macedonia

The first step in getting license for production of electrical energy from systems that use renewable energy sources is obtaining a construction permit. For that purpose it is necessary to engage a company for preparation of urbanistic documentation. Pursuant to Law on amending and supplementing the Law on construction (Official Gazette no. 31 from 22.02.2016) for photovoltaic systems placed on a roof with power of 1 MW there is no need for construction permit but the municipality issues an approval for set up of the equipment. A special request is submitted for this, pursuant to Law on construction.

From the operator of the distribution system (EVN – distribution) request and approval for connection in the distribution system.

The construction permit and approval for set up of the equipment are necessary documents for the following procedures:

- Execution of the PV system
- Obtaining permit use
- License for production of electrical energy
- Registration of the facility in the Register of facilities that use renewable energy sources
- Granting a status of preferential producer
- Purchase contract for electrical energy with the operator on the electrical energy market

For obtaining a production license for electrical energy from renewable energy sources, there is a wider procedure in the Republic of Macedonia that included the following steps:

• The investor can start the procedure for obtaining a license right after the approved construction permit.

• The procedure for issuing a licence starts at the Energy Regulatory commission of the Republic of Macedonia from the day of the admission of the request for issuance of license and necessary documentation (article 14 of the Regulation for conditions, way and procedures for issuing, change and revocation of license for performing energy activities).

• The Energy regulatory commission of the Republic of Macedonia is obliged within eight working days after receipt of the request to note the defaults. If the Energy Regulatory Commission of the Republic of Macedonia finds that the request has formal defaults, it will submit minutes that will determine a deadline for removal of the defaults, which cannot be longer than 15 days.

• If the Energy regulatory commission of the Republic of Macedonia finds that the request has no formal defaults, it makes conclusion that obligates the requestor to prepare a notice for the public media within three days.

• The Energy regulatory commission of the Republic of Macedonia makes the decision for issuing a license within a deadline that cannot be longer than 20 days of the day of completion of the preparatory session.

• The request for issuing an approval for use of construction is submitted to the Ministry of transport and communication or the municipality (art. 72, 73, 74, 75, 76 and 77 – from the Law on construction „(Official Gazette of the Republic of Macedonia “, no. 130/09).

• The construction permit ceases to be valid if the investor does not start with the construction within six months of the day when the construction permit became legally effective.

• The authorized organ of article 58 of the Law on construction (“Official Gazette“, no. 130/09) will issue the permit for use of construction within 15 days of the day of the conducted technical examination, if the commission that conducted the technical examination in the minutes concluded that the construction cam be put into function.

• The facilities that are constructed from renewable energy sources belong to the second and third category pursuant to article 57 of the Law on construction.

• The Energy regulatory commission of the Republic of Macedonia is obliged to issue the license if all conditions are fulfilled not later than 90 days of the day when the request was submitted, pursuant to article 40 of the Law on energy (“Official Gazette of the Republic of Macedonia”, no. 63/06, 36/07 and 106/08 and article 14 of the Regulation for conditions, way and procedures for issuing, change and revocation of license for performing energy activities (“Official Gazette of the Republic of Macedonia”, no. 31/09).

• Energy Agency of the Republic of Macedonia issues a certificate at the request of the investor for obtaining a temporary status of an authorized producer of electrical energy from renewable energy sources.

• After obtaining a permanent license from the energy regulatory commission of the Republic of Macedonia, the investor submits a request for a code from the Register of plants for renewable energy sources in the Energy agency of the Republic of Macedonia (art. 12, 13, 14, 15, 16, 17, 18 and 19 from the Regulations for use of renewable energy sources for production of electrical energy, (“Official Gazette of the Republic of Macedonia”, no. 127/08).

3.3.2. Procedures in the Republic of Bulgaria

In the Republic of Bulgaria the connection of photovoltaic systems to the electro distribution grid is prescribed by the Law on renewable energy sources. Renewable electrical energy (REE), including the photovoltaic systems, is promoted through:

• Securing guaranteed access to the electrical energy produced by the photovoltaic systems to transmission and distribution grids in accordance with the security criteria defined in the regulations of article 83, par. 1, item 4 and 5 of the Law on energy.

• Guarantees buying of electrical energy produced in the photovoltaic systems, for a fixed period (20 years), with a preferential price for the whole period.

Pursuant to article 24 (1) and (2) of the Law on renewable energy sources, photovoltaic systems up to 30 kW can be installed or built on roofs and façade constructions and connected to the electrical grid. What is essential for these photovoltaic systems for energy generation is that they can be connected with lower voltage – up to 0,4 kV.

In the plants with this capacity, as well as for own needs, their planning from KEBR is not necessary. They can be installed and connected in any time until the photovoltaic fulfill the protection requests of the grid. This means that the inverter which converts the voltage and electricity has all necessary protection.

Also, there are no barriers for construction of grid photovoltaic systems for own needs through sale of the surplus energy (art. 25) and there are no preferential purchase price (art. 31 and 32 of the Law on electrical energy). The surplus of the produced energy is bought on the free market at a very low price, which is an obstacle for the development of these type of systems, at least until now. With liberalization of the market of electrical energy we hope that installation of these systems will increase enormously. These are the legal frameworks of ZEVI, which give possibility for investment in photovoltaic systems.

For selection of grid system we will systematically present below the chronology of activities which the investor have to do so the system can work, as well as contacts of the investor with institutions which are responsible for issuing and obtaining all approvals, permits and final documents and contracts.

Step 1: Delivery of documents for issuance of blueprints with visa projection by the local authorities by natural way or contract for property ownership, actual blueprints of the property /time – deadline 14 to 30 days/ the document is issued by the main city architect of the municipality/ price of the document is 16 levs.

Step 2: Submission of projects – electrical and constructive minutes pursuant to art. 147, par. 1, item 14 of the Law on territorial arrangement, together with the visa projection by the municipality for coordination of projects and issuance an “Authorization for installation of FtSPT”.

Deadline: 30 + 14 days/price 250 levs

Step 3: At the same time are submitted document to the local electro company for distribution – document for ownership, blueprints with visa projection and electrical project for issuance of an Opinion for the item connection of photovoltaic systems to the electrical grid. Deadline up to 30 days/price 38 levs.

Step 4: After getting the opinion and Certificate for installation by the municipality, the documents are submitted to the electrical company for concluding contract for access and connection of photovoltaic systems to the electrical grid/deadline 30 days, at the local electro company/price – 380 levs.

Step 5: After the signing of the contract and completed mounting of photo-voltage system, a request is submitted to the local electro company for 72 hourly samples/30 days/no taxes for this.

Step 6: Signing of protocol for completion and connection of photovoltaic system with electro company/72 samples, also no taxes.

Step 7: Signing of long-term contract for sale of electrical energy (20 years at preferential prices with local electro company) within a period of 30 day.

The procedures for selection of the contractor should be in accordance with the Law on public procurement. The time for implementation of these investments is multiplied due to the problematic administration system of these type of investments.

Advantages: There should not be a problem in obtaining permits and information – institutions are municipal and public. They are convenient for set up of photovoltaic systems – their construction facilities. The municipal and state administrations also have financial technological surplus and in case of difficulties can engage public-private partnerships for achieving highly effective solutions.

Disadvantages: Time delay in the implementation of the photovoltaic systems on roofs and in some cases due to lack of knowledge!

4. Financing

4.1. Mechanisms for investment support in photovoltaic systems

4.1.1. Preferential tariffs

In order to stimulate construction of systems that use renewable energy sources, Republic of Macedonia has provided preferential tariffs for several types of systems and electrical plants.

The preferential tariff for photovoltaic systems, for the first time adopted in 2008 has been three times modified since then.

TABLE 4.1 – Preferntial prices of electrical energy produced from PV systems in the Republic of Macedonia

Year	Power of PV system 50 kW [€cents/kWh]	Power of PV system 51-1000 kW [€cents/kWh]	Preferential period in years
2008	46	41	20
2011	38	34	15

2011	30	26	15
2013	16	12	15

For photovoltaic systems, by the decision of the government of the R. Macedonia is determined maximum installed power (intake). The intake totals 18 MW, of which 4 MW are for systems up to 50 kW, 14 MW – for systems up to 51 – 1000 kW. This intake in Macedonia is almost fulfilled, so there is need for other means of support.

For the Republic of Bulgaria the preferential purchase prices were introduced by the State regulation commission for energy and water (КЕВР http://www.dker.bg). In the following tables are presented the preferential tariffs for the electrical energy produced by photovoltaic systems for the previous period and now.

TABLE 4.2 **Tariffs for PV systems mounted on roofs and facades [lv./MWh]**

Beginning of preferential tariff	**Installed power to 5 kWp [lv./MWh]**	**Installed power to 5 kWp [€cents/kWh]**	**Installed power from 5 kWp to 30 kWp [lv./MWh]**	**Installed power to 5 kWp до 30 kWp [€cents/kWh]**
29.12.2006	782,00	40,0	718,00	36,7
01.04.2009	823,00	42,1	725,00	37,1
31.03.2010	792,89	40,5	728,29	37,2
30.03.2011	760,48	38,9	699,11	35,7
30.06.2015	228,00	11,7	211,71	10,8
30.06.2016	255,39	13,1	213,92	10,9
01.07.2017	271,67	13,9	231,20	11,8

Prices are without VAT included -20%.

TABLE 4.3 **Preferential tariff [lv./MWh]**

Total installed power of PV modules	**01.7.2011**	**01.7.2012**	**01.9.2012**	**01.7.2013**	**01.7.2014**
Up to 5 kWp, mounted on roofs and facades	605,23	400,7	381,18	353,97	211,81
From 5 kWp to 30 kWp, mounted on roofs and facades	605,23	400,7	289,96	284,18	203,97
From 30 kWp to 200 kWp, mounted on roofs and facades of production premises	596,5	369,08	226,87	211,4	169,12
From 200 kWp to 1000 kWp, mounted on roofs and facades of production premises	583,77	316,11	206,34	196,58	144,68
Up to 30 kWp	576,5	268,68	193,42	195,44	152,19
From 30 kWp to 200 kWp	567,41	260,77	188,1	191,13	143,35
From 200 kWp to 10 000 kWp	485,6	237,05	171,37	176,29	134,03
Over 10 000 kWp	485,6	236,26	169,85	160,2	131,36

Prices are without VAT included -20%.

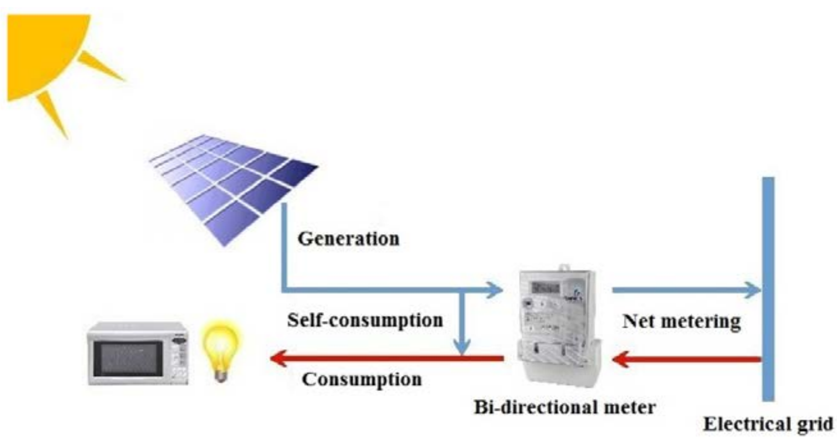
With the decisions of KEBP during the course of years, the prices of the tariffs for photovoltaic systems are constantly decreased, with small fluctuations. Also, in the recent years, the decisions were made only for PV systems to 30 kW, mounted on roofs and facades on existing facilities and neighboring terrains in urban environment, which is an indicator that the emphasis in future will be put on roof installations.

According the Bulgarian photovoltaic association (vei-bg.org from 06.09.2017) the overall installed capacity of the photovoltaic electro plants connected to the distribution grid in the Republic of Bulgaria is for systems: up to 30 kWp - 3 690,56 kW, up to 5 MWp – 682 719,53 kW and bigger from 5 MWp - 133 331,32 kW. With this, the overall capacity of the Re public of Bulgaria, including beginning of September 2017 totals about 820 MW.

4.1.2. Own consumption and exchange of electrical energy

As it has previously been mentioned, the main advantage in the vicinity of consumers, same or lower production price compared to price of electrical energy offered to households and other facilities by the distributor of electrical energy. At the same time, the produced energy by PV system set on a facility (roof, walls or surrounding area) primarily is used for covering of own consumption (by the consumers located in the facility) and the surplus or shortage of energy is transferred or undertaken by the electrical grid. Depending on the regulations of the state, the price of the transferred energy is valued differently.

Mainly there are three ways of using the PV systems for coverage of own consumption, which differ according to the dealing and payment of surplus energy. The first way is by limiting the power of PV system, where with special device (limiter) is limited the power of PV system and in not a single moment is bigger than the consumption. In this way, it is not allowed for the energy to be transferred in the grid. This way is used in case when it is not possible to have contract for transfer of the electrical energy with the supplier or operator of the distribution system. The second way enables for the energy to be transferred to the grid but there is no compensation for that. With the application of the third way it is enabled for the energy to be transferred to the grid, where the supplier grants a minimum compensation, in amount of the regulated price of electrical energy, which in the Republic of Macedonia totals 4 €cents/kWh.



Pic. 4.1: Application of PV system for own consumption

Main factors that have an impact on cost-effectiveness of application of PV systems for covering own consumption are: overall consumption and overall production of electrical energy, as well as the shape of the daily diagram of consumption. For commercial consumers the daily diagram of consumption changes from case to case and is not possible without special analysis to be estimated whether the use of PV system is favorable to be used for covering of own consumption.

It is very important to be determine the ratio of the produced and consumed energy because this limits the level of use of own energy. If there is a balance between the consumed and produced energy, also important is the degree of congruence of the diagram of consumption with the diagram of production. From this depends what portion of the generated energy directly will be consumed and what portion of the energy will be transferred to the grid.

PV systems for own consumption can be used in industrial capacities. In addition, beside lower invoices for the delivered active energy, there can be also decrease in the part of the invoice for the reactive energy. Of particular interest is the possibility for decrease of the ultimate power, which can have significant part in the electrical energy bills, especially if the ultimate burdening is during the day. For more secure results during decrease of the ultimate burdening it is recommended accumulator batteries to be used.

During application of PV system for covering own consumption it is very important to have good dimensioning of the system because the economic cost-effectiveness can be put into question.

4.1.3. Grants and tax alleviations

The municipal, educational, social and cultural institutions in R. Bulgaria have access to EU funds and national budget for implementation and undertaking of measures to improve the energy efficiency and use of renewable energy sources.

Operational programme „Regions in growth"

The operational programme "Regions in growth" 2014-2010 (OPRP 2014-2020) is one of the biggest financial instruments pointed primarily towards regional development and achieving goals of urban policy in Bulgaria. OPRP finances activities that have as a goal provision of balance in cities and contribute in achieving sustainable urban development, creation of favorable conditions for improvement of quality of life and enabling of creation of new jobs. Priority axis 2 of the Programme is purposed to help In implementation of energy efficiency measures in public buildings and blocks of flats in smaller cities, municipal center and suburban areas that provide services for the neighboring regional areas.

Program for rural development 2014-2020

The programme supports projects and investments in municipalities in rural areas in R. Bulgaria for improvement of infrastructure, road corrections, street reconstructions, water supply systems reconstruction, starting small businesses, development of rural tourism and other alternative activities. Also, the program covers projects for reconstruction and/or repairs of municipal buildings that provide public services in order to improve their energy efficiency including use of energy from RES, from the frame of measure 7 "Basic services and village renewal in rural areas in Bulgaria".

Guaranteed agreement for results

The possibilities for use of this instrument refers to companies that deals with energy efficient services of legal subjects, institutions with budget or municipal authority (hospitals, schools, kindergartens, sanatoriums, homes for elderly people, homes for disabled persons, theaters, cinemas, museums, reading houses, libraries, recreational centers, administrative buildings and others). Companies for energy efficient services with guaranteed results (known as ESCO) provide with their own resources ESCO services and investments (research, disposition, functioning and maintenance) with certified level of energy savings, return of investments together with the calculated profit.

Credits with grants – special credit lines

The municipalities in Bulgaria can use low interest rate credits for financing of projects to increase the energy efficiency and stimulate use of RES through low interest rate credits and flexible banking mechanisms from the Eurpean bank for development and reconstruction, the Fund "Energy efficiency and renwable sources", "National creditor Ecofund, MF Kozloduj" and other.

National program for energy efficiency of home buildings

This program is aimed for renovation of home buildings with a main goal – through implementation of measures for energy efficiency to provide better life conditions of citizens in the buildings, thermic comfort and higher quality of natural environment. The municipalities receive the documents for applying, evaluation, approval, provision of finances and monitoring of implementation of measures for energy efficiency of the buildings. Suitable for applying are all home buildings designed before 26 April 1999, buildings from 3 to 6 floors and for more independent facilities that have the same purpose.

Other financial mechanisms that provide grants for financing

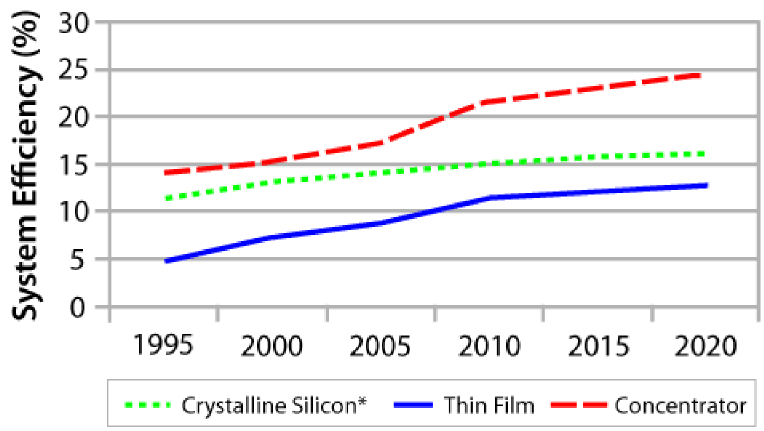
At the beginning of 2018 will start the financing of projects for use of renewable energy sources, in particular those aimed at use of geothermal water for improvement of energy efficiency of the municipal administrative buildings and institutions within the Financial mechanisms for European economic area (Norwegian financial mechanism). The amount of financial resources for these types of projects for the period 2018 – 2012 totals 32 million Euros.

5. Techno economic analysis

The technical efficiency of the use of renewable energy sources is connected with the coefficient of the useful action of the process. It presents a quotient between the received useful energy and overall invested energy. When we talk about photovoltaic systems, the input energy is the energy of the solar radiation and the goal of the engineers is to find such system which in the most efficient way will transform the solar energy into electrical energy. The technical efficiency is determined on the basis of physics and it is always smaller than one.

$$\eta_{economy} = \frac{\text{Profit project}}{\text{Costs for project implementation}} > 1$$

Nowadays the challenge of the engineers is to construct photovoltaic panels with as bigger efficiency as possible, which for a give input amount of solar radiation will produce as much as bigger amount of electrical energy as possible. Nowadays, with the development of technology, the efficiency of photovoltaic continues to grow and depending on the technology achieves about 15-20 %.



Pic.5.1 Efficiency of photovoltaic systems depending on technology

It is important to emphasize that the research is going on and that in laboratory conditions has been achieved degrees of efficiency bigger than 40 %, but they are still not available on the market due to the high prices which are unacceptable for the potential buyers.

So, if one project which is feasible from technical aspect to be acceptable and implemented it must be also acceptable for the investor from commercial aspect. Hence, there is a need for analysis of the economic efficiency of the photovoltaic systems that will be used in the commercial and administrative capacities, which is connected with the determination of the expected expenses and benefit during the lifecycle of the technical system.

The economic efficiency of a technical system can be defined as a quotient of the expected benefit since the undertaking of the project (B – Benefit) and overall expenses during the exploitation period:

$$\eta_{economy} = \frac{\text{Profit project}}{\text{Costs for project implementation}} > 1$$

In contrast to the technical efficiency which is always smaller than 1, expectations of the investor in one home photovoltaic system are that with undertaking of the project he will achieve the wished benefit or personal satisfaction, that will justify the invested financial resources. Most commonly, the benefit from the project is expressed in monetary units (for example, benefit made as a result of electrical energy sale). But not all benefits from the undertaking of the project are directly financially measurable. So, for instance, projects for production of electrical energy from solar energy through photovoltaic systems provide pure energy which is located right next to the industrial consumers. This decreases the harmful emission of greenhouse gases in the atmosphere and contributes in clean natural environment and additional benefits are the decrease of energy losses which appear during the transmission of energy from big classical electrical plants to the final beneficiaries. So, for complete evaluation of these projects for production of electrical energy from the photovoltaic systems a conversion is necessary of all benefits with suitable monetary equivalent.

We can conclude that the decision whether we will launch a certain project for construction of a photovoltaic system is a technical and economic problem where also the technical aspects and economic benefits of the project should be taken into consideration.

Although in many cases the economic efficiency has advantage over the technical, there is a connection between them because the development of technology and engineering makes the technical systems cheaper and cost-effective from economic aspect. We should take into account the wish of the investor to invest in projects that are healthy for the natural environment, the wish with his investment to contribute in the preservation of the environment and his additional expectations from the implementation of the project.

In a detailed analysis which overpass the volume of this Guide, also should be considered the accompanying risks (that offer opportunities and threats) during entering into these projects. We should mention here the risk of provision of quality photovoltaic panels, the risk connected with the price of the electrical energy (which is expected to rise), about the maintenance of the home photovoltaic systems.

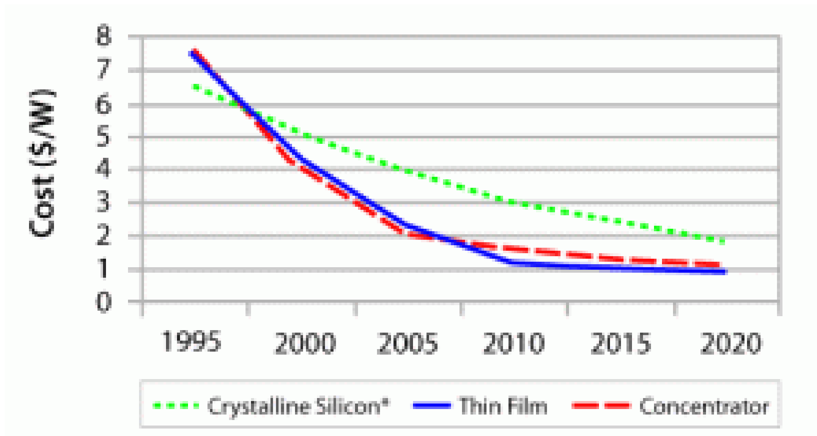
It is presupposed that the photovoltaic systems will work with availability of 99 %. It is predicted that 1 % of the projected electrical energy will not be produced because of unavailability of photovoltaic systems, when there is no solar radiation and no possibility for production of electrical energy. This high degree of confidence is based on the fact that all necessary service activities are most frequently taking place at night, when there is no solar radiation and there is no possibility for production of electrical energy by a photovoltaic system.

5.1. Analysis of the structure of expenses and profit – Cash Flow of the project for construction of photovoltaic system

The expenses that emerge during construction and exploitation of a one photovoltaic system are consisted of initial investment construction expenses and operational and maintenance expenses.

Projects that are undertaken for construction of photovoltaic systems for production of electrical energy, regardless whether they are home photovoltaic systems, systems implemented within industrial capacities or photovoltaic electrical plant are characterized with big initial investment. Positive side is that the capital expenses, with development of technology are in regular decline, so in the near future, in particular if we take into account the limited amount of fossil fuels, it is expected that the electrical energy from photovoltaic systems to be the cheapest.

The attractiveness of the production of electrical energy from photovoltaic systems to a great extent depends on their efficiency. Therefore, one of the biggest challenges of the engineers who are connected with the use of energy of the solar radiation is to construct photovoltaic panels with bigger efficiency, which for a given input amount of solar radiation will produce as much bigger as possible amount of electrical energy. In pic. 5.2 is presented the trend of increasing of efficiency of photovoltaic systems depending of the used technology.



Сл. 5.2 Movement of capital costs for construction of photovoltaic systems

The initial investment necessary for installation of photovoltaic systems, in general is consisted of:

- expenses for provision of modules and inverters,
- metal construction,
- project design,
- mounting,
- costs for provision or renting of land,
- costs for obtaining the necessary documents about construction permits.

Generally speaking, the specific costs of the project decrease with the increase of installation of the photovoltaic plant.

The indicative specific prices of solar panels depending on the producer of the solar panel and watt peak capacity of the solar panel (Wp). As we can see there is a significant difference depending on the producer of the equipment. Of course, during provision of equipment beside the price, should be taken into account the following important features of the photovoltaic panel such as:

- Quotient of the useful effect of photovoltaic panel
- Annual percentage decrease of quotient of useful effect of the photovoltaic panel in the course of time
- Age of exploitation of the photovoltaic panel
- Guaranty by the producer
- Availability of service.

On the other hand the photovoltaic systems require relatively small maintenance and operation expenses during the period of exploitation. Here we understand the servicing expenses for the system, additional expenses for repairs, cleaning of the panels, insurance, etc. Depending on the type of installed parts in the photovoltaic plant and its installation, the annual operating expenses are estimated between 20-50 EUR/kW.

The benefits that are achieved with implementation of the photovoltaic system are realized through production of electrical energy. The main goal in undertaking this projects that are implemented with limited budget at small and medium enterprises is to satisfy partially or completely own production of electrical energy, whereas the surplus of energy that will not be consumed is planned to be handed to the distribution grid. This will decrease the costs for buying electrical energy from the distribution system and in cases when there is surplus of production, it should be sold or replaced with suitable amount of electrical energy in the period when the production of electrical energy from photovoltaic system is insufficient to satisfy the own needs.

When we talk about projects for construction of photovoltaic electrical systems, the only goal is production of electrical energy and its transfer to the electro-energetic system. The price at which the electrical energy is sold can be regulated if it is a preferential producer of electrical energy or it can be a free price if the producer places the produced electrical energy on the free market. In Macedonia the current preferential prices at which the authorized producers of electrical energy from photovoltaic systems sell it is 160 €/MWh for photovoltaic systems with installed power of over 50,01 kWp.

5.1.1. Estimation of annual production of electrical energy from home photovoltaic system

One of the basic questions that every investor in photovoltaic electrical plant considers is what would be the annual production of electrical energy and what would be the distribution of that production per months. We can say that the production of electrical energy from photovoltaic electrical plant can be relatively good estimated for a give geographic location where the system is installed. What is typical for that production are the small oscillations on an overall expected production during one calendar year but also big oscillations during the different seasons which is reasonable due to the different solar insulation in the course of different months of the year. So, for example, there are big differences in the monthly production of electrical energy from the photovoltaic electrical plants in January and July, which is explainable due the different amount of solar radiation.

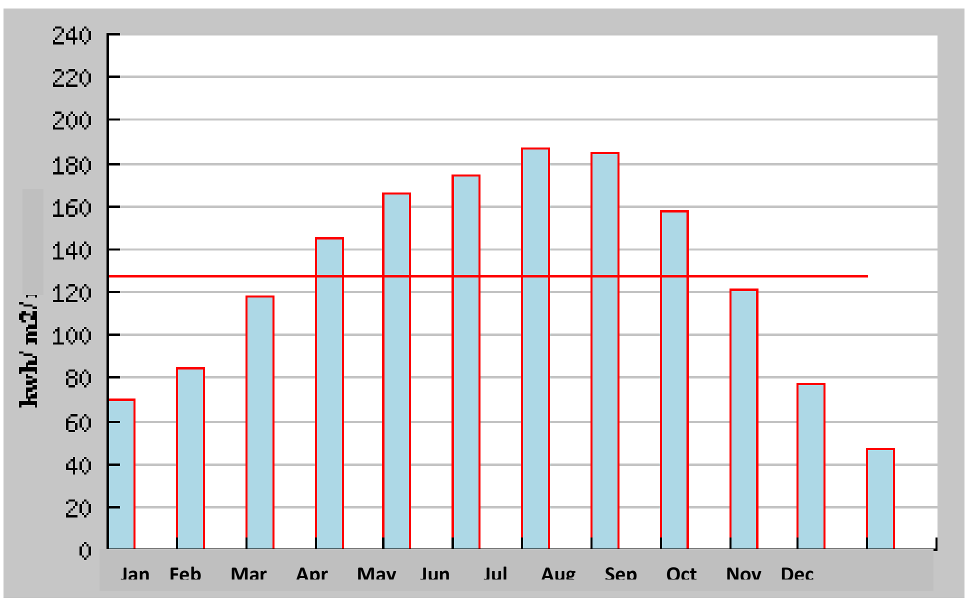
In the following table there is a comparison of the annual solar radiation in Macedonia with the leading countries in the use of solar energy in Europe.

Tab.5.1. Solar irradiation over Macedonia and solar irradiation over countries leaders in use of solar energy

Annual global irradiation (kWh/m^2)				
	Germany	Czech Republic	Spain	Macedonia
Minimum	1.074	1.115	1.365	1.482
Average	1.147	1.169	1.812	1.623
Maximum	1.445	1.267	2.028	1.722

Taking into consideration the location of Macedonia which is very attractive for use of solar energy, it is believed that in future there will be a space for bigger use of solar energy, whether for production of electrical energy through the photovoltaic plants or for production of hot water.

In pic. 5.3 we can see the solar irradiation per months for a given specific location in Macedonia. For the analyzed area the average solar radiation totals **128 kWh/m^2, total annually 1537 kWh/m^2.**



Pic.5.5 Distribution of solar radiation per months for the location Shtip in Macedonia

It is characteristic that the ratio between the solar irradiation for July and December totals more than 4, which means that the production of electrical energy from the photovoltaic system in July was four times bigger than in December. This shows that the production of electrical energy from photovoltaic plant depends in great measure from the season. The winter period is critical in particular when the solar insulation is decreased. From calculating aspect, an important feature value is the sum of the squares of deviation of the monthly solar radiation from the middle-year value. This statistical indicator named as standard deviation is a measure for overbalance of radiation. In this case the standard deviation is **49,53 kWh/m^2**

5.2. Means of financing projects for photovoltaic systems

Providing financial resources is one of the basic tasks for implementation of projects. The necessary resources for implementation of photovoltaic systems depends on the planned installation of the system. At the same time the specific investment per kWp decreases with the increase of the installed power. Thus, for implementation of home photovoltaic system installed on a house roof it necessary to provide 1200-1400 €/kWp, while for photovoltaic plants with bigger power the specific investment, on today's level of technology development (2017) totals about 1100 €/kWp.

If we make a comparison between the investment costs for construction of photovoltaic plants with different capacity it can be seen that in most cases they depend on the price of photovoltaic modules, which the producers sell on lower price if the amount is bigger. With the increase of the power of photovoltaic plants the costs for provision of inverters decreases. Namely, at bigger plants in regard to smaller, smaller number of inverters is provided but with bigger capacity.

Also, at bigger photovoltaic plants there are savings at specific costs connected with the planning, projecting, mounting, etc., but when we take into account the high costs for the bearers (construction) of the panels and electrical installation at photovoltaic systems installed on the ground, these advantages are partially compensated.

The financing of construction of photovoltaic electrical plants can be implemented in several ways:

- Own resources
- Resources provided through crediting
- Combined way of financing
- Resources provided through subsidies, donations, sponsorship or suitable development programs

Use of own resources. This way of financing is suitable for smaller investments and can be applied for financing of photovoltaic plants with smaller installed power (smaller than 50 kWp). In this case the expected profit from the investment should be compared from the realized profit from the interest when the same resources would be invested in a bank. At the same time, we must emphasise that the same resources would be invested in a bank. At the same time we must emphasize that the interest for savings at commercial banks in the Republic of Macedonia have been significantly decreased (1-2% on annual basis), which presents a stimulation for potential investors to invest their free savings in construction of photovoltaic electrical plants.

Resources provided by crediting. This way is essential when you do not have own financial assets and when it is expected the project to enable the repaying of the credit through its realized profit (in this case the produced electrical energy) and to provide additional profit. When we talk about financing of bigger photovoltaic plants with power of 100 kWp, this way of financing is the most favorable because it does not engage additional resources. It should be taken into account the production of electrical energy to cover the monthly annuities that should be paid to the bank, in order to avoid additional crediting.

Combined way of financing: The investment is partially covered by own resources and partially by bank credit. This way of financing is a good compromise of the good sides of the first two ways of financing (not to enter into bigger debt and engage more own resources). This way of financing would be suitable for financing of photovoltaic systems with power of 50-100 кWp

Resources provided through subsidies, donations, sponsorship or suitable development programs: This way of financing decreases the share of participation by the investor and common good is achieved (decrease of harmful greenhouse gases, healthy environment, fulfillment of goals for in the representation of renewable energy sources of energy in the overall production). For instances, during a construction of photovoltaic plant the state can give up on the tax for land or to subsidy a certain percentage in covering the initial expenses of the investors. Funds can be provided through suitable development programs and projects financed by the European Union (EU), which primary goal is promotion of production of electrical energy from renewable source at the commercial and administrative users.

5.2.1. Characteristics of credits

When a financial analysis is being prepared, it is necessary to define the key features of the credits that finance the project: amount of credit, rate interest, deadlines of credit, grace period and additional expenses that are connected with administrative procedures.

The interest rate is determined by the banks or agencies. The interest rate defines the interest or compensation which the borrower of the loan gives to the lender for the service: giving money. Usually, interest rates on short-term and long-term credits are different. Interest rates is connected with the investment risk, so it is expected more risky project to be financed with credits that have bigger interest rates. Also, short-term credits due to their certainty as a rule have smaller interest rates. As far as the financing of projects connected with construction of photovoltaic systems, essential are credits with low interest rates or so called "green" credits that would stimulate the investors to continue investing in such projects.

Maturity of the credit is the time agreed with the bank (lender) for service of the loan. Ideal loan is the one that lasts the same period as the project that is financed with its assistance. But in practice it often impossible to be like that. Therefore, it is necessary to define a period that covers the main part of the investments, in particular those that are with highest percentage in the overall costs. If the loan is of shorter period than the project implemented by its assistance, the project will have to generate greater income so the investment is paid off as soon as possible. On the other hand, if the loan lasts longer than the project financed by its assistance, the project will be put in a situation to have a need for additional credit for replacement of amortized elements and the initial credit for the same project will still not be serviced. The time for service of the credit depends on the type of the project and ability to generate profit that will service the credit.

Also, the time for payment is longer for bigger loans. So it is expected that if you take a bank credit for implementation of photovoltaic plant (about 5000 €) the loan maturation to be 5-10 years and if you take a credit for financing of a loan for photovoltaic electrical plant, the period for repayment would be from 10 to 15 years.

The grace period is the time in which the borrower still has not started to repay the loan. But the commercial banks usually offer this possibility when the loan is bigger and long-term but not at the short-term loans. The reason why this mechanism exists is to overcome the period where the project has not generated profit yet.

There are two types of grace periods. The first type is more common and refers only to the capital fund. During the grace period, the interest is paid to the lender but not the capital fund of the loan. In this way, after the expiration of the grace period the borrower owes the same amount of the capital fund as in the beginning.

The second type of grace period refers to the interest. In this case, the interest is not repaid but is added to the capital fund and in this way the overall amount that should be repaid is regularly increasing during the grace period. What is not usual and characteristic for this type of grace period is that the period is shorter.

Also, during making arrangements for the financing loans for photovoltaic systems it should be taken into account for the so called hidden expenses that appear during application for the loan at the commercial banks and additional expenses that might arise during the closing of the credit. As one of the significant factors for crediting in the agreements are the penalty interests rates, which the bank has the right to pay from the borrower (investor) if he does not service his obligations regularly towards the lender (bank).

In Tab. 5.2 are presented the monthly installments that should be paid to the bank if we take a credit of 100.000 € for implementation of photovoltaic electrical plant which goal is production of electrical energy for sale or own needs. We can see from the table that the monthly installment depends on the interest rate (%) and the years of credit repaying. If the credit that is used for investment differs from 100.000,00 €, the value of the monthly installment presented in table 1 should be calculated with the amount of the taken credit and to divide it by 20.000,00. So, for instance, if for implementation of photovoltaic system aimed for commercial and administrative user you take a bank credit in amount of 250.000 €, with interest rate of 5% and repaying period of 12 years, from the table we read the interest rate of 5% and repaying period of 12 years a value of 924,89 €. To calculate the monthly installment for the credit which totals 250.000 €, that value is multiplied with 250.000 and divided by 100.000, so we receive the monthly installment for the credit which totals 2312,23 €.

TABLE 5.1 – Monthly installment of credit repaying for implementation of photovoltaic electrical plant to avoid additional crediting.

Amount of credit:	100.000,00 €				Photovoltaic electrical plant		
Type of payment:	monthly						
	Interest rate (%)						
Years of payment	0,5	1	2	3	4	5	6

3	2799,24	2820,81	2864,26	2908,12	2952,40	2997,09	3042,19
4	2104,67	2126,15	2169,51	2213,43	2257,91	2302,93	2348,50
5	1687,93	1709,37	1752,78	1796,87	1841,65	1887,12	1933,28
6	1410,12	1431,55	1475,04	1519,37	1564,52	1610,49	1657,29
7	1211,68	1233,12	1276,74	1321,33	1366,88	1413,39	1460,86
8	1062,86	1084,32	1128,09	1172,96	1218,93	1265,99	1314,14
9	947,11	968,60	1012,53	1057,69	1104,10	1151,73	1200,57
10	854,51	876,04	920,13	965,61	1012,45	1060,66	1110,21
11	778,76	800,32	844,59	890,38	937,67	986,45	1036,70
12	715,63	737,23	781,68	827,79	875,53	924,89	975,85
13	662,22	683,86	728,50	774,92	823,12	873,06	924,72
14	616,44	638,12	682,95	729,70	778,35	828,87	881,24
15	576,76	598,49	643,51	690,58	739,69	790,79	843,86

5.3. Time dimension of the money and Cash Flow of the project

The economic valorization of the technical projects, in particular projects connected with production of electrical energy from renewable energy sources is a complex task which should primarily give an answer to the question whether future expected benefits, with acceptable risk, can justify the investment and whether the proposed model of investment is the best way to achieve the requested goal.

The financial evaluation of the investments in photovoltaic systems, which primary goal is production of “clean” electrical energy can be divided into the following steps:

- Estimation of the ash Flow
- Adopting criteria for evaluation and calculation of cost-effectiveness indicators of the investment and
- Analysis of the results, comparison with the adopted criteria for acceptability with decision making whether to accept or refuse the project as an investment

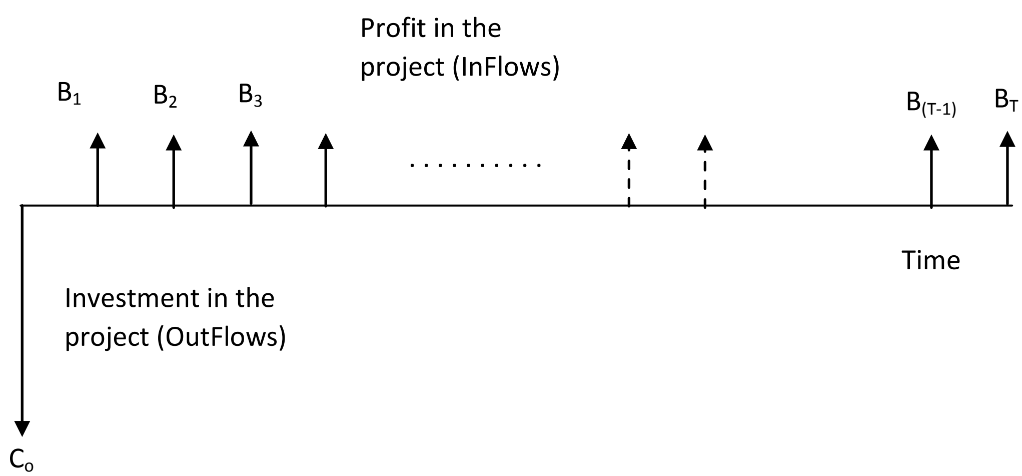
During economic valorization of the projects a generally accepted fact that today’s value of one dollar is bigger than the value of that same numerously same one dollar in the future (''A nearby penny is worth a distant dollar!''). This finding for the variable value of money has more reasons. One is that in every society, more or less inflation is present, which devaluates the purchasing power of future money in comparison with the same amount of current money. Besides, it must be admitted that of several reasons there is a real risk for money return which increases with the period of waiting. So, every investor primarily is interested to return the invested resources as soon as possible and to realize bigger profit.

In today’s market oriented environment, full of uncertainties, the wish to get the money fast is always present. So, the promise to get 1000 € after 5 days is far worthier than the promise the same amount of money will be get in 5 years. The logic for this is simple: the first event is much more obvious and certain in comparison to the second one. Intuitively: you can invest the money in bank and receive a particular interest which in five years will increase the initial value of the deposit.

Third reason for introducing the time dimension of the money value is the possibility for their reinvestment. One dollar today is worth more than a dollar received after one year because it can be productively invested during that current year. Waiting a year to pass to get the money, in fact we make a loss (expense) due to the missed opportunity, which is equal to the expected profit from the missed investment.

Because the money value has time dimension, during economic analyses of projects, practically it is impossible simple compilation of cash-flows that happen in different time periods. So, in order to reduce all cash-flows on one reference point, the method of actualization is used with which all cash-flows are actualized with the help of actualization rate (discount rate) of the first year of the project start.

(Cash Flow) presents the balance between all future Cash In Flows and Cash Out Flows in nominal amount connected with certain period and given investment project. Cash flows are presented on a time axis, where the negative part of the axis with an arrow pointed down are inserted the expected profits from the undertaking of the project. In pic. 5.4 is presented the typical cash-flow of a photovoltaic project, where the investments are in the beginning (zero) year (C_0), while for the other period of exploitation of the project are predicted positive inflows as result of the produced electrical energy from a home photovoltaic system. The costs in the initial year, mainly are connected with planning, designing, obtaining permits, while in the first year the costs are connected with the construction of photovoltaic plant.



Pic.5.6 Typical Cash Flow diagram for project for home photovoltaic system

5.4. Methods for economic analysis for projects from renewable energy sources

The methods that are used for estimation of the economic cost-effectiveness of the investment projects for production of electrical energy from renewable energy sources is a complex process that need technical and economical knowledge. Project managers must well and essentially know the methods of economic analysis because their regular application is important for objective estimation of efficiency of the investment, as well as selection and ranking of investment projects.

Project managers, also, must differentiate the investment criteria from the methods for calculation of economic effectiveness of investments. The investment criteria tends towards achieving a certain effect (maximization of profit, minimization of loss, maximization of overall production), while the methods for estimation of economic effectiveness of the investment enable on the basis of already determined criteria to make a selection between several possible investment projects.

Furthermore, in this Guide, we will explain the most acceptable and most elaborated methods for estimation of economic effectiveness of investment projects in the engineering practice in retrospection of their application on different types of projects connected with the analysis of economic efficiency of investment in photovoltaic systems for production of electrical energy.

In the process of evaluation and decision making there is a tendency to eliminate the time dimension of the money value. That is why the methods that are used for valorization of projects make balancing of all income and revenues from the project at the same reference time.

The current value of money is evaluated after certain rate of actualization (discount rate). The rate of actualization (discount rate or capitalization rate) is an interest rate that is used so that the cash-flows that are taking place in future are converted in current values. The current value of money is calculate according to the following formula:

$$PV = \frac{FV_n}{(1+k)^n} = \frac{FV_n}{(1+s_a)^n}$$

Where:

PV - current value of the cash flow;

FV_n - value of the cash flow taking place in year n;

k - interest rate for conversion of future current flow into present;

s_a - degree of actualization (discount rate);

In general, economic and financial analyses are made with rates of actualization that are with some percentage point bigger of the current interest at the commercial banks. Rate of actualization makes devaluation of the cash flows that happen in distant future. It includes risk of losing the value, where in more risky projects or calculation with a current that has a greater risk of loss of its value, a calculation that is performed is with bigger actualization rate.

5.4.1. Method – Pay Back Period

With the method of payback period (PBP) is calculated the time necessary for the return of the amount of long-term invested resources. The shortest time is calculated T, for which the summarized net cash flow of present time covers the initial investment. For a project in a photovoltaic system where the initial investment happen in the first year, the payback period of the investment is the shortest time for which the condition is fulfilled.

$$NPV = -I_0 + \sum_{i=1}^{T} \frac{B_{ni}}{(1+s_a)^i} > 0$$

It is important to emphasize that the time (number of years) for pay back of the money should not be the same as the economic age of the investment project, which is, as a rule, longer. The selection of the deadline for pay back of the money is mainly based on the technological advancement. In fact, industrial companies are facing with shorter cycles of technologies and the growing competition and therefore is essential for t to be shorter because the fast pay back of the investment means bigger security and liquidity of the investment of the company that makes the investment. In other words, the projects with shorter payback period deadlines for the invested resources lowers the risk of the investment. It is believed that the risk degree grows proportionally with the duration of the deadline of payback period of investment.

Strong side of this method is simplicity and that is why this is one of the factors of its popularity in engineering sense. It can be used for comparison of several alternative projects, where effective is the one which has shorter deadline of payback period of return of invested resources, i.e., it has smaller t and vice versa, the project that has bigger t will be rejected.

This method is very popular among investors who would like to know long they can expect to return their invested resources. The method can give good indications for the cost-effectiveness of the investment in a home photovoltaic system. But if we talk about a complete and thorough economic analysis of the cost-effectiveness of investment in more complex and more expensive projects, more respected and used method is the method of net-present value, method of cost-benefit ratio and internal rate of profitability.

5.4.2. Method of Net Present Value

The calculation of Net Present Value is reduced to calculation of two equivalent cash flows, that are happening at a zero time, i.e., at the moment of the making of the analysis.

Net Present Value – NPV is the balance between the present value of all cash inflows or benefits and present value between all cash outflows of the project or costs (C) and cab be calculate according to the following formula:

If we suppose that the duration of the project is $T = n$ years , and annual cash flows are happening at the end of every year, the equation for calculating the net present value (NET) can be written in the next following form:

$$NPV = \sum_{i=0}^{n} \frac{B_i - C_i}{(1+s_a)^i} = \sum_{i=0}^{n} \frac{B_i}{(1+s_a)^i} - \sum_{i=0}^{n} \frac{C_i}{(1+s_a)^i} = \sum_{i=0}^{n} \frac{CF_i}{(1+s_a)^i}$$

where:

B_i - profit (benefits) that are made in the year *i*;

C_i costs that are made in the year *i*;

s_a - rate of actualization (discount rate);

The method of net present value is applicable to any type of projects. This method is theoretically supported and quantitative and enables comparison of cash flows at the same time points. Strength of the method is that it respects the overall age of the project.

It can be concluded that the net present value is an indicator of how big are the expected benefits reduced to present time, that will be received by undertaking the analyzed project. As such it can help the investor in projects for photovoltaic systems for production of electrical energy to estimate the expected profits during the whole economic duration of the project and to decide whether they are sufficient enough so that the project to be accepted as an investment.

From economic pint of view the project is acceptable for investment if the calculated net present value is positive. If the net present value is negative, then it is rejected as unacceptable investment. The criteria for acceptability of the project investments are presented in tab. 5.3

Tab.5.3. Criteria of acceptability of project according to the method of net present value

If...	So...	Then
NPV > 0	Investment will increase the income of the household	Project can be accepted
NPV < 0	Investment will decrease the income of the household	Project should be rejected
NPV = 0	Investment will not either increase nor decrease the income of the household	Decision cannot be reached based on this factor. Other factors should be taken into account and additional analyses performed.

This method can be used for comparison of projects which investment is approximately the same. The application of this method can help the investor correctly to point its investments in the right course and to realize a maximum profit.

When we talk about photovoltaic electrical plants, the investments are significant and the research show that bigger profit can be expected if the exploitation period is increased.

In literature are given several weak sides of the method of net present value, where we can mention:

1. Subjectivity of the estimation of actualization rate (discount rate) – too high or too low rate of actualization changes the essence for efficiency of the project as an investment
2. The criteria does not express good enough the impact of the duration of the operational period. Comparison of two projects with different exploitation period can be insecure
3. During ranking and selection of projects it does not express immediate different ratio of the investments. For example, project A with total benefit of 102 mil € and costs of 100 mil € has equal net present value as project B with total benefit of 12 mil. €, and overall value of costs 10 mil. €.

5.4.3. Calculation of Profitability Index - PI – Benefit/Cost ratio - BCR

Another indicator which is used for valorization of project is **Profitability Index – PI** or frequently known as **Benefit-Cost ratio – BCR**. With the application of this method the third weak side of the method net present value is overcome, which does not express well the relative ratio of the investments.

With the application of this method, profitability index of project A totals 1,02, while profitability index of project B totals 1,2. This is a good indicator that project B is better as an investment comparison with project A, which can be intuitively concluded due to increased risk for implementation of the same profit in project A as in project B but with 10 times bigger engaged capital.

Profitability index is calculated as quotient of present value of all cash income values and present value of all cash revenues in the project. It is calculated according to the following formula:

$$PI = \frac{B}{C} = \frac{\sum_{i=0}^{n} \frac{B_i}{(1+s_a)^i}}{\sum_{i=0}^{n} \frac{C_i}{(1+s_a)^i}}$$

If the investments are taking place only in the initial year, which is most frequent and real case during establishment of photovoltaic system for production of electrical energy, profitability index is calculated as a quotient between the present (actualized/discounted) value of the operational cash-flows and present value of initial investments.

$$PI = \frac{\sum_{j=1}^{n} \frac{B_{nj}}{(1+s_a)^j}}{I_0}$$

B_{nj} - net profit of the year , after the deduction of all costs, including taxes

I_0 - initial investment

s_a - Actualization rate rate(discount rate);

Obviously, investment is acceptable if profitability index is bigger than 1,0. If profitability index is lower than 1,0, investment is not acceptable for implementation. In case where profitability index is equal to 1, the project is on the border line of acceptability. The criteria for acceptability of the investment according to this criteria are presented in Tab. 5.4.

Tab.5.4. Criteria of acceptability of project according to profitability index (Benefit-Cost method)

If...	So...	Then...
PI > 1	Investment will increase the income of the household	Project can be accepted
PI < 1	Investment will decrease the income of the household	Project should be rejected
PI = 1	Investment will not either increase nor decrease the income of the household	Decision cannot be reached based on this factor. Other additional factors should be taken into account

In case of comparison of two projects using Benefit-Cost method, from economic aspect more acceptable is the in which profitability index is bigger.

5.4.4. Calculation of Internal Rate of Return - IRR

The Internal Rate of Return (return of investment) is one of the most useful methods for evaluation of projects. IRR is defined as rate of actualization where the present net present value is equal to zero.

$$NPV = \sum_{i=0}^{n} \frac{B_i}{(1+IRR)^i} - \sum_{i=0}^{n} \frac{C_i}{(1+IRR)^i} = \sum_{i=0}^{n} \frac{B_i - C_i}{(1+IRR)^i} = 0 \qquad (1)$$

The acceptability of the project according to the Internal Rate of Return criterion depends on the costs of the capital of the company. If the calculated IRR overpasses the percentage costs of the capital, then the investment is acceptable. If the calculated IRR is lower than the percentage costs of the capital, the investment in the project is rejected.

Very often as a comparison indicator can be used the following indicators:

1. Interest rate of assets that finance the project. According to the IRR method the projet is acceptable if the calculated IRR is bigger than the interest rate of resources that finace the project and
2. (Required Rate of Return). The calculate IRR to be bigger than the required rate of return.

The calculation if Internal Rate of Return, which is solution to the equation (1), requires knowledge of mathematics or some commercial software package. Most frequently is calculate iteratively with a selection of an initial solution which is equal to the required rate of return of the project or with the use of the tools GoalSeek or Solver which are part of the program Excel.

When two projects are compared with the help of their internal rate of return, from economic aspect more acceptable is the project that has bigger internal rate of return.

5.4.5. Case study – construction of photovoltaic plant

The construction of a single photovoltaic plant is a complex and unique technical project which is undertaken in order to produce clean electrical energy from renewable source. In order to realize that it is necessary several technical and economic conditions to be met. The very initial investment can be divided into several segments:

- Costs for provision of construction land
- Costs for obtaining the necessary documents and permit
- Designing and projecting the plant
- Equipment supply
- Bearing construction for the panels
- Installation of the equipment

In the further course of the project also must be predicted

- Costs for maintenance and servicing of the plant
- Insurance costs for the equipment

One of the most problematic items for the investor to make a decision for investment for construction of photovoltaic plant is the first item, provision of construction land for photovoltaic plant. In order to construct such plant, you must obtain a construction permit. Several documents are needed to obtain such permit but what is more crucial this procedure in the Republic of Macedonia can last too long which can be discouraging for the investor or he can decide to redirect the investment. In general, the overall procedure for provision of all necessary documents should be simplified and rationalized in order to stimulate the investments for construction of new photovoltaic plants.

Pic 5.1: Photovoltaic plants constructed in R. Macedonia

As a case study we will consider two photovoltaic plants: one with a power of **50,01 kWp,** and another with a power of 49,99 **kWp.** The estimated investment for both plants is 55.000 €. The production of electrical energy from these plants is paid in accordance with the existing FEED IN tariffs in 2017 in the Republic of Macedonia, which total 160 €/MWh for photovoltaic plants with power to 50 kWp and 120 €/MWh for photovoltaic plants with power over 50 kWp. The expected annual production of electrical energy from these two plants is estimated at E=**65 MWh.** The working period of the photovoltaic plant is estimated to 25 years.

First, for these two marginal values of the photovoltaic plants we will analyze the necessary time for return of the investment, depending on the discount rate s_a.

TABLE 5.2 – Necessary time for return of investment depending on the discount rate and installed power of the home photovoltaic system.

	0%	1%	2%	3%	4%	5%	6%
49,99 kW	5,92	6,16	6,42	6,71	7,04	7,42	7,85
50,01 kW	8,22	8,69	9,24	9,89	10,69	11,69	13,04

From the received results we can conclude that for real values of the discount rate, the return time of the investment in a photovoltaic plant up to 49,99 kWp totals from 7,5 – 8 years, which is an acceptable challenge for investment.

For photovoltaic plants with installed power of 50,01kWp, due to the lower subsided price of electrical energy is 11,5-13 years. The investment in bigger photovoltaic plants would be favorable due to the cheaper price that would be received for photovoltaic panels and enlarging of inverters, for which additional analyses should be made.

In continuation of this Guide are given analyses of net present value of a PV project depending on the discount rate for a period of 15 years, for which is guaranteed the validity of feed in tariffs.

The analyzes of the expected net present value depending on the discount rate are made for an exploitation period of 15 to 20 years. The results from the analyses are presented in tab.5.6 and tab.5.7 respectively. From the results it can be clearly seen the dependence of net present value in each of these projects from the discount rate. Therefore, during the analyses the investor should be provided with sufficient information and conduct more what-if analyses before he reached the final decision. The results also show that the investments generate profit and that due to existing legal regulations it is better to construct two or three smaller photovoltaic plants from 49,99 kWp rather than one bigger with installed power of 100 kWp or 150 kWp. Also can be noted that the exploitation period of 15 to 20 years positively impacts on the increase of the net present value of the project.

TABLE 5.3 – Dependence of net present value (€) in function of discount rate during exploitation period of 15 years

	0%	1%	2%	3%	4%	5%	6%
49,99 kWp	78.641	67.807	58.099,5	49.379,9	41.529,2	34.444,3	28.035,8
50,01 kWp	42.137	34.011	26.730	20.191	14.303,14	8.989,5	4.183

TABLE 5.4 – Dependence of net present value (€) in function of discount rate during exploitation period of 20 years

	0%	1%	2%	3%	4%	5%	6%
49,99 kWp	119.028	100.905	85.163	71.458	59.426	48.875	39.575
50,01 kWp	71.396	57.804	45.997	35.703	26.694	18.781	11.806

The analysis of the internal rate of return of a photovoltaic plant is over 50 kWp depending on the period of the exploitation and shows that if the exploitation period is between 15-20 years, the IRR is in the interval of 7-8%, at an increase of the exploitation period to 25 years the internal rate of return is 8,24%. If the photovoltaic plant is with power lower than 50 kWp, for a period of exploitation of 15-20 years IRR is within limits of 12-12,42%, whereas extending the exploitation period for additional five years does not lead to IRR increase. This clearly shows that with the increase of the exploitation period over 20 years of the photovoltaic plant the economic effects as a result of aging begin to decrease. More detailed results from the analyses are presented in Tab.5.8.

TABLE 5.5 – Dependence of internal rate of return from duration of exploitation period of a photovoltaic plant and its power

	10	15	16	17	18	19	20	25
49,99 kWp	9,34%	12,02%	12,20%	12,31%	12,38%	12,41%	12,42	12,18%
50,01+ kWp	3,15%	6,96%	7,30%	7,56%	7,76%	7,91%	8,03%	8,24%

From the analyses can be seen that according to the existing legal regulation in the Republic of Macedonia, where with feed in tariffs is subsided production of electrical energy from photovoltaic plants, it can enable a profitable investment. Also, according to this way for subsiding there is bigger promotion of one bigger photovoltaic plant on more subjects which installed power does not exceed 49,99 kWp.

Also the economic cost-effectiveness of the investment is expected in the future to be increases and interest in their installation due to:

- Lower specific cost price of installed kWp for photovoltaic electrical plant
- High prices of electrical energy
- Provision of green credits with interest rate closer to 0%.
- Need for provision of bigger own production from renewable source, etc.