UNIVERSITY OF PADUA
FACULTY OF ENGINEERING
MASTER'S DEGREE IN MECHANICAL ENGINEERING

PHOTOVOLTAIC SYSTEMS IN HUNGARY AND ITALY: COMPARISON FOR A POWER PLANT

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1.1 List of figures and tables

2 Abstract

The work shows a rapid view of the types of photovoltaic cells and their functioning. We considered the most common cells, like single crystal silicon (mono), polycrystal silicon (poly), amorphous silicon and some other alloys like Cadmium Tellurite (CdTe) and Copper Indium Gallium Selenide (CIGS).

Then we reported the Italian and Hungarian electric overall, showing graphics about national production and consumption. We displayed the shared quota for each type of electric resource, focusing on renewable sources.

After that we analyzed the cost of photovoltaic plants, pointing out trends, forecasts and prices for global, European, Italian and Hungarian market.

Using the software Sunny Design 3 we estimated the principal parameters for a photovoltaic power plant with the same capacity of Montalto di Castro plant. We showed the performance ratio and the annual energy yield for Venice and Budapest, considering four different alternatives of PV modules for each city. Then we assessed the total costs of investment and the annual fixed costs. Thus with the help of the software Matlab we implemented a script to estimate the revenue from feeding the grid taking into account the actual Fits and calculating the payback period for each station.

With another web application, Photovoltaic Geographical Information System, we estimated again the annual energy yield in the two cities for 3 types of PV module.

The comparison of the PV systems in Hungary and Italy through different software and the data obtained confirm that Italy is more advanced in the field and that the Italian Government promotes the use of renewable energies more than Hungary.

3 Introduction

The **Sun** can satisfy all our needs if we learn to benefit with intelligence the energy that constantly irradiates the Earth. It has shone in the sky for less than 5 billion years and, however, it is estimated that it has reached just half of its existence. During the last year the sun radiated energy towards the earth four thousand times and more than the entire world population consumption. It would be foolish not to take advantage of that, given the technological means available, considering that this energy source is **free, clean and inexhaustible** and can even free us from dependence on oil and other alternative unsafe and contaminant energy sources.

Oil price is higher and higher, and pollution is less sustainable, thus making renewable alternative energy sources an indispensable necessity. This energy can be used directly or converted into electricity. Appropriately treated and controlled, it is possible to sell the energy produced and feed the grid following national standards and rules. Economic incentives and the enormous progress of electronic technology allow the use of photovoltaic systems with sustainable costs. Equipment for direct connection on the net allows to take advantage of government incentives on the total energy produced. An increasing interest in the use of inverters without transformers, for direct connection to the network of photovoltaic systems, is growing, due to cost reductions and high returns.

The choice of a photovoltaic solution represents an investment of sure and easily calculable returns thanks to financing schemes provided by different national laws.

4 Photovoltaic cells

At present, most commercial photovoltaic cells are manufactured from silicon, which is the same material as sand. In this case, however, silicon is extremely pure. Other exotic materials like gallium arsenide are just at the beginning of the use in this field.

The four general types of silicon photovoltaic cells are:

- Single-crystal silicon
- Polycrystal silicon (also known as multicrystal silicon)
- Ribbon silicon
- Amorphous silicon (abbreviated as "aSi," also known as thin film silicon).

The terminology for different type of silicon crystalline is:

Descriptor	Symbol	Grain Size	Common Growth Techniques
Single crystal	sc-Si	>10cm	Czochralski (CZ) float zone (FZ)
Multicrystalline	mc-Si	1mm-10cm	Cast, sheet, ribbon
Polycrystalline	pc-Si	1µm-1mm	Chemical-vapour deposition
Microcrystalline	µc-Si	<1µm	Plasma deposition

4.1 Single crystal silicon

Most photovoltaic cells are single-crystal types. To make them, silicon is purified, melted, and crystallized into ingots. The ingots are sliced into thin wafers to make individual cells. It was the first form of photovoltaic technology and it started in the 1955. Because each wafer is cut from a single crystal, each cell is a uniform shade of dark blue. They are the most ordinary and largely available form of photovoltaic cell. During lab tests the sunlight panels receive was converted up to 25 per cent into electricity; in practice, however, their efficiency is near to 16 per cent. Typically, most of the cell has a slight positive electrical charge. A thin layer at the top has a slight negative charge.

Cells are attached to a base called a ‘backplane’. This is a layer of metal used to physically reinforce the cell and to provide an electrical contact at the bottom.

The top of the cell must be open to sunlight, so a slim grid of metal is put on the top instead of a continuous layer. The grid must be slim enough to allow relevant amounts of sunlight, but large enough to transfert relevant amounts of electrical energy.

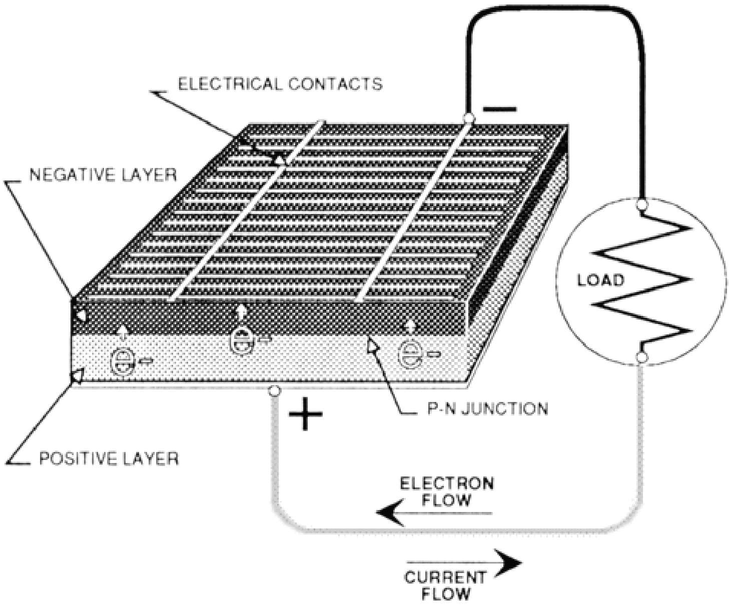


Figure 1 Operation of a Photovoltaic Cell

Light, including sunlight, is usually understood as particles called "photons." When the light hits a photovoltaic cell, photons get into the cell. When a photon hits an electron, it shoves off it, leaving an empty hole.

These electrons move towards the top layer of the cell. As photons continue to enter the cell, electrons continue to be shoved off and move to the top.

A flow of electrons starts if there is an electrical path outside the cell, between the top grid and the backplane of the cell. Loose electrons go out to the top of the cell and reach the external electrical circuit. Electrons from further back in the circuit move up to fill the empty electron holes.

Most cells produce a <u>voltage</u> of about one-half volt, regardless of the surface area of the cell. However, the larger the cell, the more <u>current</u> it will produce.

The cell is inside a circuit with some resistance, and that affects current and voltage. The amount of available light influences current production. The temperature of the cell influences its voltage. Having the knowledge about the electrical performance characteristics of a photovoltaic power supply is very important.

Single-crystalline wafers usually have better material characteristics but their cost is higher. Crystalline silicon has an ordered crystal structure, in which every atom stays in a determined position. Crystalline silicon shows predictable and uniform behaviour, but, due to the slow and precise manufacturing processes required, it is also the most expensive type of silicon.

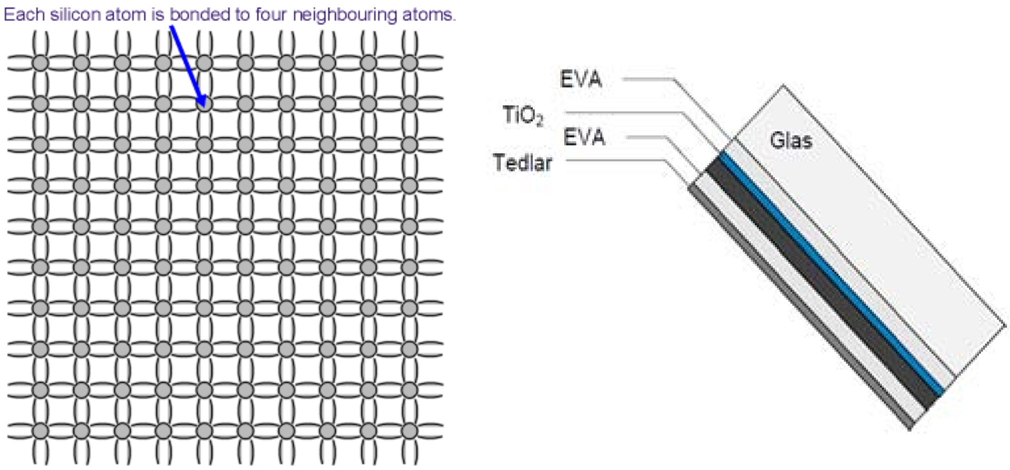


Figure 2 regular arrangement of silicon atoms in single-crystalline silicon and cell layered structure

The proper arrangement of silicon atoms in single-crystalline silicon causes a sharp band structure. Each silicon atom has four electrons in the external shell. Pairs of electrons from adjacent atoms are shared. In this way each atom shares four bonds with close atoms.

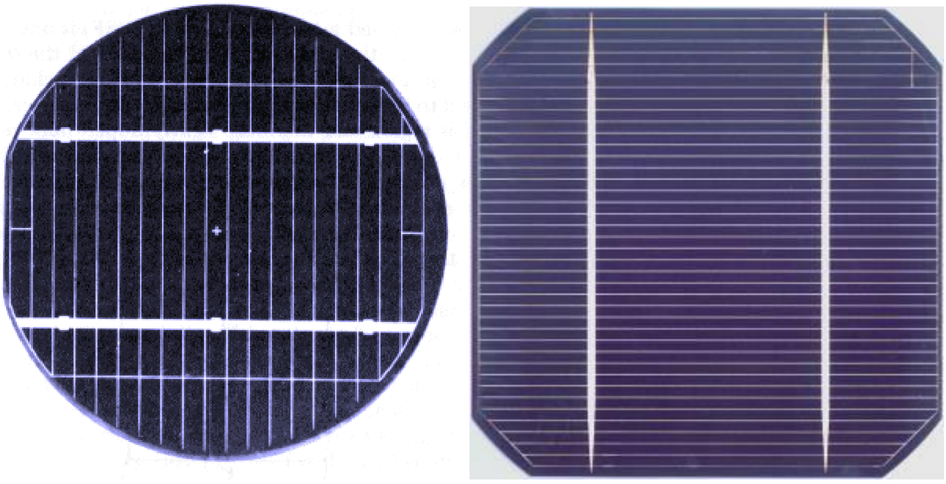


Figure 3 Single crystalline in circular or semi-square solar cells

Single crystalline silicon is ordinarily made as a large cylindrical ingot producing circular or semi-square solar cells. Initially the semi-square cells are circular but then edges are cut off so that a higher number of cells can be packed into a rectangular module, with a higher efficiency.

The important characteristics of this type of pv panels are:

- Conversion efficiency about 13%
- The technology used is solid and reliable
- Differentiated modules for costumers
- Few degradation of efficiency during a period of 100 hours
- Sometimes heavy weight
- The appearance is not usually the best
- Modules semi-flexible or rigid

4.2 Czochralski process

Single crystalline substrates are typically differentiated by the process by which they are made. The most widely used type of silicon wafer is Czochralski (Cz) wafers which are used for solar fields and integrated circuit industry. How to make a large single crystalline silicon ingot by the Czochralski process is described below, taken from pveducation.org

“The use of quartz crucibles in the manufacture of Cz substrates causes the incorporation of ppm (10^{18} cm^{-3}) oxygen into the silicon ingot. The oxygen itself is relatively benign but creates complexes with boron doping that degrades the carrier lifetime. N-type ingots fabricated with phosphorous dopants have similar oxygen concentrations but do not show the degradation effect nor do wafers with lower resistivity or gallium dopants.”

Figure 4 cylindrical section cut off to make wafers

4.3 Float Zone Silicon process

The CZ process is widely used for commercial substrates, but it has some disadvantages for high efficiency laboratory or niche market solar cells. CZ wafers hold inside a large amount of oxygen in the silicon wafer. Oxygen impurities decrease the lifetime in the solar cell, thus reducing the voltage, current and efficiency. Furthermore, the oxygen and complexes of the oxygen with other elements may become active at higher temperatures, making the wafers sensitive to high temperature processing. To remove these problems, Float Zone (FZ) wafers can be used.

In this process, a molten region is slowly passed along a rod or bar of silicon. Impurities in the molten region are incline to remain in the molten region rather than being integrated into the solidified region, thus permitting a very pure single crystal region after the molten region has passed. Due to the difficulty to grow large diameter ingots and the very high cost, FZ wafers are usually used for laboratory cells and rarely used in commercial production.

4.4 Polycrystalline silicon

Polycrystalline cells are manufactured and work in a similar way. The lower cost of the silicon used is the main difference. Techniques for the production of multicrystalline silicon are simpler than for single crystal material. However, the material quality of multicrystalline material is lower than that of single crystalline material. This is due to the presence of grain boundaries. Grain boundaries introduce high localized regions of recombination due to the introduction of extra defect energy levels into the band gap, and this reduces the overall minority carrier lifetime from the material. In addition, grain boundaries reduce solar cell performance by blocking carrier flows and supplying shunting tracks for current flow across the *p-n* junction. Polycrystalline cell manufacturers state that the low cost of the material produces more benefits, even if the efficiency is lower.

Figure 5 Slab of multicrystalline silicon after growth

Grain sizes must be on the order of at least a few millimeters to avoid significant recombination losses at grain boundaries. This allows also single grains to extend from front to back of the cell, providing less resistance to carrier flow and generally decreasing the length of grain boundaries per unit of cell. For these reasons multicrystalline material is widely used for commercial solar cell production.

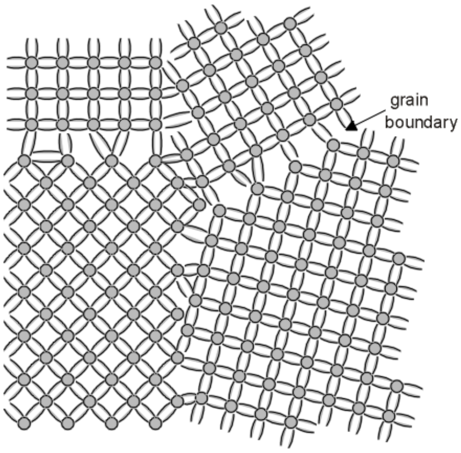


Figure 6 boundary between two crystal grains

At the boundary between two crystal grains, the bonds are strained, degrading the electronic properties.

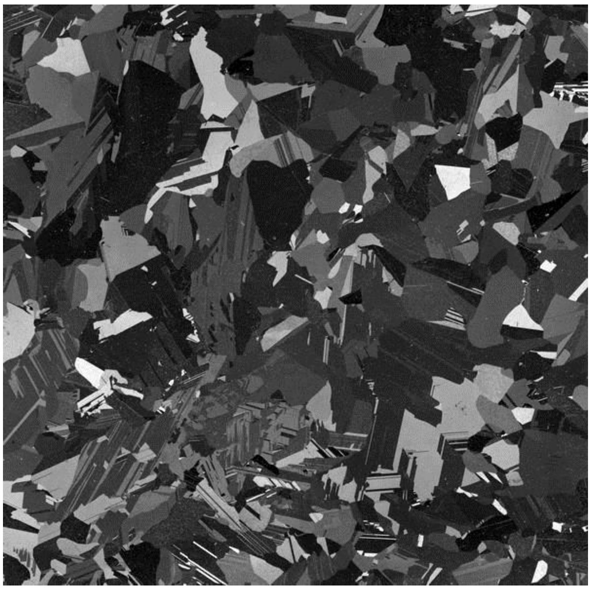


Figure 7 A 10 x 10 cm^2 multicrystalline wafer

The wafer has been textured so that grains of different orientation show up as light and dark.

4.5 Ribbon silicon (polycrystal)

The process of ribbon-type photovoltaic cells, in opposition to the crystalline type which is made from an ingot, is to grow a ribbon from the molten silicon. These cells operate in the same way as single and polycrystal cells.

The anti-reflective coating used on most ribbon silicon cells gives them a prismatic rainbow appearance.

4.6 Amorphous or thin film silicon

The previous three types of silicon used for photovoltaic cells have a distinct crystal structure. The amorphous silicon has no structure. Amorphous silicon is usually called thin film silicon and sometimes abbreviated "aSi".

Amorphous silicon units are made by depositing very thin layers of vaporized silicon in a vacuum onto a support of glass, plastic, or metal.

Amorphous silicon cells are produced in a variety of colours.

They are made up in long rectangular "strip cells” because their size can be several square yards. These are connected in series to form "modules."

Multiple layers can be deposited because the layers of silicon allow some light to pass through.
The photovoltaic cell can produce more electricity because of multiple layers.
Each layer can be set to receive a particular band of light wavelength.

The performance of amorphous silicon cells can achieve not more than 15% upon initial exposure to sunlight. This drop takes around six weeks. Manufacturers usually publish post-exposure performance data, so if the module has not been exposed to sunlight, its performance will exceed specifications at first.

The efficiency of amorphous silicon photovoltaic modules is less than half that of the other three technologies. This technology has the potential of being much less expensive to produce than crystalline silicon technology.

For this reason, there are a lot of investigations to improve amorphous silicon performance and producing processes. This type of PV module suits rural electrification, solar home system, grid connected system, solar water pump system or cathodic protection.

The important characteristics of this type of pv panels are:

- Make multi-substrates (also flexible)
- Good appearance
- Possibility to create pv panels which can substitute architectural elements (tiles, sheets)
- Degradation of the efficiency in the first 100 hours of 10-15%
- After the first degradation efficiency about 6%
- Double space for the same electricity generation compared to Si crystalline

4.7 Multi-junction cells

Cells made from multiple materials have multiple band gaps. So, it will respond to multiple light wavelengths and some of the energy that would otherwise be lost to relaxation as described above, can be captured and converted.

For example, if one had a cell with two band gaps in it, one tuned to red light and the other to green, then the extra energy in green, cyan and blue light would be lost only to the band gap of the green-sensitive material, while the energy of the red, yellow and orange would be lost only to the band gap of the red-sensitive material. Making similar analysis to those executed for single-band gap modules, it can be proved that the perfect band gaps for a two-gap module are at 1.1 eV and 1.8 eV.

Light of a particular wavelength does not interact at all with materials that are not a multiple of that wavelength. This means that one can do a multi-junction cell by making layers of the different materials on top of each other. Usually the shortest wavelength layer is put on the "top" and other increasing through the body of the cell. As the photons have to cross the cell to achieve the correct layer to be absorbed, to collect the electrons generated at each layer we need to use transparent conductors.

Usually alloys are used for the multi-junctions cells. They provide more efficiency and in this way bandgaps can be modified. There are lots of types of alloys used for the photovoltaic parks, and they are used not only in the terrestrial field, but also in the space. An example of alloy is with Germanium.

4.7.1 Germanium substrate

Germanium wafers offer high strength at minimal thickness and concur busily to the overall cell performance. Germanium substrates are enforced in III-V triple-junction solar cells, a solution that nowadays is widely used to power virtually all satellites placed in orbit, as well as in terrestrial solar cells to power photovoltaic plant systems. There is only one big supplier of Germanium pv and it is Umicore (USA).

Thanks to the closely matching thermal and crystallographic properties of Germanium and Gallium Arsenide, Germanium substrates provide an interesting alternative for the epitaxial growth and layer transfer of III-V compounds. For proper nucleation, the wafers are precisely cut off along the appropriate direction and have been cleaned.

Umicore is one of the best supplier for EPI-ready, dislocation free Germanium substrates for III-V multi-junction solar cells for **space** applications. Germanium technology has gradually replaced Si-based solutions. Germanium is the preferred substrate because it provides high strength at minimal thickness also with hard radiation. Advanced triple junction solar cells with Germanium substrates offer the best end-of-life performance over weight ratio.

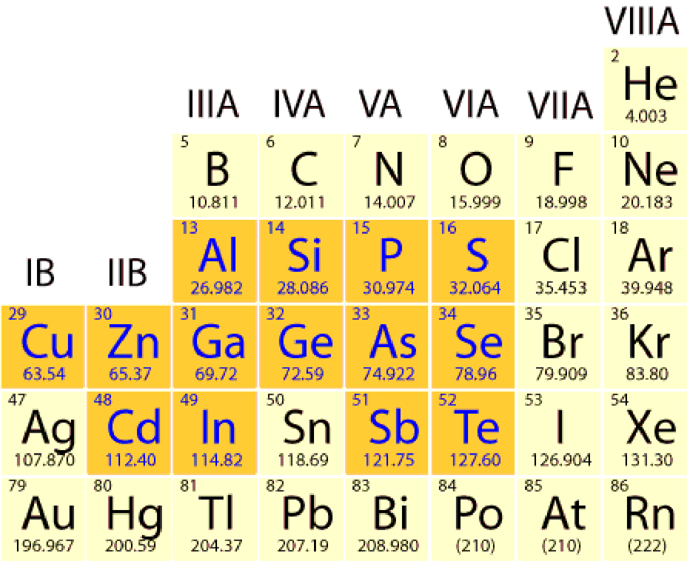
The high-efficiency solar cells on Germanium can also provide good application in the field of **terrestrial** photovoltaic, whereby the cells are integrated in a concentrator system based on refractive or reflective optics. Under concentration, the most fully-developed solar cells on Germanium have a conversion efficiency of 41 % and open the way for sustainable energy generation and lower cost.

Figure 8 monocrystalline EPI-ready germanium wafers

Germanium offers an interesting alternative to silicon. It has larger excitonic Bohr radius compared to silicon because it has smaller electron effective mass and a larger dielectric constant. This results in a more prominent quantum confinement effect thus allowing the possibility of engineering the effective band gap over a large range. More importantly, wafers can be fabricated below 400 °C whereas Si nanocrystals are typically fabricated at much higher temperature ~1100 °C. The low temperature growth of Ge nanocrystals offers significant advantages for processing compatibility and for reduced processing costs.

4.7.2 Alloys semiconductors

The atoms in a semiconductor are materials from either group IV of the periodic table, or from a combination of group III and group V (called III-V semiconductors), or of combinations from group II and group VI (called II-VI semiconductors). Because different semiconductors are made up of elements from different groups in the periodic table, properties vary between semiconductors. Silicon, which is a group IV, is the most commonly used semiconductor material as it forms the basis for integrated circuit (IC) chips and is the most mature technology and most solar cells are also silicon based.



IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
							2 He 4.003
		5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.183
		13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.064	17 Cl 35.453	18 Ar 39.948
29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.922	34 Se 78.96	35 Br 79.909	36 Kr 83.80
47 Ag 107.870	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.904	54 Xe 131.30
79 Au 196.967	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.980	84 Po (210)	85 At (210)	86 Rn (222)

Table 1 Section from the periodic table with more common semiconductor materials in blue

A semiconductor can be either of a single element, such as Si or Ge, a compound, such as GaAs, InP or CdTe, or an alloy, such as $Si_xGe_{(1-x)}$ or $Al_xGa_{(1-x)}As$, where x is the fraction of the particular element and ranges from 0 to 1.

There are lots of types of alloy semiconductors, and in these recent past years there has been a big research about that. This is due to the fact that with alloys the proper band gap for our goals can be found. Some examples of alloy semiconductors are listed below:

4.7.3 Aluminium gallium arsenide ($Al_xGa_{1-x}As$)

Aluminium gallium $Al_xGa_{1-x}As$ is a semiconductor material with very nearly the same lattice constant as GaAs, but with a larger band gap. The *x* in the formula above is a number between 0 and 1 (this indicates an arbitrary alloy between GaAs and AlAs). The band gap varies between 1.42 eV (GaAs) and 2.16 eV (AlAs). For $x < 0.4$, the band gap is direct. The formula *AlGaAs* should be considered an abbreviated form of the above, rather than any particular ratio. Aluminium gallium arsenide is used as a barrier material in GaAs based heterostructure devices. The AlGaAs layer confines the electrons to a gallium arsenide region (QWIP). AlGaAs with composition close to AlAs is almost transparent to sunlight. It is used in GaAs/AlGaAs solar cells.

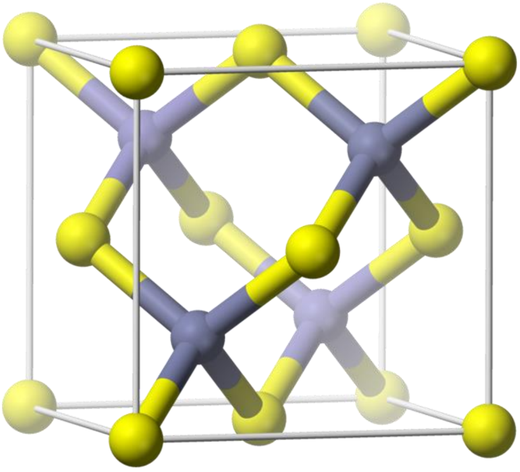


Figure 9 The crystal structure of aluminium gallium arsenide

The toxicology of AlGaAs has not been fully investigated. Dust is an irritant to skin, eyes and lungs. The environment, health and safety aspects of aluminuim gallium arsenide sources and industrial hygiene monitoring studies of standard MOVPE sources have been recently reported in a review.

Indium gallium arsenide is a ternary alloy of indium, gallium and arsenic. It's a well-developed material.

The band gap energy of GaInAs can be determined from the peak in the photoluminescence spectrum, provided that the total impurity and defect concentration is less than $5\times10^{16}cm^{-3}$. The band gap energy depends on temperature and increases as the temperature decreases for both n-type and p-type samples. The band gap energy at room temperature is 0.75 eV and lies between that of Ge and Si.

Single crystal epitaxial films of InGaAs can be deposited on a single crystal substrate of III-V semiconductor having a lattice parameter close to that of the specific gallium indium arsenide alloy to be synthesized. Three substrates can be used: GaAs, InAs and InP. A good match between the lattice constants of the film and substrate is required to maintain single crystal properties and this limitation permits small variations in composition on the order of a few per cent. Therefore the properties of epitaxial films of GaInAs alloys grown on GaAs are very similar to GaAs and those grown on InAs are very similar to InAs, because lattice mismatch strain does not generally permit significant deviation of the composition from the pure binary substrate. Ga0.47In0.53As is the alloy whose lattice parameter matches that of InP at 295 K.

GaInAs lattice-matched to InP is a semiconductor with properties quite different from GaAs, InAs or InP. It has an energy band gap of 0.75 eV, an electron effective mass of 0.041 and an electron mobility close to 10,000 $cm^2 \cdot V^{-1} \cdot s^{-1}$ at room temperature, all of which are more favorable for many electronic and photonic device applications when compared to GaAs, InP or even Si.

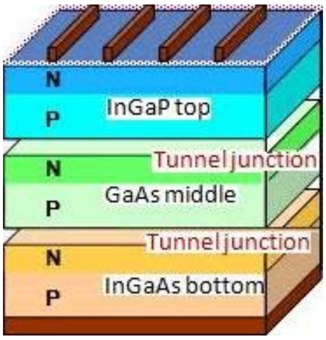


Figure 10 Cell's bottom indium gallium arsenide layer

4.7.4 Indium gallium phosphide

Indium gallium phosphide (InGaP) is a semiconductor composed of indium, gallium and phosphorus. It is used mainly in HEMT and HBT structures, but also for the fabrication of high efficiency solar cells used for space applications. Gallium indium phosphide has a tendency to grow as an ordered material rather than a truly random alloy.

Other applications of gallium indium phosphide include semiconductor lasers such as vertical-cavity surface-emitting laser for plastic optical fibers and high energy junction on double and triple junction photovoltaic cells.

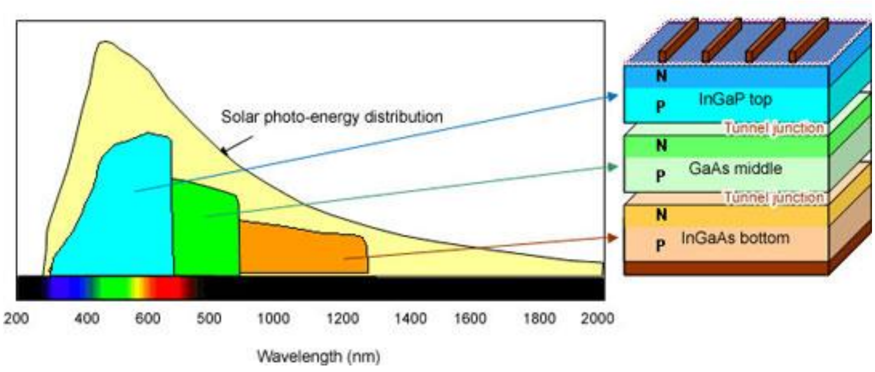


Figure 11 Wavelength sensitivity of triple-junction cell for the InGaP, GaAs and InGaAs parts of the structure

The basic structure of the latest triple-junction compound solar cell uses proprietary Sharp technology that enables efficient stacking of the three photo-absorption layers, with an InGaP (indium gallium phosphide) top layer, GaAs (gallium arsenide) middle layer and InGaAs (indium gallium arsenide) bottom layer, separated by tunnel junctions.

4.7.5 Copper indium gallium selenide

CIGS is a I-III-VI_2 compound semiconductor material composed of copper, indium, gallium, and selenium. The material is a solid solution of copper indium selenide and copper gallium selenide, with a chemical formula of $CuIn_xGa_{(1-x)}Se_2$, where the value of x can vary from 1 (pure copper indium selenide) to 0 (pure copper gallium selenide).

The bandgap varies continuously with *x* from about 1.0 eV (for copper indium selenide) to about 1.7 eV (for copper gallium selenide).

A copper indium gallium selenide solar cell is a thin film solar cell that is manufactured by depositing a thin layer of copper, indium, gallium and selenide on glass or plastic backing, along with electrodes on the front and back to collect current. Because the material has a high absorption coefficient and strongly absorbs sunlight, a much thinner film is required than that of other semiconductor materials.

CIGS is one of the mainstream thin-film PV technologies. CIGS layers are thin enough to be flexible, allowing them to be deposited on flexible substrates.

Fig 12 Thin film of flexible CIGS

However, as all these technologies normally use high-temperature deposition techniques, the best performance normally comes from cells deposited on glass.

CIGS has a high absorption coefficient of more than 10^5/cm for 1.5 eV and higher energy photons. The National Renewable Energy Laboratory declares that CIGS solar cells can achieve efficiencies around 20%. That is a primate in the thin-film solar cell. Higher efficiencies (around 30%) can be obtained by using optics to concentrate the incident light. The use of gallium increases the optical band gap of the CIGS layer as compared to pure CIS.

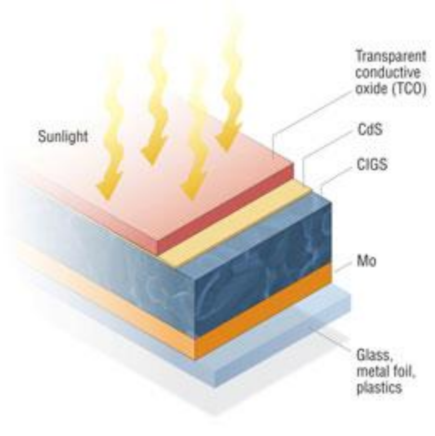


Fig 13 CIGS photovoltaic cell structure

4.7.6 Cadmium telluride

Cadmium telluride is a thin semiconductor layer designed to absorb and convert sunlight into electricity. It is one of the cheapest solar cells in the market of photovoltaic.

On a lifecycle basis, CdTe photovoltaic has the smallest carbon footprint, lowest water use and shortest energy payback time of all solar technologies. In 2013 it had the 5% of the worldwide photovoltaic production, and that amount is more than half of the thin film solar cell technology.

In 2014 this technology achieved from 16.1% up to 17.0% of efficiency, and it was developed by First Solar. Since CdTe has the optimal band gap for single-junction devices, efficiencies close to 20% may be achievable in practical CdTe cells.

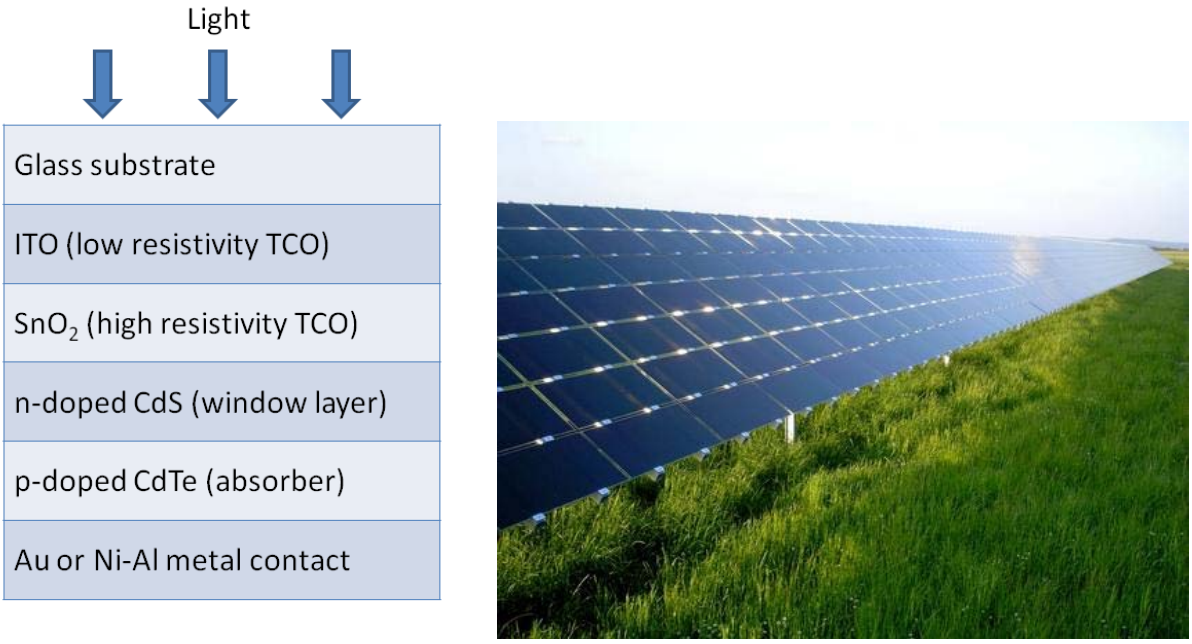


Figure 14 Cross-section of a CdTe thin film solar cell and CdTe photovoltaic array

5 Italian electric overall

In Italy, the issue of energy supply is always of great interest because this country depends on foreign imports for 83% of its primary energy needs.

5.1 The strong dependence on fossil fuels in the primary energy mix

In 2010, Italian gross demand of primary energy amounted to 2183.9 TWh (187.79 Mtep,). 82.7% of the requirement was satisfied by fossil fuels: more specifically, oil covered 38.5% of the total, natural gas 36.2% and coal 8%. The energy mix was completed by renewable sources (265.8 TWh, 12.2%), constituted mainly by hydroelectric power (67.6%), and by the net import of electricity (113 TWh, 5.1%). In Italy, natural gas is widely employed in electricity production, the conversion concerns roughly a third (36%) of the primary input, causing a greater dependence from this kind of source compared to other European countries. Almost all the remaining consumption occurs in the industrial sector (18.8%) and for heating of homes and commercial/service buildings (40.8%). Regarding oil, only 5.5% is converted into electric power, while 54.7% is employed by the transportation sector. Coal is mainly used to produce electricity (71.5%) and the residual part is given to the industries. It is worth noting that 82% of the Italian primary energy supply comes from imports, resulting in a strong dependence on foreign fossil fuels. The domestic production of fossil fuels amounts to a total of 142 TWh; 56% of the domestic production consists of gas (80.1 TWh, 10.1% of the entire gross availability of natural gas) and 42% of oil (59.1 TWh, 7% of the total amount); including the increasing contribution of renewable sources (246 TWh), the total internal production constitutes 18% of the whole energy mix.

5.2 Electrical energy demand in Italy in 2013

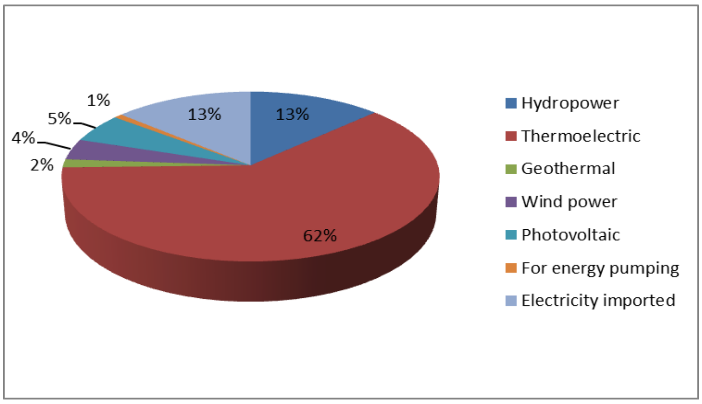


Figure 15 Consumption of electric energy in Italy (Terna 2012)

In 2013 the demand of electric energy was 318.5 million KWh. The demand of energy was satisfied by the 86.8 % from the national production, for an amount of 276.3 billion KWh, considering pumping energy and auxiliaries. The remain amount (13.2%, 42.1 billion KWh) was covered from the import from other countries, with a reduction of 2,2% previous year. The consumption of the total electric energy in 2013 was 297.3 billion KWh.

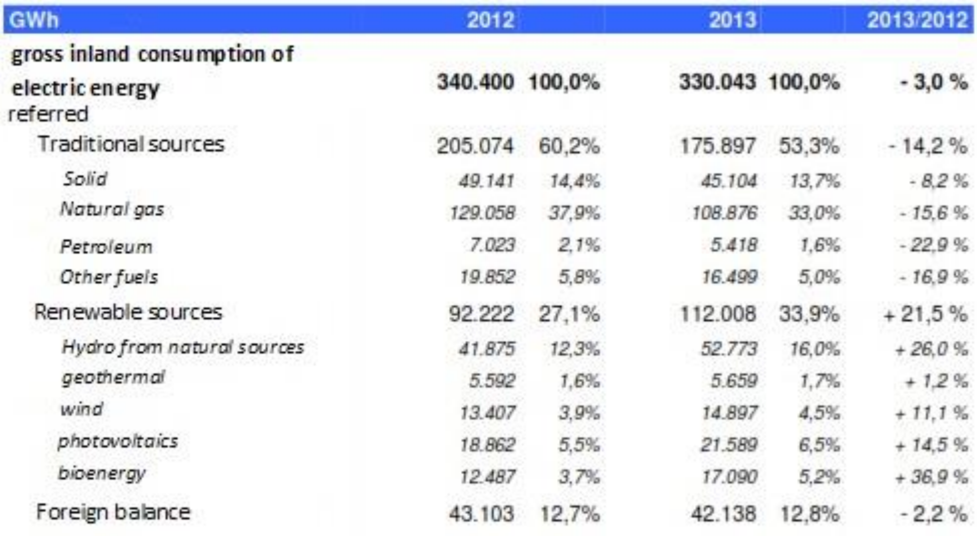
5.3 Distribution of consumption of energy

In the industrial section the amount is 124.9 billion of KWh (42%). For the auxiliaries it is 99.8 billion KWh. For domestic uses 67 billion KWh and for agriculture 5.7 billion KWh.

There is an increment of the hydroelectric power (+24.7%) with 54.7 billion KWh. The production from renewable sources (hydric, eolic, photovoltaic, geothermic and bioenergy) is increased about 21.5 %. There was a big increase for the photovoltaic energy (+14.5%) with an amount of 21.6 billion KWh. Also the eolic energy had an increase of +11.1% with an amount of 14.9 billion KWh. For the bioenergy the increase was +36.9% with 17.1 billion KWh.

The production from the thermic sources was the 65.5 % of the total amount of the national production. The most fuel used for the production is the natural gas with a 57.8 % of the total amount.

Table 2 Italian consumption of electric energy in 2012 and 2013 (Terna 2013)



GWh	2012		2013		2013/2012
gross inland consumption of electric energy referred	**340.400**	**100,0%**	**330.043**	**100,0%**	**- 3,0 %**
Traditional sources	205.074	60,2%	175.897	53,3%	- 14,2 %
Solid	*49.141*	*14,4%*	*45.104*	*13,7%*	*- 8,2 %*
Natural gas	*129.058*	*37,9%*	*108.876*	*33,0%*	*- 15,6 %*
Petroleum	*7.023*	*2,1%*	*5.418*	*1,6%*	*- 22,9 %*
Other fuels	*19.852*	*5,8%*	*16.499*	*5,0%*	*- 16,9 %*
Renewable sources	92.222	27,1%	112.008	33,9%	+ 21,5 %
Hydro from natural sources	*41.875*	*12,3%*	*52.773*	*16,0%*	*+ 26,0 %*
geothermal	*5.592*	*1,6%*	*5.659*	*1,7%*	*+ 1,2 %*
wind	*13.407*	*3,9%*	*14.897*	*4,5%*	*+ 11,1 %*
photovoltaics	*18.862*	*5,5%*	*21.589*	*6,5%*	*+ 14,5 %*
bioenergy	*12.487*	*3,7%*	*17.090*	*5,2%*	*+ 36,9 %*
Foreign balance	43.103	12,7%	42.138	12,8%	- 2,2 %

Table 3 Italian production of electric energy in 2012 and 2013 (Terna 2013)

GWh	2012	2013	2013/2012
Gross production	**299.275,9**	**289.803,2**	**-3,2%**
- hydro	43.854,0	54.671,6	24,7%
- thermal	217.561,4	192.986,8	-11,3%
- geothermal	5.591,7	5.659,2	1,2%
- wind	13.407,1	14.897,0	11,1%
- photovoltaics	18.861,7	21.588,6	14,5%
consumption of auxiliary services	**11.470,4**	**10.970,5**	**-4,4%**
Net production	**287.805,5**	**278.832,6**	**-3,1%**
- hydro	43.256,4	54.068,4	25,0%
- thermal	207.327,3	183.403,9	-11,5%
- geothermal	5.251,7	5.320,1	1,3%
- wind	13.333,0	14.811,6	11,1%
- photovoltaics	18.637,0	21.228,7	13,9%
For pumping	**2.689,1**	**2.495,2**	**-7,2%**
For consumption	**285.116,4**	**276.337,4**	**-3,1%**

5.4 Focus on renewable sources

Solar

Italy is one of the world’s largest producers of electricity from solar power with an installed photovoltaic capacity of 17,968 MW at the end of 2013 and 603,196 plants in operation as at the end of 2013.The total energy produced by solar power in 2013 was 21,299 GWh, about 6.7% of the total electricity demand of 332.3 TWh. The installed photovoltaic capacity, compared to that of the previous year, grew of 29% in 2012 and 9% in 2013.

As for December 2012, the installed capacity was approaching 17 GW, with such an important production that several gas turbine power plants started to operate at half their potential during the day. This field gave employment to about 100,000 people, especially in design and installation.

Wind energy

Best wind resources in Italy are located in the south, particularly the Apennine Mountains, on the coast and in the major islands. Also the relatively large off-shore potential is located in the southern coastal areas and islands. This means that a large share of non-programmable electricity would be fed into the grid in such areas. Unfortunately, the power grid in these areas is poor for historical reasons, since these areas are less densely populated and larger consumption centers are located in the North.

Biomass

The current resources of biomasses, which derive principally from agricultural and forest residues, firewood, livestock muck and the biodegradable portion of solid urban waste, can achieve not more than 20-25 Mtoe/year. More quantities of raw material can be generated by renewing the non-food agricultural sector and the forest sector, together with the recovery of abandoned agro-wood territories, which extend for at least 2 million hectares.

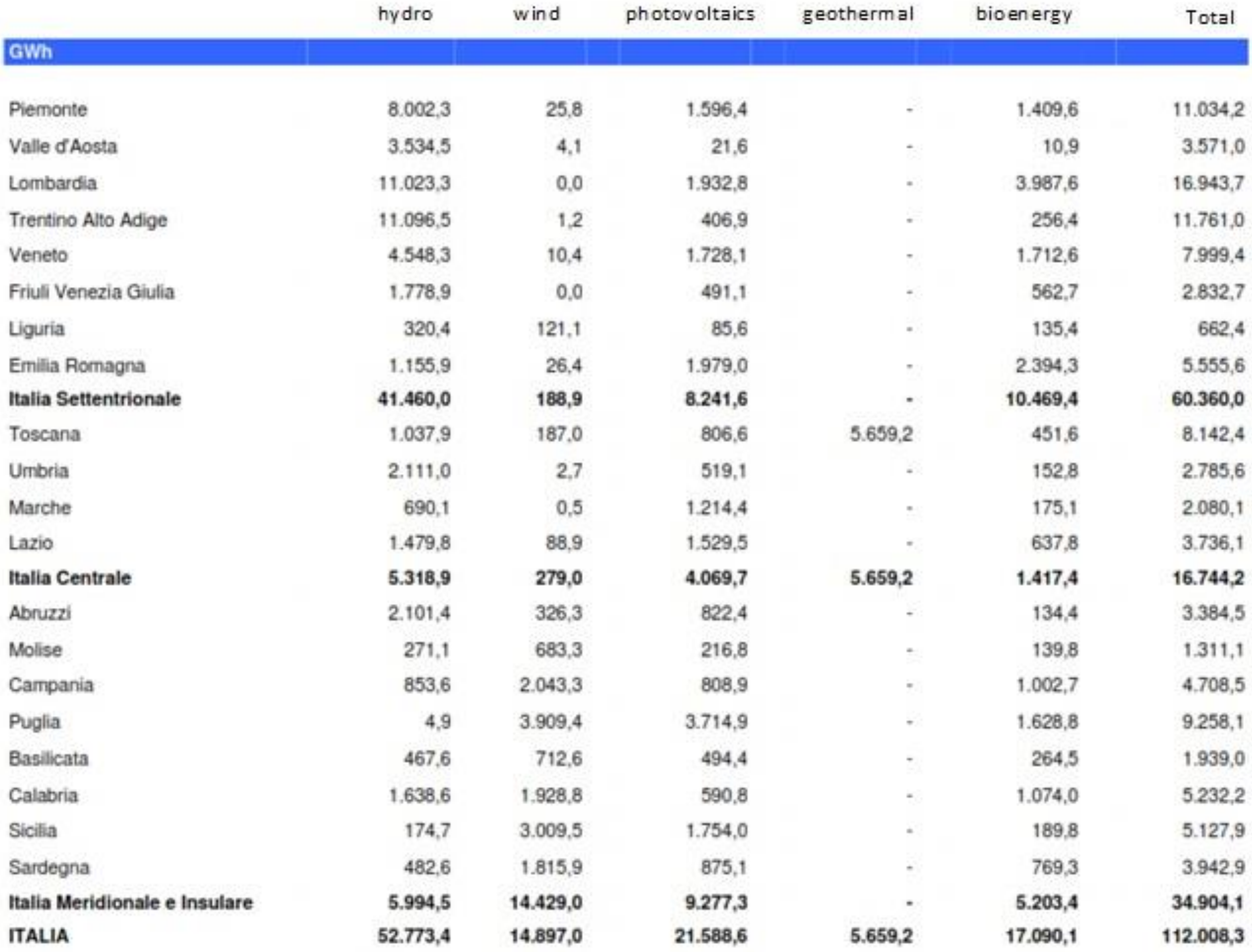
Hydro

Since long time ago water energy has been the major national energy source in Italy and the primary resource alternative to fossil fuel sources. There are more than 2000 hydroelectric power plants mainly in the Alpine region, of which 300 have a production capacity of more than 10 MW. The 80% of electricity is produced in large plants. The other 20% is covered with small and medium plants under 10 MW, which were developed and added in recent years. The hydroelectric power plants in 2007 achieved the 72% of the electricity production from renewable sources. However, its potential has been fully exploited.

Geothermal

The geothermal potential is remarkable economically speaking. The high temperature resources (>150° C) are gathered in the Apennines in Tuscany, Latium and Campania and on some volcanic islands of the Tyrrhenian Sea. The medium and low temperature (< 150°C) sources instead can be found on large areas of the national territory. The high-temperature resources are employed for the production of electricity and direct uses, while the medium and low temperature resources can be used mostly for heating systems.

Table 4 Renewable sources per region (Terna 2013, GWh)



GWh	hydro	wind	photovoltaics	geothermal	bioenergy	Total
Piemonte	8.002,3	25,8	1.596,4	-	1.409,6	11.034,2
Valle d'Aosta	3.534,5	4,1	21,6	-	10,9	3.571,0
Lombardia	11.023,3	0,0	1.932,8	-	3.987,6	16.943,7
Trentino Alto Adige	11.096,5	1,2	406,9	-	256,4	11.761,0
Veneto	4.548,3	10,4	1.728,1	-	1.712,6	7.999,4
Friuli Venezia Giulia	1.778,9	0,0	491,1	-	562,7	2.832,7
Liguria	320,4	121,1	85,6	-	135,4	662,4
Emilia Romagna	1.155,9	26,4	1.979,0	-	2.394,3	5.555,6
Italia Settentrionale	**41.460,0**	**188,9**	**8.241,6**	**-**	**10.469,4**	**60.360,0**
Toscana	1.037,9	187,0	806,6	5.659,2	451,6	8.142,4
Umbria	2.111,0	2,7	519,1	-	152,8	2.785,6
Marche	690,1	0,5	1.214,4	-	175,1	2.080,1
Lazio	1.479,8	88,9	1.529,5	-	637,8	3.736,1
Italia Centrale	**5.318,9**	**279,0**	**4.069,7**	**5.659,2**	**1.417,4**	**16.744,2**
Abruzzi	2.101,4	326,3	822,4	-	134,4	3.384,5
Molise	271,1	683,3	216,8	-	139,8	1.311,1
Campania	853,6	2.043,3	808,9	-	1.002,7	4.708,5
Puglia	4,9	3.909,4	3.714,9	-	1.628,8	9.258,1
Basilicata	467,6	712,6	494,4	-	264,5	1.939,0
Calabria	1.638,6	1.928,8	590,8	-	1.074,0	5.232,2
Sicilia	174,7	3.009,5	1.754,0	-	189,8	5.127,9
Sardegna	482,6	1.815,9	875,1	-	769,3	3.942,9
Italia Meridionale e Insulare	**5.994,5**	**14.429,0**	**9.277,3**	**-**	**5.203,4**	**34.904,1**
ITALIA	**52.773,4**	**14.897,0**	**21.588,6**	**5.659,2**	**17.090,1**	**112.008,3**

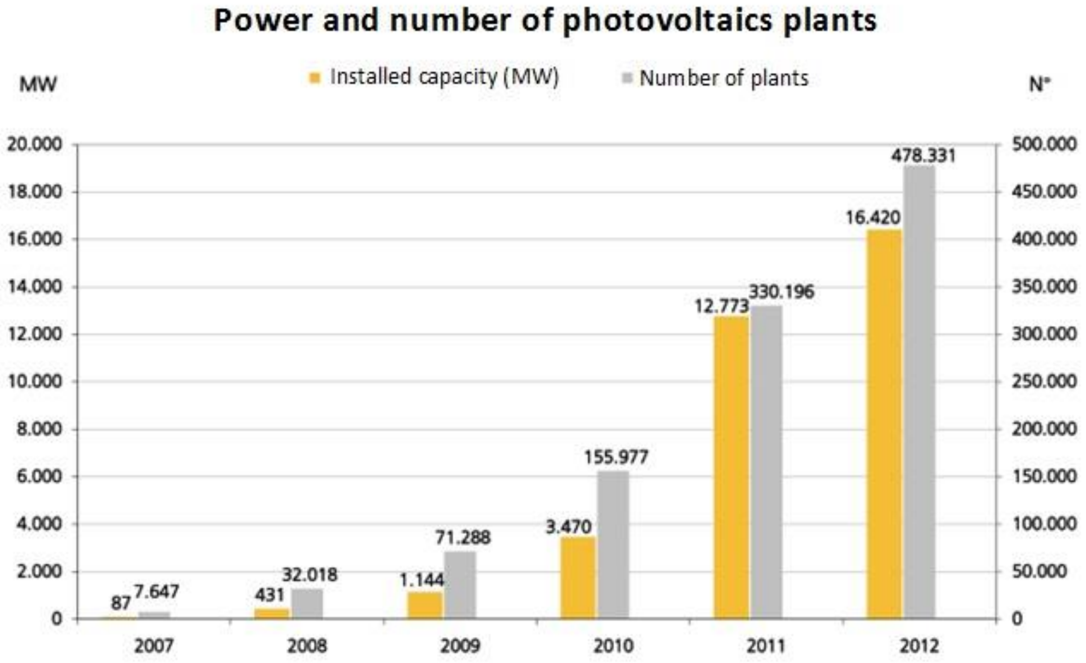


Figure 16 Power and number of photvoltaics plants (Terna 2012)

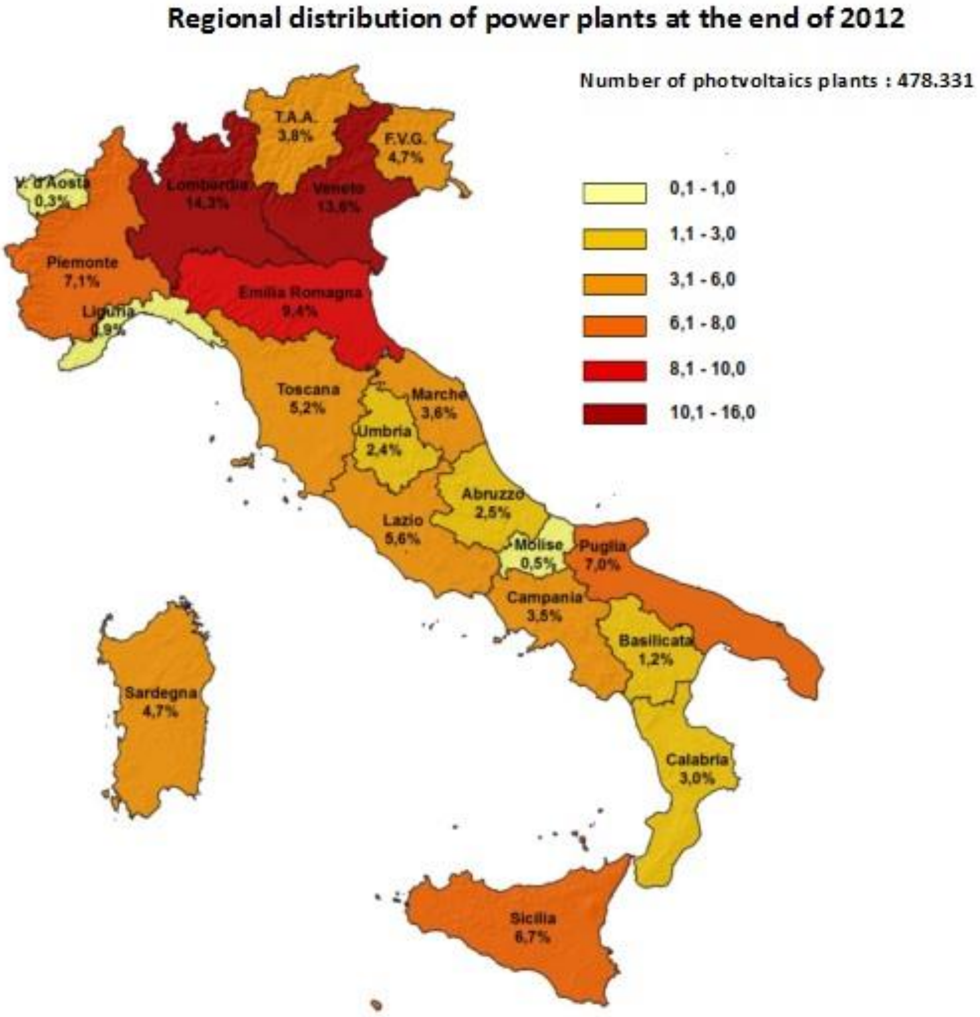


Figure 17 Regional distribution about power plants (Terna 2012)

6 Hungarian electric overall

6.1 Introduction

For Hungary the main electric power come from fossil fuels. In 2009 the amount was about 75% of the total, and it comes from Russia, essentially through a single transport route (the Brotherhood pipeline), which results in a vulnerable situation for Hungary in terms of the security of supply.

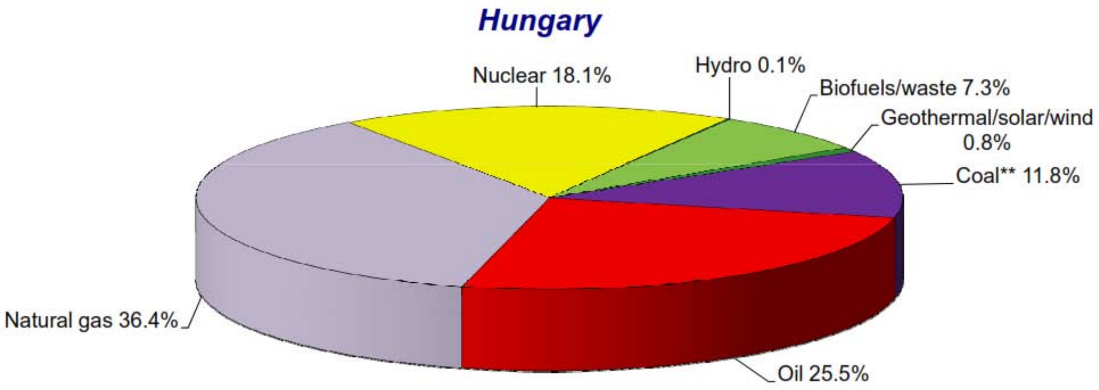


Figure 18 Hungary's primary energy use 2012 (IEA)

The current Hungarian gas storage capacity exceeds 50 percent of the annual natural gas consumption (5.8 billion m3). According to the requirements of the IEA and the EU, crude oil and oil products are stored at a quantity equivalent to at least 90 days of consumption.

Renewable energy in final energy consumption was 6.6% in 2008 (7.4% in 2010 is foreseen by the NREAP (national renewable energy action plan)). Hungary ranks in the lowest third among EU member states (2008 EU-27 average: 10.3 percent) lagging behind even the countries of a similar level of economic development (Bulgaria 9.4 percent, Czech Republic 7.2 percent, Poland 7.9 percent, Romania 20.4 percent and Slovakia 8.4 percent).

The reason is because neighbour countries have more favourable and better hydro energy potential which is exploited very well, counter Hungary. On the basis of Directive 2009/28/EC14, this indicator should reach 13 percent in Hungary by 2020.

In terms of the utilization of renewable energy sources, Hungary has so far failed to make full use of the available domestic potential. According to the findings of a survey conducted in

2005 and 2006 by the Renewable Energy Subcommittee of the Hungarian Academy of Sciences, the theoretical annual renewable energy potential is around 720000 GWh, the full exploitation of which can never be achieved.

Table 5 Hungary's fossil fuel resources

Energy carrier	Geological resources (2010)	Extractable reserves (2010)	Production (2008)	Production (2009)
	(million tons)			
Crude oil	209,4	18,4	0,81	0,80
Black coal	1625,1	1915,5	-	-
Brown coal	3198,0	2243,8	1,39	0,95
Lignite	5761,0	4356,3	8,04	8,03
Uranium	26,8	26,8	-	-
	billion m^3			
Natural gas	3563,0	2392,9	2,88	3,12

One of the most important sources in the past was coal. After 1960s the extraction of coal was reduced gradually. It will be a good thing increasing the use of Hungarian coal, fulfilling environmental requirements.

Sources of natural gas provide at least 3563 billion m3. However at the moment there are not solutions for the extraction of it, so it is useless. If we consider just the working mining, the volume that can be extracted is 56.6 billion m3 at 1 January 2008, ensuring supply for 21 years.

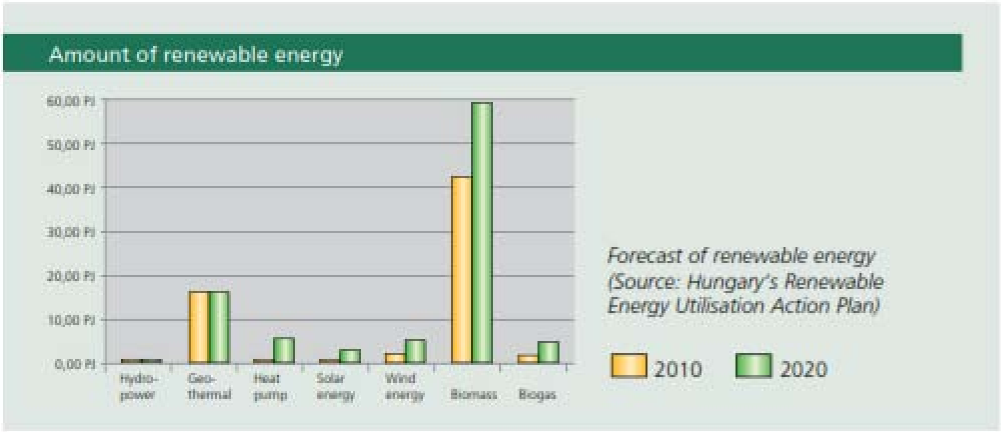
We can estimate the volume of gas that can be mined. Using the actual technology knowledge, drilling of fifty wells a year, at least 30 percent of that industrial asset can be mined over the forthcoming 30 years. That would cover over one-third (34.2 percent) of domestic demand.

In Hungary there was also the production of uranium, which took place near the village of Kôvágószôlôs. From the uranium mined uranium oxide was produced. Subsequently it was processed into fuel in the former Soviet Union. At the end of 1997 the mine was closed for economic reason, so Hungary was no longer in the market of uranium. Since 2006, however, the increase of market demand has spurred intensive search for uranium in Southwest Hungary (Mecsek, Bátaszék, Dinnyeberki and Máriakéménd).

6.2 Focus on renewable energies in Hungary

Since the mid of 1990s in Hungary the mass media have started to support the use of renewable energy. The price of oil and gas has increased rapidly, so renewable energy has become a valid opportunity and alternative. Discussing about it, Hungary would have a lot of benefit from renewable sources, especially in the agricultural production. Despite that, the cost of energy will be much higher than normal sources, so it wouldn't be a good investment and not economically competitive.

After joining the European Union (2003) renewable energy utilization started to grow intensively in Hungary. Before 2004 the energy coming from renewable source was only 0.5% of the total amount. In 2009 it was 4.3%, so there was a good increasing. At present biomass represents almost 80% and geothermal 8.2% of renewable energy use. Hungary is rich in renewable energy sources. Pellets and other solid biomass are the most used resources in the ratio of the renewable sources. The graphic underneath shows the distribution of renewable sources.



Forecast of renewable energy (Source: Hungary's Renewable Energy Utilisation Action Plan)

Figure 19 Renewable energy potential in Hungary

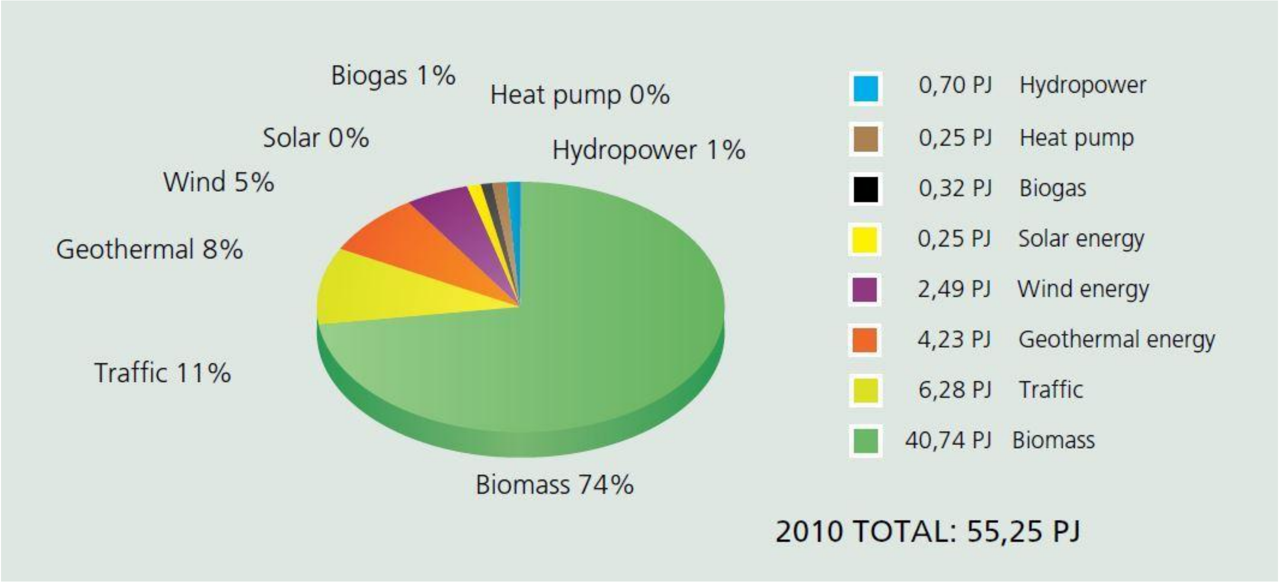
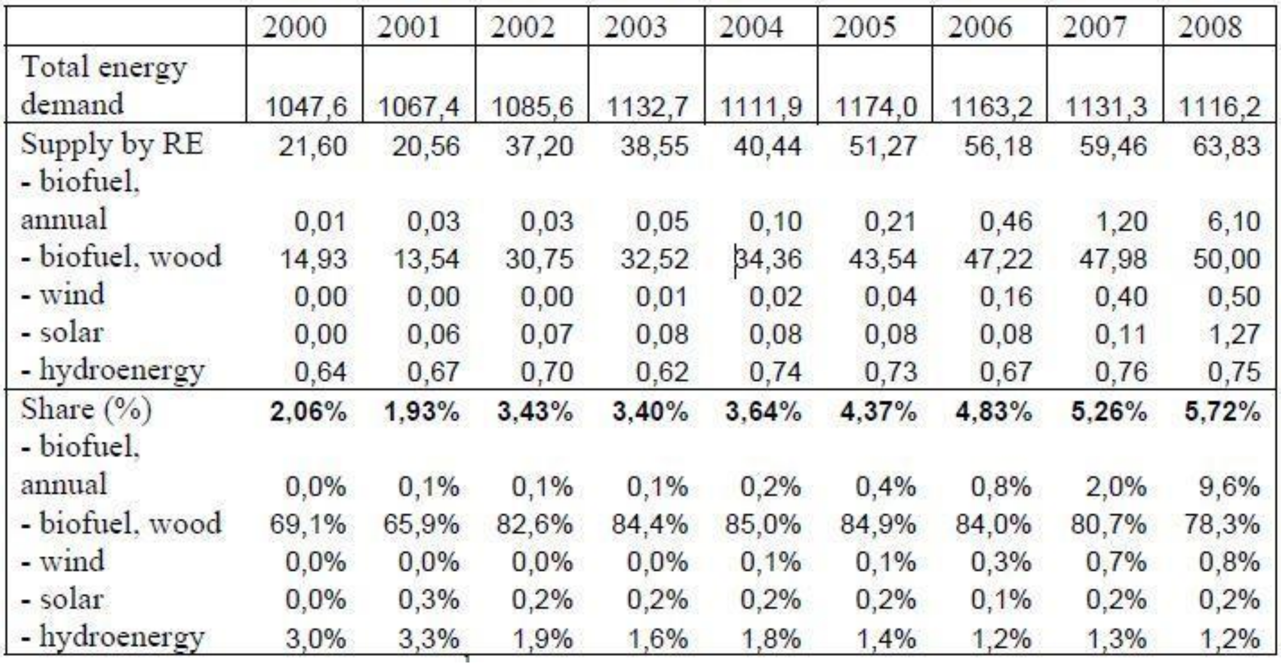


Figure 20 Ratio of renewable energies (2010)

From this graphic we can see the distribution of green energy. Wood is the most used with an amount of 40.74 Pj. After that there is a good amount of geothermal energy, which provides 4.23 Pj. For the moment solar energy has a really small amount in renewable energy, but it is increasing very rapidly and it is taking significantly part of the amount in these years. Also hydro energy has a small amount (0.7 PJ) and it is decreasing. Wind energy has been recently introduced in Hungary and for the moment it is not much utilized.

The following table shows briefly the amount of production and share of renewable energy in total energy demand:

Table 6 Production and share of renewable energy in total energy demand



	2000	2001	2002	2003	2004	2005	2006	2007	2008
Total energy demand	1047,6	1067,4	1085,6	1132,7	1111,9	1174,0	1163,2	1131,3	1116,2
Supply by RE	21,60	20,56	37,20	38,55	40,44	51,27	56,18	59,46	63,83
- biofuel, annual	0,01	0,03	0,03	0,05	0,10	0,21	0,46	1,20	6,10
- biofuel, wood	14,93	13,54	30,75	32,52	34,36	43,54	47,22	47,98	50,00
- wind	0,00	0,00	0,00	0,01	0,02	0,04	0,16	0,40	0,50
- solar	0,00	0,06	0,07	0,08	0,08	0,08	0,08	0,11	1,27
- hydroenergy	0,64	0,67	0,70	0,62	0,74	0,73	0,67	0,76	0,75
Share (%)	**2,06%**	**1,93%**	**3,43%**	**3,40%**	**3,64%**	**4,37%**	**4,83%**	**5,26%**	**5,72%**
- biofuel, annual	0,0%	0,1%	0,1%	0,1%	0,2%	0,4%	0,8%	2,0%	9,6%
- biofuel, wood	69,1%	65,9%	82,6%	84,4%	85,0%	84,9%	84,0%	80,7%	78,3%
- wind	0,0%	0,0%	0,0%	0,0%	0,1%	0,1%	0,3%	0,7%	0,8%
- solar	0,0%	0,3%	0,2%	0,2%	0,2%	0,2%	0,1%	0,2%	0,2%
- hydroenergy	3,0%	3,3%	1,9%	1,6%	1,8%	1,4%	1,2%	1,3%	1,2%

In the next graphic we can see what Hungary wants to achieve in the 2020 for renewable energy.

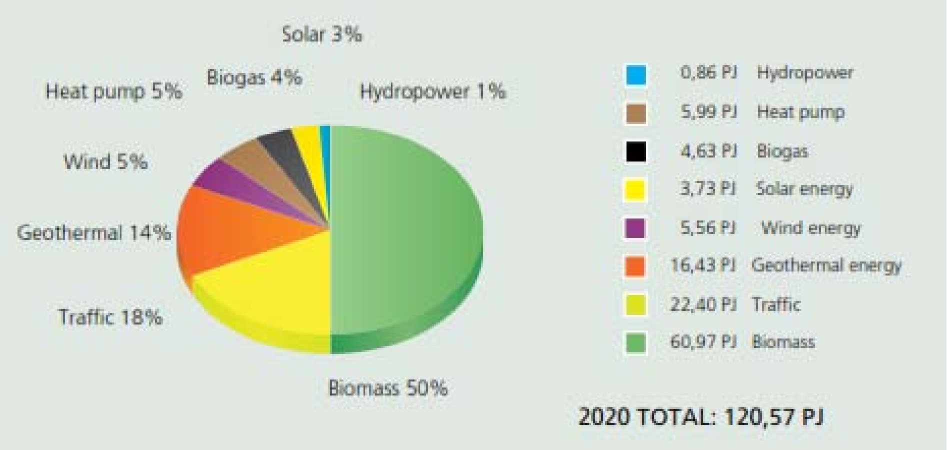


Figure 21 Ratio of renewable energies (2020)

6.3 Overall view of wind power energy in Hungary

In 2010 the participation of the wind turbines in the total amount of renewable energy was about 5%. Based on surveys, the potential capacity of wind power in Hungary is much more than the utilized power at the moment. According to the guideline of the government and the limitation of the controllability of the electric system, for 2020 Hungary wants to achieve 740 MW from the energy of wind turbine.

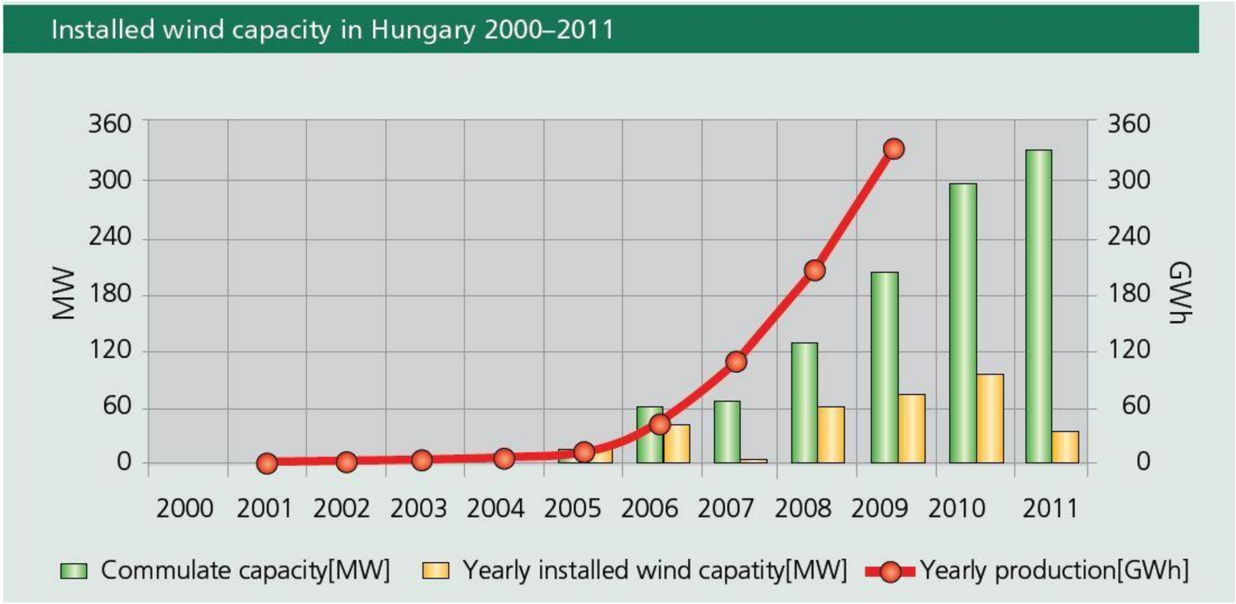


Figure 22 Cumulate and yearly installed wind capacity in Hungary between 2000 and 2011

The graphic shows how wind power is increasing year per year. In fact, almost 43% of the territory allows a suitable economic utilization of wind power. In areas which are 75 m above sea level, the annual average wind speed is above 5.5 m/s. In higher areas the wind is also faster, so that more efficiency can be reached.

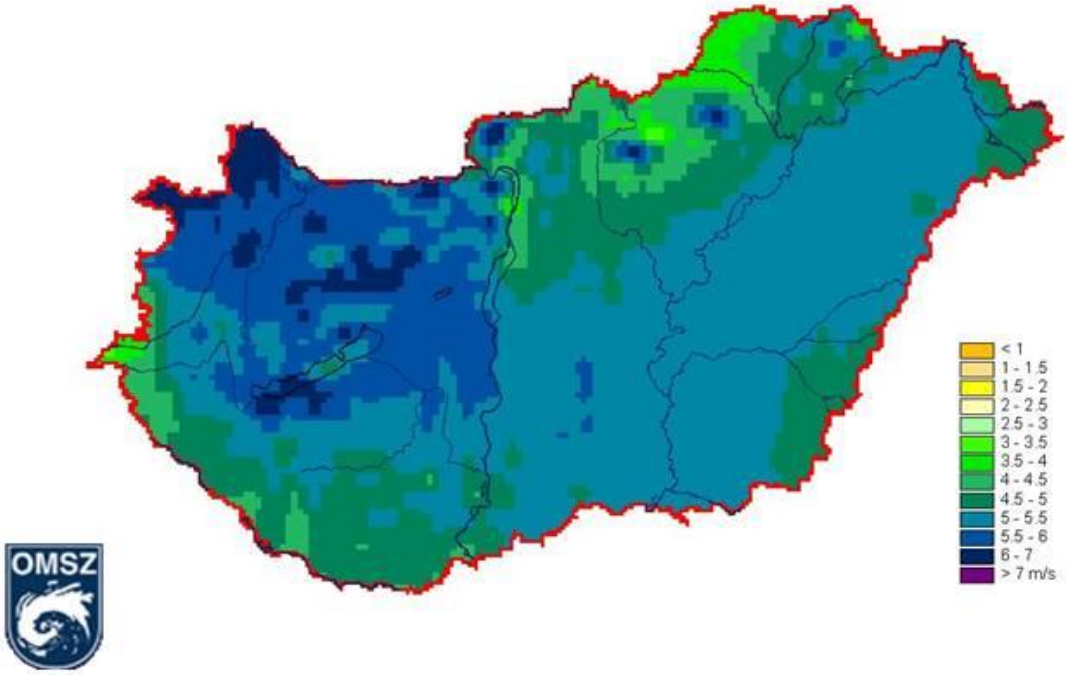


Figure 23 wind speed on 75m above surface Country-side

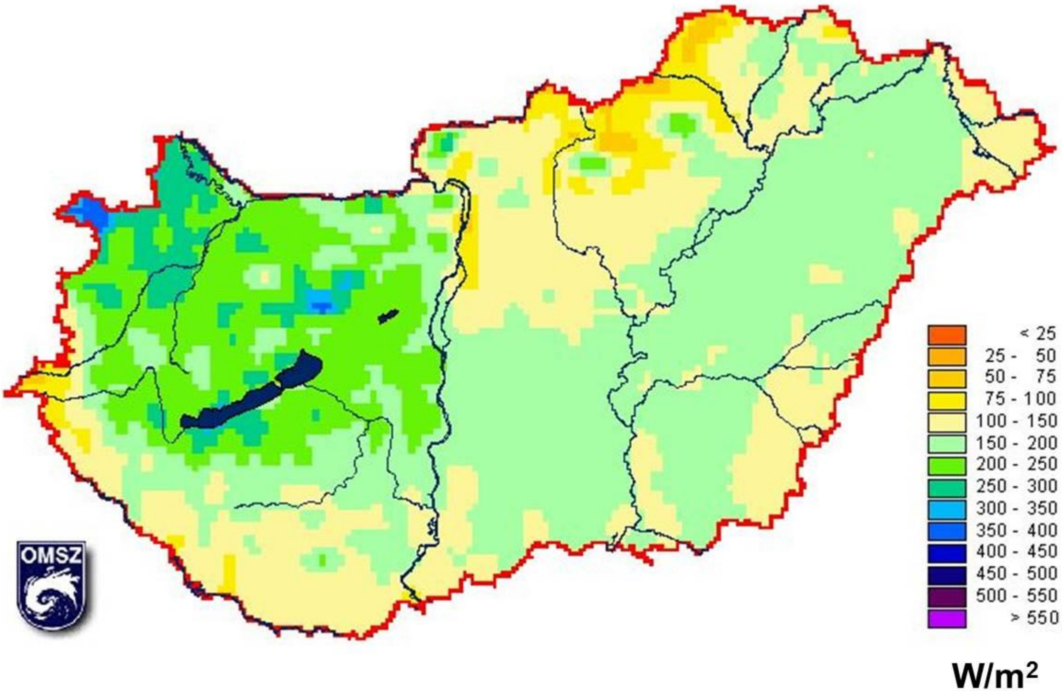


Figure 24 Specific wind performance (W/m2) on 75m above surface Country-side wind potential on 75m

To permit the construction of wind turbines there are several licenses in Hungary. First of all it is required the environmental license, then plan and permit of construction, Network connection agreement with Transmission System Operator (TSO) and Network connection agreement with Distribution System Operators (DSO).

Application for Hungarian Trade Permitting Office must be provided to get permit for the building of all wind turbine and park. This is the main authority for construction licensing and no local governments!

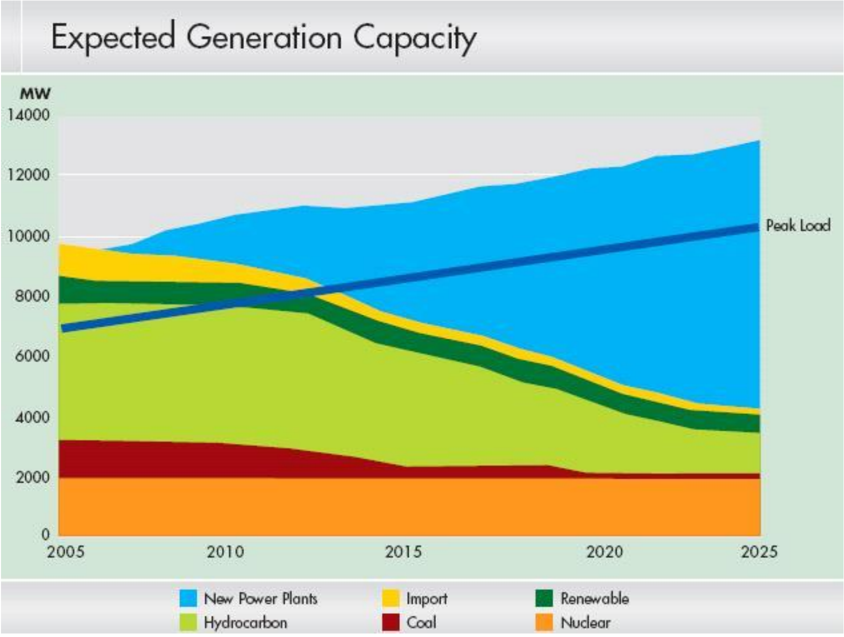


Figure 25 Expected generation wind power in next years

6.4 Overall view of biomass, biogas and biofuels in Hungary

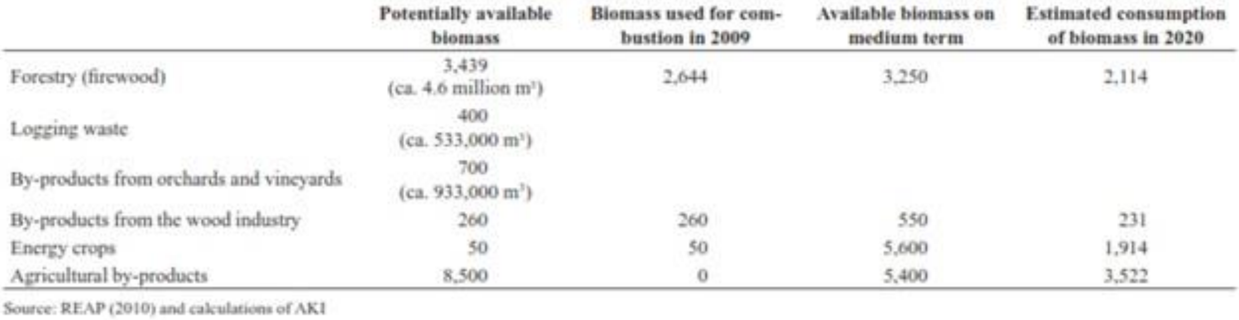
Agriculture and forestry have been amongst the decisive branches of Hungarian economy for a long time. Hungary's natural endowments, the climate, the quality of soil as well as long-time tradition and expertise can provide for excellent production results both in terms of quality and quantity. Hungarian agriculture and food industry is traditionally export-oriented. Despite all the favorable conditions, however, due to the unavoidable restructuring of economy in the early 1990s and the loss of traditional markets, agriculture lost much of its importance in terms of economic output.

Out of the total 9.3 million hectares of the total area of Hungary, 7.7 million hectares are productive land (including forests, fish ponds etc.), 5.9 million hectares of which are agricultural land – a share which is uncommonly high in Europe. Of this, 77% is arable land and 18% is grassland. Kitchen gardens, orchards and vineyards account for 5% of the agricultural land area. For this reason Hungary possesses good agro-ecological conditions for a competitive production of biomass. A lot of food can be produced and at the same time also a big biogas production potential. Anyway, there are some limitations due to the competitiveness of the energy. Bioenergy can primarily play a more important part in fulfilling local heating demands in the future, but there is also an intent to place emphasis on the spread of small and medium-capacity combined electricity and heat generating systems.

6.4.1 Biomass

Hungary's solid biomass potential is based on the volume of raw materials available or producible under the criteria of sustainability. In recent years 7 million m^3 timber were annually logged, of which 5.5 million m^3 were actually used, 3,5 million m^3 were laminated timber including fibre wood, firewood and pulpwood. Taking into account the criteria of forest management and the results of forest planting objectives 9 million m^3 can be logged in Hungarian forests each year between 2015 and 2020, of which roughly 5 million m^3 can be used for energy production.

Table 7 Estimated amount of the available solid biomass for energy recovery in Hungary (thousands tons)



	Potentially available biomass	Biomass used for combustion in 2009	Available biomass on medium term	Estimated consumption of biomass in 2020
Forestry (firewood)	3,439 (ca. 4.6 million m³)	2,644	3,250	2,114
Logging waste	400 (ca. 533,000 m³)			
By-products from orchards and vineyards	700 (ca. 933,000 m³)			
By-products from the wood industry	260	260	550	231
Energy crops	50	50	5,600	1,914
Agricultural by-products	8,500	0	5,400	3,522

Source: REAP (2010) and calculations of AKI

6.4.2 Biogas

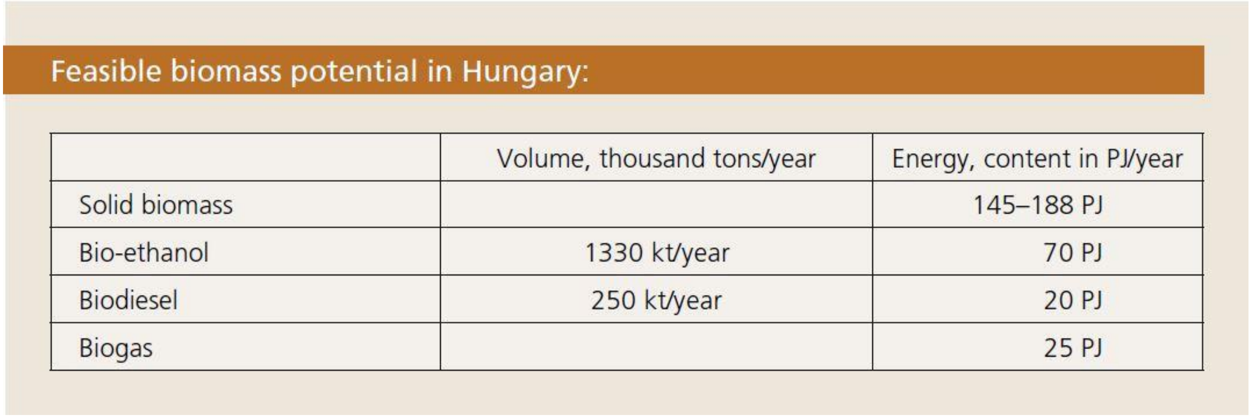
Biogas is a very widely used energy source, capable of replacing natural gas, producing electricity and heat and usable as motor fuel. Biomethane, created by cleaning biogas up to natural gas quality can be fed into the gas network. Biogas can also be used for combined heat and power generation in modern block heat power plants. In Hungary there are 20 plants using biogas for co-generation. Initially such biogas plants were constructed at waste water treatment facilities but recently the number of plants using manure has expanded. Given appropriate support, these manure plants can become much more widely-spread and the number of plants using waste from the food industry can also considerably rise. This is underlined by the increasingly stricter environmental regulations prohibiting the flushing of liquid manure into waters to reduce the agricultural nitrate pollution of water.

6.4.3 Biofuels

Raw materials used for bioethanol production include plants with high sugar content (e.g. sugar beet, sugarcane) or crops that can be converted to sugar (e.g. maize, wheat, potatoes with starch etc., or trees, grasses, grain stalks, straw containing cellulose). Bioethanol production can be based on a wide range of raw materials including existing agricultural by-products and waste. In Hungary the main raw materials used in first generation bioethanol production are maize, wheat, Jerusalem artichoke and sugar beet.

In addition several cultures are being tested (e.g. sweet sorghum). The technology of the near future, however, is a second-generation bioethanol production based on cellulose, currently under development. Its wider dissemination in factories is expected to take place after 2012-2015. In terms of raw materials Hungary is in a favorable position to produce bioethanol. 6-7 million tons of maize is annually harvested, of which increasingly less is used as fodder while the amount exported and industrially processed is rising. Locally grown maize is available in much larger quantities than the estimated demand in the near future. The volume of maize and cereal-based ethanol can go up to 700-800,000 tons/year, exceeding the expected needs of Hungarian motor fuel producers and sellers multiple times by 2020. To achieve this aim bioethanol plants must be set up at a different rate than the current disappointing one.

Table 8 Biomasses potential



Feasible biomass potential in Hungary:

	Volume, thousand tons/year	Energy, content in PJ/year
Solid biomass		145–188 PJ
Bio-ethanol	1330 kt/year	70 PJ
Biodiesel	250 kt/year	20 PJ
Biogas		25 PJ

6.5 Overall view of hydropower in Hungary

In Hungary this type of energy is one of the oldest. It had a great role in the generation of energy in past years. The strengths of this energy are that it is clean and renewable, and it has a good efficiency of conversion. Choosing this type of energy, we can reduce drastically the greenhouse effect, because we would not produce CO2. However in Hungary there are just small opportunities to have this type of plants due to the fact that there are just small rivers' falls. Actually in Hungary there are 11 hydropower plants plus 6 smaller hydropower plants.

At the beginning of the 20th century some watermills were converted to smaller hydropower plants.

The theoretical potential of electricity generation is around 7500 GWh/year.

Hydropower potential in Hungary is limited to 3 larger power plants, and several small power hydropower plants.

The main plants are:

- Tiszalök
- Kenyer
- Ikervar
- Kisköre

6.5.1 Tiszalok

This is the biggest hydropower plant.

Figure 26 Tiszalok hydropower plant

6.5.2 Kenyer

It produces 9 million KWh per year. It means approximately that it can supply the year energy demand of 4000 households. It saves 13000 tons of coal.

Figure 27 Kenyer hydropower plant

5.5.3 Ikervar

It was the first hydropower plant built. The output power is approximately 3,710 MWh.

Figure 28 Ikervar hydropower plant

6.5.4 Kiskore

It was planned for 103.000 MWh of capacity, during more 30 years work the average capacity per year is 86.000 MWh as seen in figure 32. This is enough electricity for 30 thousand household.

Figure 29 Kiskore hydropower plant

6.6 Overall view of geothermal energy in Hungary

For the most part, Central Europe has only low-enthalpy geothermal resources. Hungary, however, due to its unique geological position astride the Pannonian Basin, a “geothermal hot spot,” is the exception to the rule. While all of the country’s geothermal resources developed to date are low- and medium-enthalpy, a few high-enthalpy resources have been discovered. As yet, they remain undeveloped. Hungary’s geothermal gradient is higher than the world average, and reaches as high as 58.9ºC in some spots. The water fee to use geothermal water has increased substantially, becoming a significant operating cost. Proliferation of water and energy saving operations will be one of the most important challenges of the near future in Hungary. In addition to the direct costs of the construction of wells and reinjection, the most important limiting factor in the case of geothermal energy is the provision of funding, which is due to the costs associated with the establishment of a heat supply and distribution systems. For these reasons there are no geothermal plants in the country; however some pilot programs tried to establish some plants but they are under investigation.

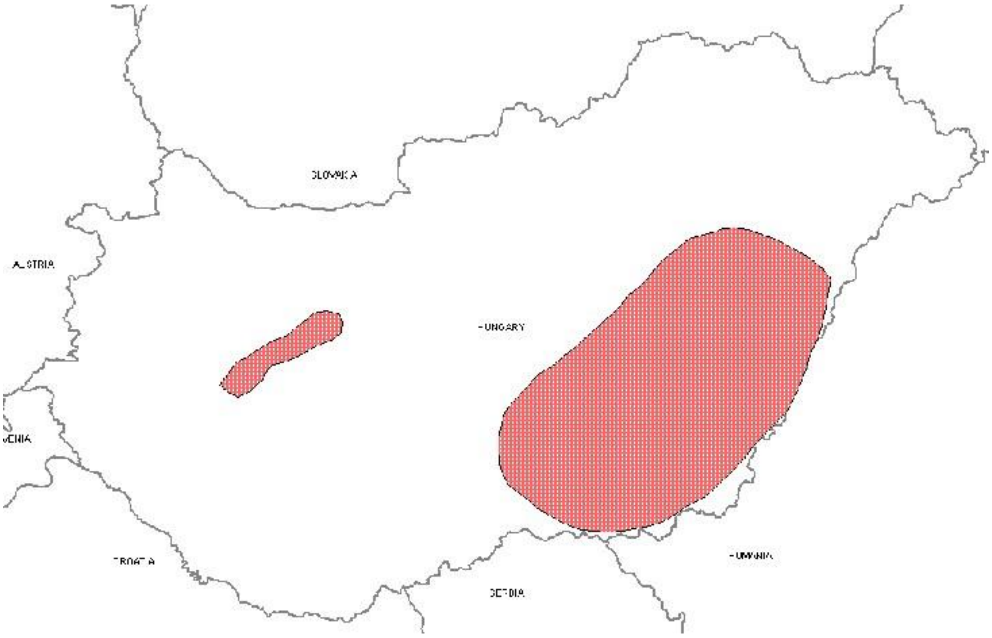


Figure 30 Geothermal resource

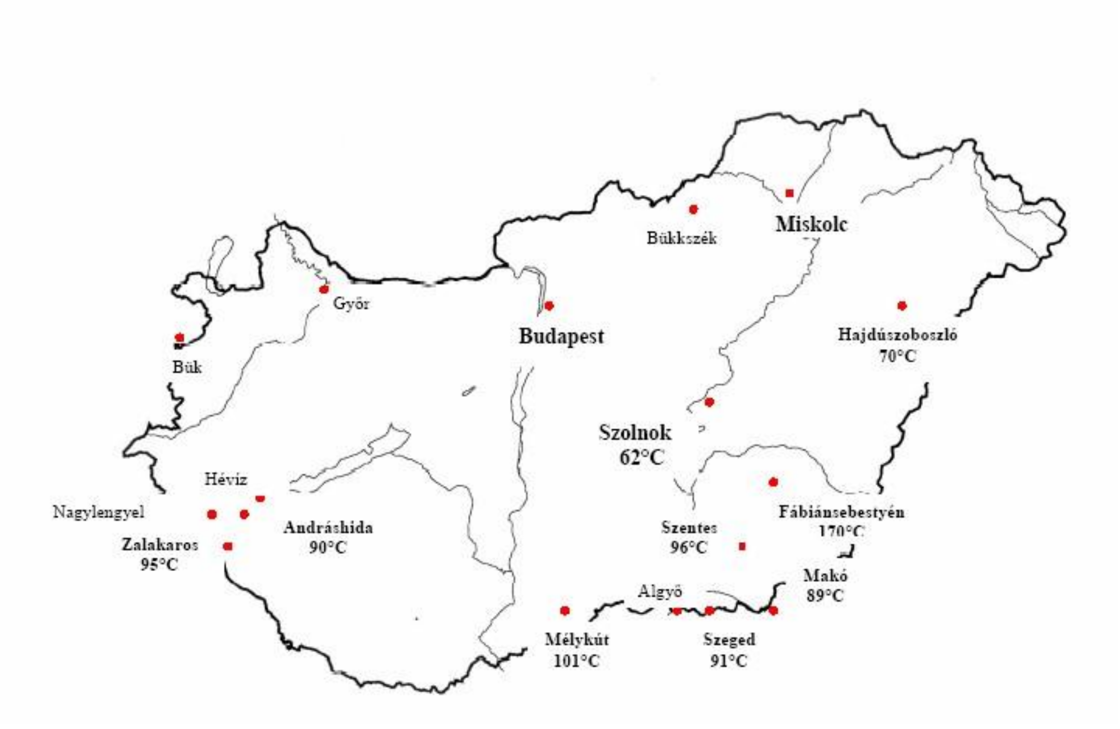


Figure 31 Wellhead Temperature Regions of Water Wells areas

6.7 Overall view of photovoltaic energy in Hungary

Hungary has good potential for the use of solar energy. The number of sunny hours in Hungary is between 1,950-2,150 per year at an intensity of 1.200 kWh/m2 per year. Unfortunately Hungarian photovoltaic market is not well-developed. At the end of 2012 the photovoltaic plants in Hungary have 6 MW cumulative installed capacity. The main reason behind the slow market expansion is the low and non-functional feed-in tariff: there is a mandatory buy-back of the solar electricity, but feed-in tariff is only approximately 0.11 €/kWh. In this way the time of payback is very long and not guaranteed. Therefore in Hungary the tariff does not fit the standard of other countries thus not making the growth of the market fast. There has been a plan to introduce a "classic" feed-in tariff in Hungary for years, however in early 2013 it was again postponed, and it cannot be expected before 2014.

According to Ernst & Young, Hungary has high solar irradiation, but the country struggles with its insufficient grid capacity and very difficult permitting processes. In Hungary the number of solar PV installation was increased in 2012, both by private and local authorities and the business field. The average capacity is lower than 50 kWp. These investments do not require permit for the installation.

Table 9 Installed and cumulated capacity in 2012 in Hungary

Applications	**Cumulated in 2011** (in kWp)	**Installed in 2012** (in kWp)	**Cumulated in 2012** (in kWp)
Off grid	400	100	500
On grid	2338	870	3238
Total	**2738**	**970**	**3738**

Big installations are rare. The first installations of PV systems have started at the beginning of 2000s. 2006 was the first year when the on-grid PV capacity exceeded the off-grid capacity and it has predominated since then. In 2011 a 400 kWp installation began its operation in Újszilvás, at present it has the biggest solar PV capacity in Hungary, but another project is under construction in Szeged with 600 kWp. In 2011 the on-grid capacity was 1,900 and off-grid was 400 kW. In the long run the rooftop and building integrated PV system applications are expected to be dominant.

6.7.1 PV history in Hungary

In 1973 the photovoltaic development started. At the end of 1975 there was the first installation. In 1979 the silicon solar cell was developed and his efficiency achieved about 15%, which was patented. In 1982 the PV Working Group was founded in the Hungarian Electro technical

Association. Later, in 1983 the Hungarian Solar Energy Society was founded and then, in 1989, the Pannonglas SOLARLABS. These are the first companies to develop and build solar systems and photovoltaic systems. Nowadays there are a lot of companies that are trying to improve and achieve better and better results about efficiency.

PV applications in Hungary are essentially divisible in 4 categories:

- Off grid systems (80 KWp)
- Grid connected systems (55 KWp)
- Quasi-autonomous power supplies (3 KWp)
- Consumer products (n.a)

The PV installation instead has 3 big areas:

- For buildings and for other objects
- For free land areas
- Data input: Hungarian statistical yearbook

Some potential data about PV in Hungary

1. Solar modules could be installed mainly on one side of the saddle roofs and on 0.431*flat roofs.
2. Solar modules could be installed really only 50% of the principle areas and 25% of the railway. (shading & others).
3. Because of orientation loss the effective solar areas are with 10% lower.
4. Calculating with 10% average module efficiency 1 m solar module nominal power = 100 Wp
5. Calculating with 80% matching and other conversion losses 1 kWp solar arrays produce yearly average in Hungary at different tilt angles as follows: at 30° 1200 kWh/year, at 45° 1150 kWh/year and at 60° 1100 kWh/year.

The yearly average electrical energy production of the solar equipment to be installed potentially in Hungary is 486 billion kWh. The yearly demand of electrical energy in Hungary today is less than 40 billion kWh. That means the potential is more than 12 fold. Increasing the number of PV fields means more buildings facades but less solar thermal collectors.

Figure 32 First PV installation in Hungary 1975 (Off grid)

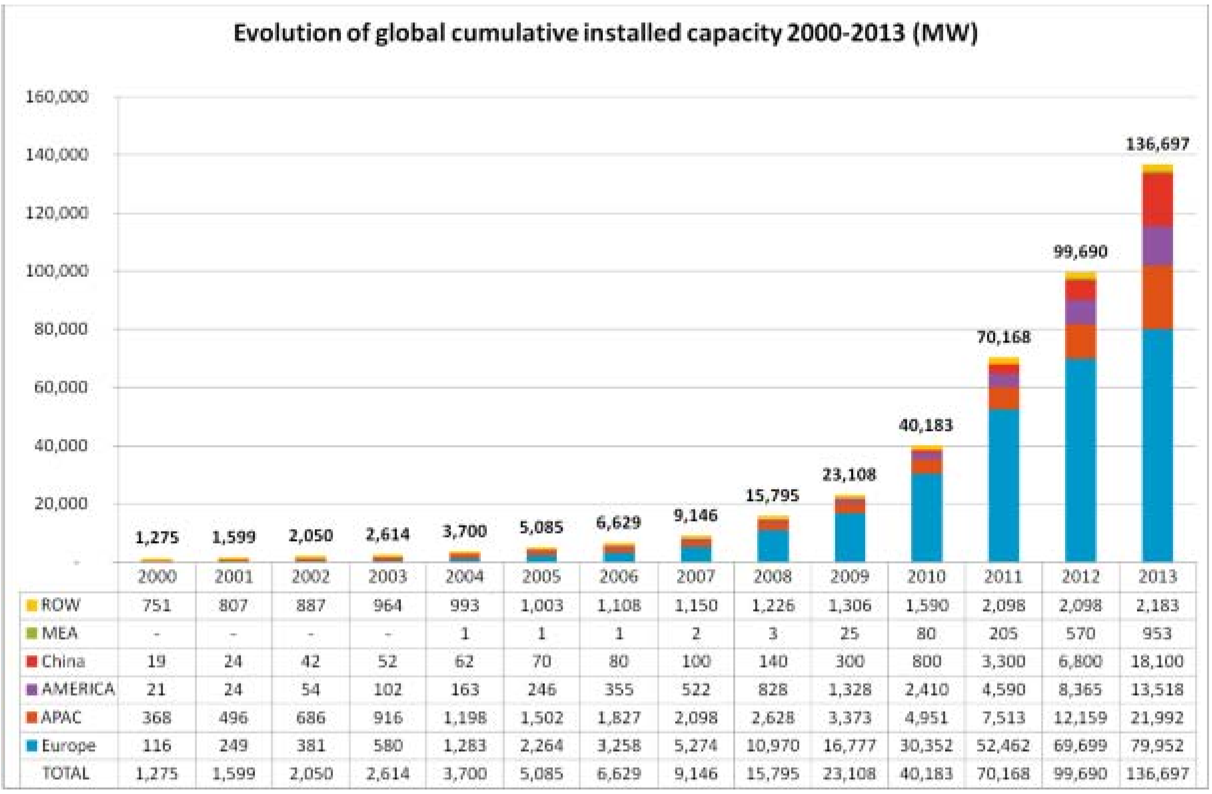
Figure 33 10 kWp grid connected PV systems

7 Cost analysis

Solar energy is a very important resource, it is free and unlimited because it is from the sun, but the most important fact is that it is CLEAN. That is something priceless, because it does not harm humans at all with CO_2 or other dangerous substances. Obviously, there is a market which sets prices for the supply, the demand and the value of the object. In the next paragraph we want to analyze the trend of the selling and of the price of photovoltaic panels in the last few years.

7.1 Overview of global trend

PV is one of the fastest growing renewable energy technologies today and in the future it is estimated to play a major role in global electricity production. The global installed PV capacity has grown from 1.8 GW in 2000 to 136 GW at the end of 2013, with a growth rate of 44% per year. That was possible thanks to attractive policy incentives (e.g. feed-in tariffs and tax breaks). Assuming an average capacity factor of 0.2 that means that PV alone produced 235 TWh of electrical power2013



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
🟨 ROW	751	807	887	964	993	1,003	1,108	1,150	1,226	1,306	1,590	2,098	2,098	2,183
🟩 MEA	-	-	-	-	1	1	1	2	3	25	80	205	570	953
🟥 China	19	24	42	52	62	70	80	100	140	300	800	3,300	6,800	18,100
🟪 AMERICA	21	24	54	102	163	246	355	522	828	1,328	2,410	4,590	8,365	13,518
🟧 APAC	368	496	686	916	1,198	1,502	1,827	2,098	2,628	3,373	4,951	7,513	12,159	21,992
🟦 Europe	116	249	381	580	1,283	2,264	3,258	5,274	10,970	16,777	30,352	52,462	69,699	79,952
TOTAL	1,275	1,599	2,050	2,614	3,700	5,085	6,629	9,146	15,795	23,108	40,183	70,168	99,690	136,697

Figure 34 Global cumulated installed capacity (EPIA 2013)

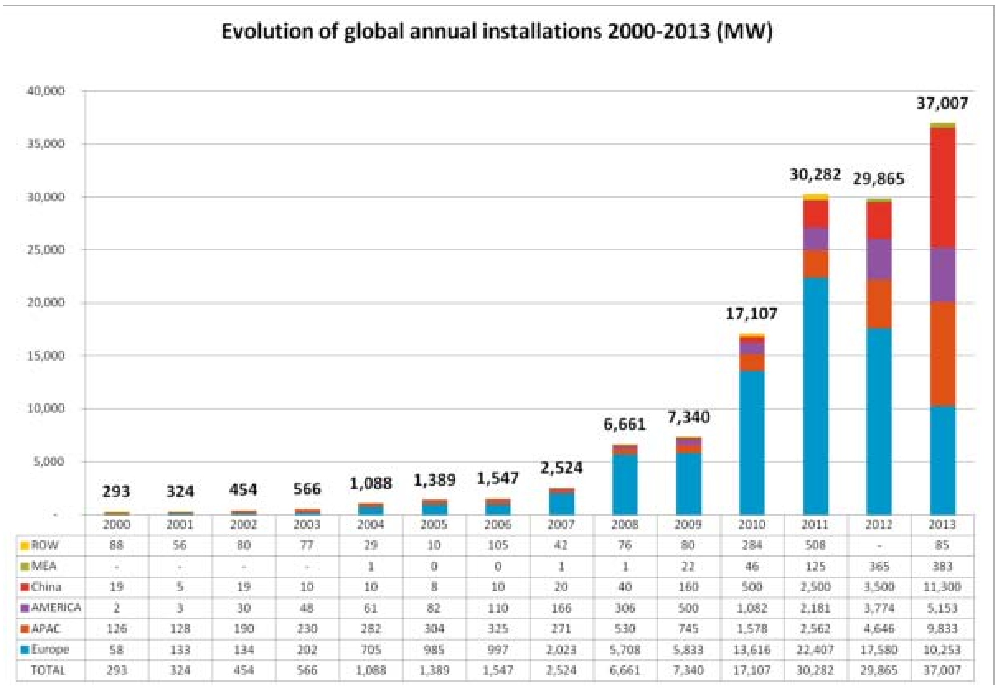
This rapid extension in capacity has led to important cost reductions. Each time the cumulative installed capacity has doubled, PV modules have declined by 20% to 22%.

Till mid-1990s, most PV systems were off-grid applications for telecommunications, remote houses and rural electricity supply. Driven by various support and incentive schemes introduced by most countries the number of grid-connected application increased quickly. In the last decade grid-connected installations have overrun the off-grid applications, thus becoming the larger sector of PV technologies. The growth in the utility-scale systems has also accelerated in recent years and now has become a significant market.

In 2010, new installed PV capacity was 16.6 GW. Most of its growth was possible thanks to the quick expansion of the German and Italian markets. With 7.4 GW installed in Germany in just one year, the country continues to dominate the global PV market. Italy installed 2.3GW, starting to take advantage of its wide solar resources.

In 2011, 27.7 GW of new PV capacity was installed, 66% more than in 2010. Europe accounted for around 75% (20.9 GW) of all new capacity added in 2011. Italy, consolidated from its growth in 2010, added an impressive 9 GW of new capacity, increasing the total installed capacity by 260%. Germany added 7.5 GW in 2011. Six countries added more than one GW in 2011 (i.e. Italy, Germany, China, United States, Japan and France).

Facing the worldwide financial crisis started in 2009, 2012 is a problematic year for the PV market. From the graphic below we can see how the market had a break in growth.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
ROW	88	56	80	77	29	10	105	42	76	80	284	508	-	85
MEA	-	-	-	-	1	0	0	1	1	22	46	125	365	383
China	19	5	19	10	10	8	10	20	40	160	500	2,500	3,500	11,300
AMERICA	2	3	30	48	61	82	110	166	306	500	1,082	2,181	3,774	5,153
APAC	126	128	190	230	282	304	325	271	530	745	1,578	2,562	4,646	9,833
Europe	58	133	134	202	705	985	997	2,023	5,708	5,833	13,616	22,407	17,580	10,253
TOTAL	293	324	454	566	1,088	1,389	1,547	2,524	6,661	7,340	17,107	30,282	29,865	37,007

Figure 35 Global installed capacity (EPIA 2013)

The capacity installed in 2012 was a little bit less than 2011, thus marking the first negative trend for the market. Moreover, if we focus on the European market, we see negative data emerging from the graphic. In 2012 17 MW were installed in Europe instead of the 22 MW in 2011. This means a contraction of 22% of the market. It was the year of the record for Germany with 11.4 GW, thus maintaining a reasonable level of installation in the European market. The other share came from Italy. Aside from these two, the UK, Greece, Bulgaria and Belgium provided a large part of the European market development.

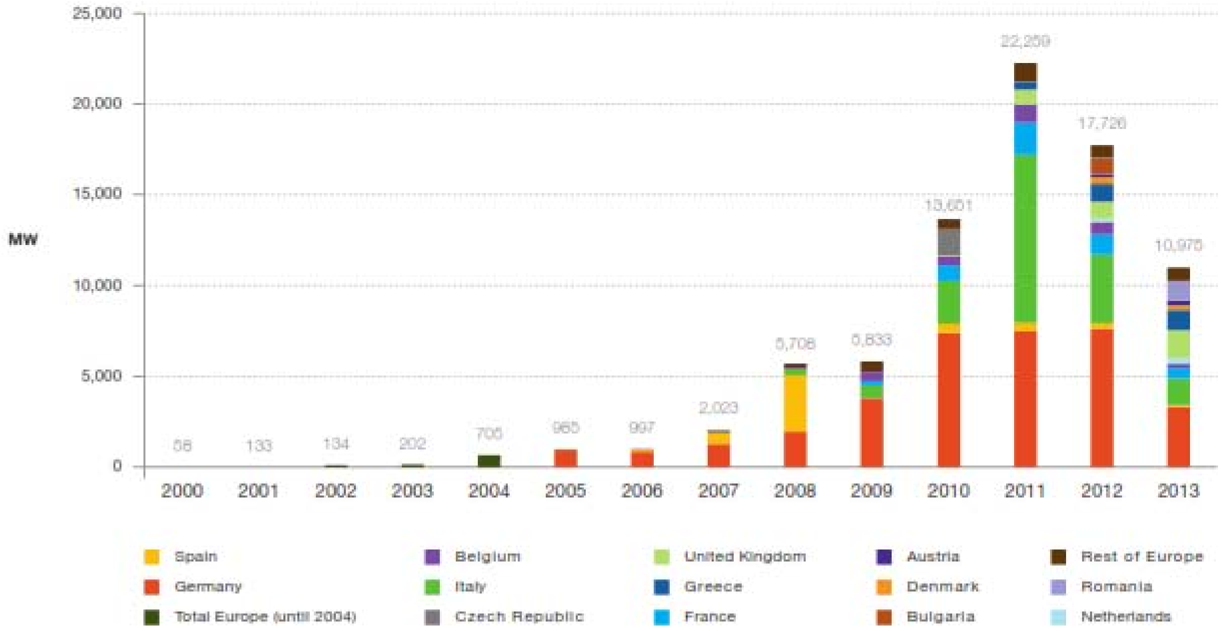


Figure 36 Installed capacity in Europe

2013 marks a relevant reduction in the market, about 7 GW less than 2011 (41% less than the previous year). The decline of Germany and Italy as the main protagonists of the European market was confirmed. While the sum of the market in other countries remained around 6 MW, the two countries provided just 5 MW, with a substantial reduction compared to the previous year. Also in other countries of EU there was a decrease of the market, like Belgium and France, but that was compensated by the boom in Greece and Romania. Anyway, despite the crisis, some developments were achieved in the UK, and in some other smaller market countries, such as Switzerland, the Netherlands and Austria.

Europe's PV development was unreached for a long time till 2013. The USA and Japan, once PV pioneers, used to be behind Europe in terms of PV penetration, whereas China has already reached their level in just a few years of fast development.

The development of PV has usually corresponded to economic development; first starting in OECD countries (Europe, North America, Japan, Australia), then spreading in emerging countries.

In the graph below we can see the European PV cumulative capacity segmentation by country in 2013. We notice how some countries have the quasi-totally percentage of ground-mounted type plants. This is the case of Romania, Bulgaria and Spain, which means they have invested in big grid-connected plant, to serve the national consumption. This quick increase in this type of installation has developed in recent years, especially for Romania, as we said before. From data of 2012, a decrease of the share of ground-mounted for 2013 was expected, but that didn't happen. Actually the share became higher than the previous year.

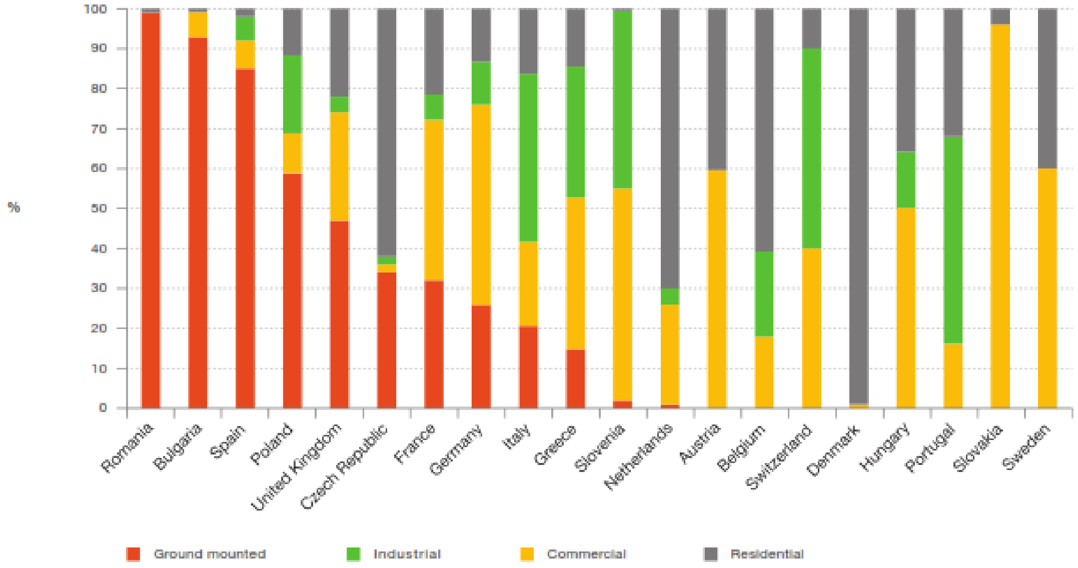


Figure 37 Segmentation of PV market in Europe

7.1.1 Forecasts of PV in Europe until 2018

Taking into account the previous data and the financial crisis which is still standing, it is difficult to predict a stable model for the future years. The European PV market peaked in 2011 with more than 22 GW installed. Such a high level was not sustainable and the market went down to 17.7 GW in 2012. The 2013 market declined further to nearly 11 GW, which is the lowest level since 2009 in Europe. Each year, some markets had a boom before experiencing a failure in the following years, and the market was supported by different countries every year. A data example can be given when we look at the countries that installed close to or at least 1 GW each year.

The instability of markets in Europe leads to say that there are no countries in Europe that once experienced a serious PV boom can maintain the same market level, with the exception of Germany.

Besides, the traumatic decrease of some FiT programs reduced some markets in 2014, with a difficult possibility of emerging markets in Europe that could mitigate the decline.

In the High Scenario, the market could stabilize in 2014 and grow again from 2015 onwards, driven by the approaching competitiveness of PV and emerging markets in Europe. To reach this level we need a stabilization in the wide European market (Germany, Italy) and keeping on the current policies in UK and growing again in Spain and France and in the other countries which entered the market in the past few years.

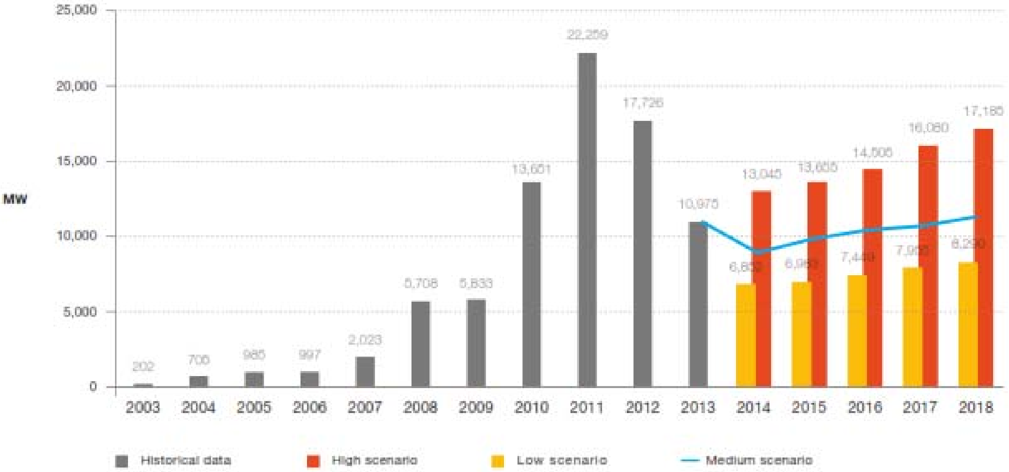


Figure 38 Forecasts of the installed capacity in Europe

In this way the total capacity installed in Europe by 2018 could achieve between 118 and 156 GW

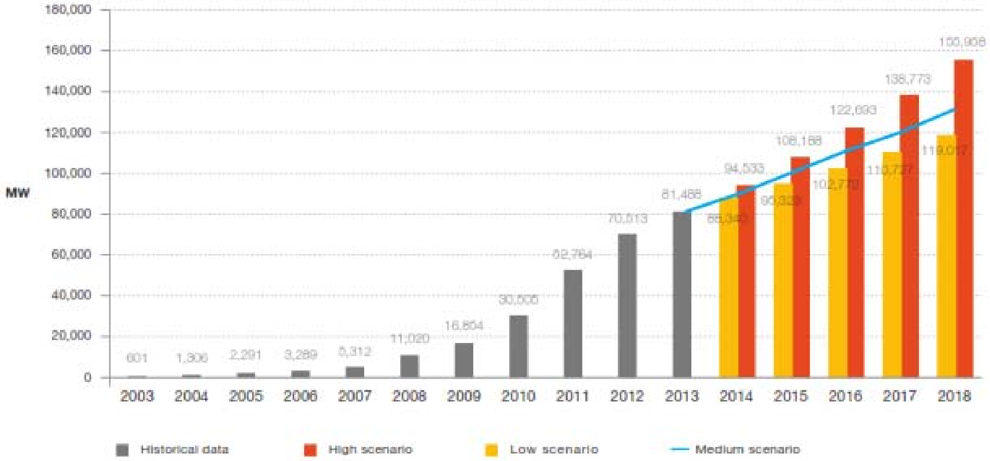


Figure 39 Forecasts of the cumulated installed capacity in Europe

In the coming years it will be worth focusing on the countries where PV has not developed yet, because they have not taken advantage of their potential yet and also for the single chance to improve and experience a different market development than what has been experienced until now in most European countries. The history of PV shows that a stable policy structure using support schemes in a balanced way gains market confidence. Poland, Croatia and Hungary can develop in the coming years in different ways. Also outside the European Union, Turkey and some Balkan states will become significant points. For markets developed in previous years, the recovery of France should be carefully followed and animated in a way that fits the specifics of this country. Also in Spain PV will not resume unless solutions are found to struggle the relative isolation of the country from a grid perspective. Finally, the self-consumption shows a growth of general interest, but in the real markets it remains unsure because the regulatory framework conditions are unstable and not reliable, especially charges and taxes. In 2013, the sum of installations that were driven by self-consumption in Europe amounted to over 2 GW. The hope of PV development for Europe is the growth of the self-consumption like the main subject which has to be as fast as possible.

The following table details for most EU markets the cumulative installed capacity at the end of 2013, the official National Renewable Energy Action Plan (NREAP) target for PV by 2020 and the necessary yearly market to reach this 2020 target (linear projection).

	Cumulative installed capacity in 2013	NREAPs' 2020 target for PV	Necessary yearly market until 2020	Target reached in...	Market in 2011	Market in 2012	Market in 2013
Austria	613	322	n/a	reached in 2012	92	175	250
Belgium	2,983	1,340	n/a	reached in 2011	996	683	215
Bulgaria	1,020	303	n/a	reached in 2012	135	843	10
Croatia	20	52	4.5	2014-2015	-	-	20
Czech Republic	2,175	1,695	n/a	reached in 2010	12	116	88
Denmark	548	6	n/a	reached in 2010	9.6	316	216
France	4,673	4,860	26.7	2014-2015	1,777	1,115	613
Germany	35,715	51,753	2,291.2	2014-2015	7,485	7,604	3,304
Greece	2,579	2,200	n/a	reached in 2013	426	912	1,043
Hungary	22	63	5.9	2014-2015	2.0	8	10
Italy	17,928	8,000	n/a	reached in 2011	9,251	3,759	1,448
Netherlands	665	722	8.1	2014-2015	58	195	305
Poland	7	2	n/a	reached in 2012	1.3	4	1
Portugal*	278	720	63.1	2016-2020	38	70	36
Romania	1,151	260	n/a	2014-2015	1.6	46	1,100
Slovakia	524	300	n/a	reached in 2011	321	15	0
Slovenia	212	139	n/a	reached in 2012	43	122	11
Spain	5,340	8,367	432.5	2016-2020	472	332	118
Sweden	40	8	n/a	reached in 2011	4	8	18
United Kingdom	3,375	2,680	n/a	reached in 2013	813	925	1,546
Rest of EU 28	99	308	29.9	2016-2020	24	17	42
Total EU 28	**79,964**	**84,381**	**630.9**	**2014-2015**	**21,961**	**17,265**	**10,395**

Figure 40 Target for 2020 of cumulated installed capacity in Europe

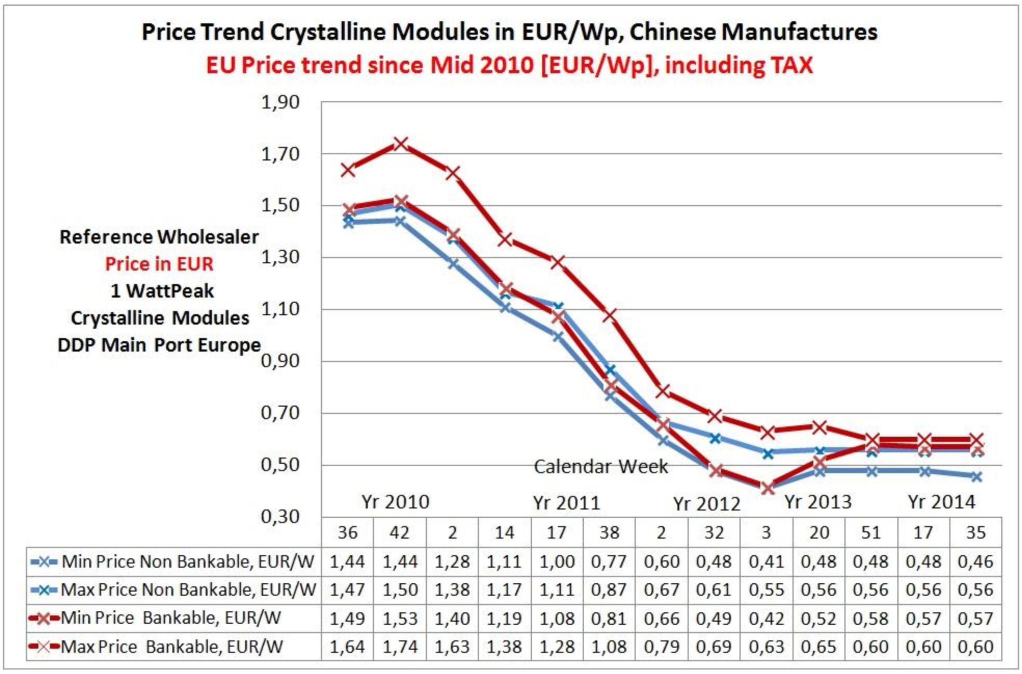
7.2 Price trend for PV systems

From the beginning of the first application in the far 1979 up to now, the price of PV modules has decreased rapidly and constantly. Usually, the price is not expressed in Euro, but in Euro per Watt. In the graph below we can see how the price trend in the last decades has dropped down fast.

Figure 41 Prices fall of modules from 1979

An observation similar to the famous Moore's Law can be made: it states that prices for solar cells and panels fall by 22 per cent for every doubling of industry capacity. In the graph it is unfortunately not clear due to the logarithmic scale.

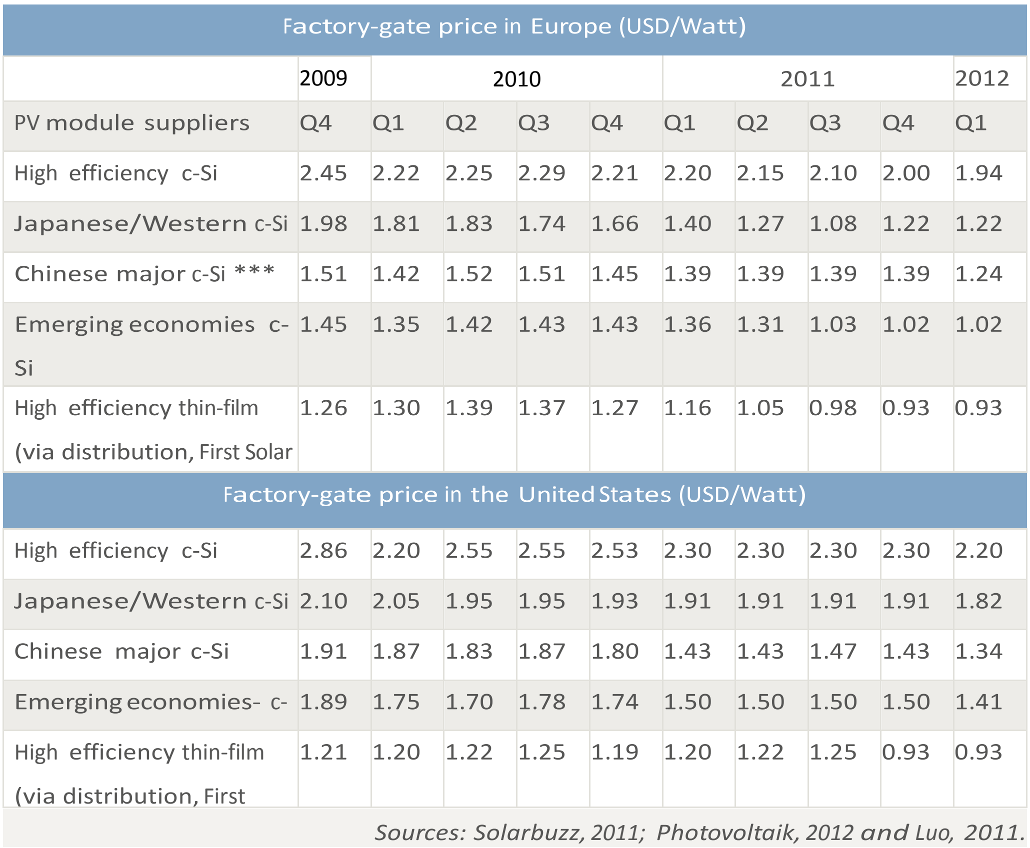
As we can see the price in the far 1979 was US$ 20 for Wp for CdTe technology, in 2014 it is US$ 1.05. The reduction of the price is about 95%. If we focus in the last few years the picture that emerges from Europe is shown below. The decrease in 4 years is more than 1 euro per watt, a 62% drop. This data is related to the wide spread of the technology.



	36	42	2	14	17	38	2	32	3	20	51	17	35
Min Price Non Bankable, EUR/W	1,44	1,44	1,28	1,11	1,00	0,77	0,60	0,48	0,41	0,48	0,48	0,48	0,46
Max Price Non Bankable, EUR/W	1,47	1,50	1,38	1,17	1,11	0,87	0,67	0,61	0,55	0,56	0,56	0,56	0,56
Min Price Bankable, EUR/W	1,49	1,53	1,40	1,19	1,08	0,81	0,66	0,49	0,42	0,52	0,58	0,57	0,57
Max Price Bankable, EUR/W	1,64	1,74	1,63	1,38	1,28	1,08	0,79	0,69	0,63	0,65	0,60	0,60	0,60

Figure 42 Prices of modules in the last years

Another interesting data to show are the different prices in different markets. The graph below shows the lower cost of modules in Europe compared to United States.



Factory-gate price in Europe (USD/Watt)										
	2009	2010				2011				2012
PV module suppliers	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
High efficiency c-Si	2.45	2.22	2.25	2.29	2.21	2.20	2.15	2.10	2.00	1.94
Japanese/Western c-Si	1.98	1.81	1.83	1.74	1.66	1.40	1.27	1.08	1.22	1.22
Chinese major c-Si ***	1.51	1.42	1.52	1.51	1.45	1.39	1.39	1.39	1.39	1.24
Emerging economies c-Si	1.45	1.35	1.42	1.43	1.43	1.36	1.31	1.03	1.02	1.02
High efficiency thin-film (via distribution, First Solar	1.26	1.30	1.39	1.37	1.27	1.16	1.05	0.98	0.93	0.93
Factory-gate price in the United States (USD/Watt)										
High efficiency c-Si	2.86	2.20	2.55	2.55	2.53	2.30	2.30	2.30	2.30	2.20
Japanese/Western c-Si	2.10	2.05	1.95	1.95	1.93	1.91	1.91	1.91	1.91	1.82
Chinese major c-Si	1.91	1.87	1.83	1.87	1.80	1.43	1.43	1.47	1.43	1.34
Emerging economies- c-	1.89	1.75	1.70	1.78	1.74	1.50	1.50	1.50	1.50	1.41
High efficiency thin-film (via distribution, First	1.21	1.20	1.22	1.25	1.19	1.20	1.22	1.25	0.93	0.93

Sources: Solarbuzz, 2011; Photovoltaik, 2012 and Luo, 2011.

Figure 43 Comparison of prices of modules between Europe and United States

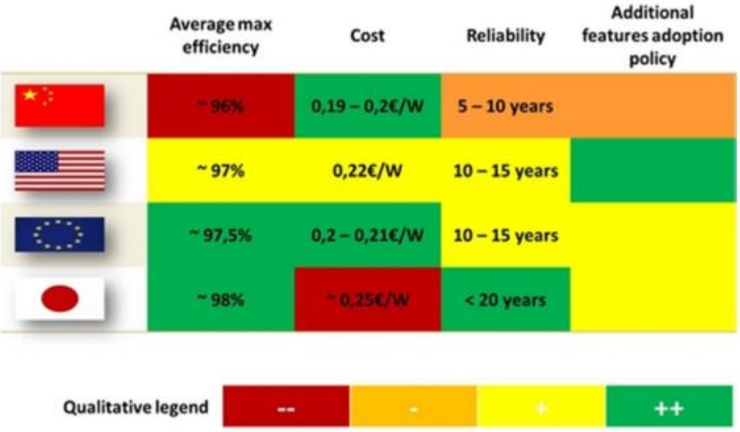
The reason of this small increment of price in the United States is due to the mature market in Europe developed some years earlier and the constant research and investments which allow Europe to gain the supremacy in the production and application.

The price of the module is usually shared in this way:

Figure 44 Shared price of module

However, the price of a PV system is not just the module, but there also some other costs named BOS (Balance of system costs), which usually include the inverter, the business process, the structural installation, the racking, site preparation attachments, electrical installation, wiring and transformers. For utility-scale PV plants, it can be as low as 20% (for a simple grid-connected system) or as high as 70% (for an off-grid system), with 40% being representative of a standard utility-scale ground mounted system. The average cost of BOS and installation for PV systems is in the range of USD 1.6 to USD 1.85/W in 2010.
Rooftop-mounted systems have BOS costs about USD 0.25/W higher than ground-mounted systems, primarily due to the additional cost of preparing the roof to receive the PV modules and slightly more costly installation (EPIA 2010, Photon 2011).

The **inverter** is one of the most important components of a PV system. It converts DC electricity from the PV modules into AC electricity to feed the grid. The size of inverters ranges from a small textbook devices for residential mount to large container solutions for utility-scale systems, like PV plants. The size and numbers of inverters required depend on the installed PV capacity. Inverters are the primary power electronics components of a PV system and typically they share the 5% of the total installed system costs. In 2012 the inverter costs ranged from 0.15 €/W to 0.35 €/W. Larger systems record lower inverter costs per unit of capacity.



	Average max efficiency	Cost	Reliability	Additional features adoption policy
🇨🇳	🟥 ~ 96%	🟩 0,19 – 0,2€/W	🟧 5 – 10 years	🟧
🇺🇸	🟨 ~ 97%	🟨 0,22€/W	🟨 10 – 15 years	🟩
🇪🇺	🟩 ~ 97,5%	🟩 0,2 – 0,21€/W	🟨 10 – 15 years	🟨
🇯🇵	🟩 ~ 98%	🟥 ~ 0,25€/W	🟩 < 20 years	

Qualitative legend	🟥	🟧	🟨	🟩
	--	-	+	++

Figure 45 Inverters efficiency, cost and reliability

Mounting structures and racking hardware components for PV modules are usually already designed systems of aluminium or steel tracks. They share more and less the 6% of the total capital cost of PV costs.

Mounting structures are different due to the location of the site. If they are for rooftop for residential and commercial use they have some type of solutions, for ground-mounted the set is different.

Combiner box and miscellaneous electrical components incorporate all remaining installation components, including combiner boxes, wires/conductors, conduits, data monitoring systems, and other miscellaneous hardware.

Site preparation and system installation are the largest components of the BOS and installation costs. They include site preparation, any physical construction works, installation and connection of the system. Costs of labour, usually the biggest quota, increase rapidly the installation costs, and vary by project and country.

System design, management and administrative costs incorporate system design and management costs for project, funding and permissions. For residential and small scale PV systems, these costs are often included in the total PV installed prices decided by companies. For large scale installations these costs can be handled directly by the sponsor or given to a service provider. In the United States in 2010 they accounted for an average 37% of the total system costs (GTM Research, 2011).

Electricity storage systems for off-grid PV systems capable of provide electricity at night or during cloudy periods. A lot of electricity storage systems are on the market, or under development, but they are expensive and seem to be more suitable for large-scale applications. Standard lead-acid batteries have been the best technology until now for small scale systems. Battery raises the cost of the PV system, but much less than grid connection in remote areas. Their use is necessary not only for remote residential and commercial applications, but also for off-grid repeater stations for mobile phones, radio beacons, etc. The lifetime of a battery, assuming the discharge does not reach the 20% of the capacity, is approximately 10 years. Another negative aspect to mention is the capacity. If for example we have a PV system which can generate 1 KWp, usually the capacity of the battery shall be around 5 times the power of the system, thus 5 KWp. The cost is near to 1500 €/KW for generated energy, without considering a battery change controller.

The graphic below shows a sum of the total cost of a whole PV system.

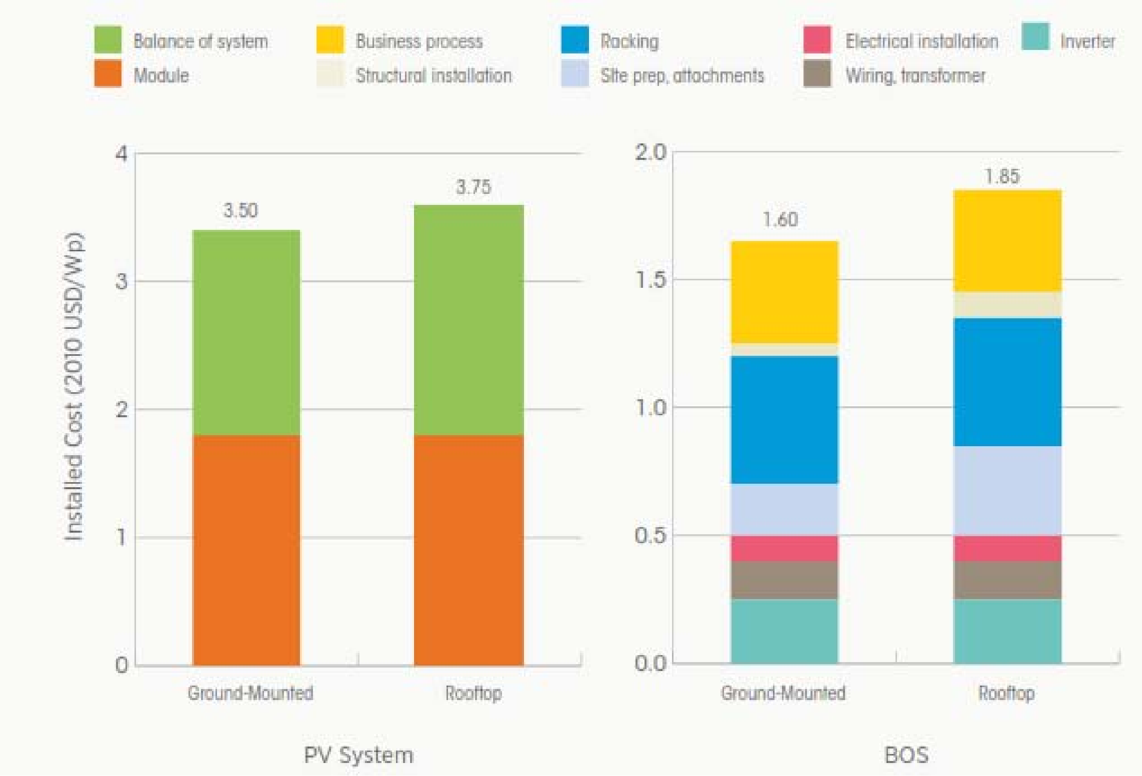
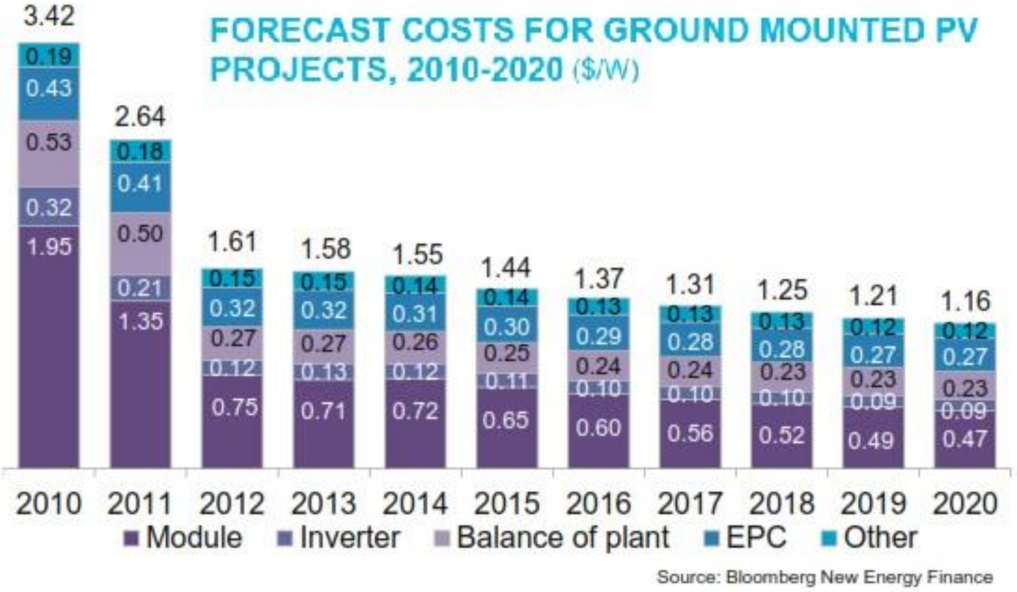


Figure 46 Shared price of a PV plant

However, the data shown are obsolete, due to prices outdated and now reduced up to 60 % or more.

Anyway the purpose of this graph is not to display the average price of a complete PV system, but the shared percentage of the price for each component of a whole PV system, which has been substantially stable for a long time.

In the study made by Bloomberg New Energy Finance in 2014 the forecast for a complete PV systems will follow the graphic below. As we can see, the fast decrease recorded from 2010 to 2012 will stop sharply, but it will continue slowly and constantly bringing the price of a whole PV system to 1.16 €/W in 2020.



Source: Bloomberg New Energy Finance

Figure 47 Price forecasts for a PV plant (BONY 2010)

7.2.1 LCOE parameter

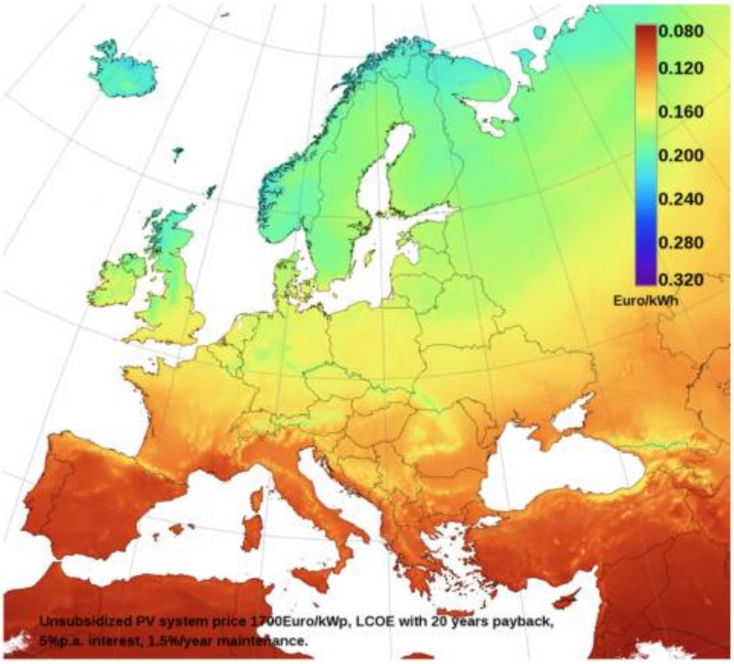
The Levelized Cost of Energy (LCOE) is the price at which electricity must be produced from a specific source to break even over the lifetime of the project. It is an economic parameter of the cost of the energy-generating system including all the costs over its lifetime: initial investment, operations and maintenance, cost of fuel and cost of capital. The formula of the LCOE is:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t+M_t+F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where It = Investment expenditures in year t, Mt= operations and maintenance expenditures in year t, Ft= fuel expenditures in year t, Et = electricity generation in the year t, r = discount rate and n = investment period considered in years.

This parameter can be used for every type of energy generating systems, and include also PV systems. For PV systems the value of Ft is 0, because fuel is not used.

From a study conducted by the European commission in 2013, we can display the PV LCOE distribution for Europe. They made a study considering a rooftop plant with a cost of 1700€/KW, with a 20 years payback time, 5% of financial p.a. interest and maintenance every 18 months. The results are shown in the graphic map below.



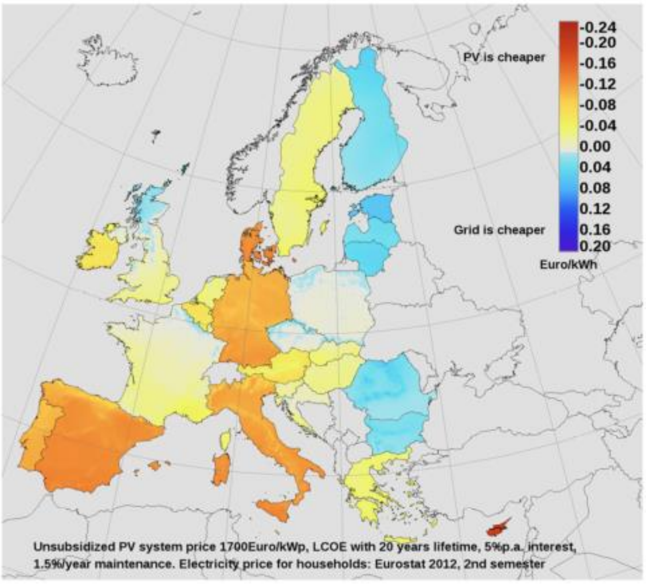
Unsubsidized PV system price 1700Euro/kWp, LCOE with 20 years payback, 5%p.a. interest, 1.5%/year maintenance.

Figure 48 LCOE values for Europe

The values range from a minimum of 0.08 EUR/kWh in southern Mediterranean to 0.32 EUR/kWh in the most northern regions.

The LCOE does not include any incentive or subsidy scheme for the PV system. However it assumes cost-free exchange with the grid.

This parameter was compared with the electricity retail price in 2012 for household, and some interesting data emerged. At this EUR 1700/kWp level, the PV LCOE is above the retail electricity price in FI, ES, LT, LI, RO and BU, as well as for some less sunny parts of UK, F, PL and CZ. In the other Member States the population benefits by a situation in which the PV LCOE is less than the residential electricity price. This amounts to 57% of EU citizens.



Unsubsidized PV system price 1700Euro/kWp, LCOE with 20 years lifetime, 5%p.a. interest, 1.5%/year maintenance. Electricity price for households: Eurostat 2012, 2nd semester

Figure 49 Photovoltaic convenience in Europe

The analysis assumes that there is full and free net metering and it does not include any feed-in tariff or subsidy scheme. That means this is the worst scenario for PV systems; in fact, if we consider feed-in tariffs and benefits from each State for the use of PV the LCOE would be less than the previous. Moreover, this study was conducted using the data from the second semester of 2012, which are already outdated. For most of the countries the retail electricity price for residential and for industrial use is nowadays essentially the same as in 2012 , or even a little bit higher. For PV systems instead the price decreased of 15% in 2013 and 12% in 2014, so the LCOE dropped down. Adopting a PV system linked to the grid is becoming much more advantageous than the normal grid for a greater number of countries. The big obstacle to this technology is the great investment that people and companies have to sustain to achieve the functioning of the system.

7.2.2 Focus on Italian situation

In 2013 were added 1.45 GW of new capacity, bringing the total to 17.9 GW in approximately 550,000 plants. The 21% of PV installed in 2013, 305 MW of power, was without benefits from FiT tariffs. Many could take advantage of the tax deductions, since 67% of the installed power is concentrated in residential sizes. There are also the first major appearances even in installations in grid-parity: respectively the 12.8%, 12.2% and 8% of the new power installed without benefits is part of the commercial segment (20-200 kW), solar power plants (> 1 MW) and industrial sizes (200-1000 MW).

In the past two years residential installations have declined much less than those of other sizes. While the general data for the Italian PV market shows from 2011 to 2013 an average contraction of 61% per year, the demand for PV systems under 20 kWp dropped only 18% a year. That was possible thanks to indirect incentive measures, tax deductions and metering, as well as the ease of use for self-consumption. The residential has accounted for 39% of the total installed in 2013 and approximately the 36% of these small plants were realized thanks to deductions. Along with the commercial segment, plants between 20 and 200 kW, domestic installations accounted for over 60% of installed in 2013.

The most critical situation is in the industrial segment, the size above 200 kW: there was a contraction of 47% compared to 2012. One of the problem was the need for systems of this size to achieve higher levels of self-consumption to compensate the inability to access the net metering (limited just for plants below 200 kW), and the great difficulty to access to credit due to the exhaustion of the incentive scheme. Power plants with more than 1 MW resisted, mainly thanks to feed-in premium tariffs (85% of installed in 2013 in this segment).

In 2014 however there was a market for about 1.4 GW. The residential segment, thanks to deductions which remained till December up to 50%, accounts for about half of the installations; about 40% of the market instead consists of commercial and industrial installations that focus on high values of self-consumption (next to 80%).An important factor to promote the development of these projects is the metering, which makes the plants below 200 kW the most favored. They account for about 60% of the segment. Finally there are power plants above 1 MW, consisting primarily of projects already developed and which however had not access to the incentive.

In 2013 the average **price** of turnkey plants dropped down in a range between 12% for the residential segment (<20 kW) and 18% for power plants (> 1 MW) compared to 2012, however the trend of the falling price is decreasing. One of the causes of the lower prices was mainly the effect of oversupply, linked to modules and other components accumulated in the warehouses of the distribution chain and sold with discount. Besides there was a reduction of the cost of the components like inverter and design and installation, which followed the trend already shown in 2012.

For the new PV modules placed on the market during 2013, there was instead a substantial stability. The fall of prices was arrested for the direct effect of the anti-dumping measures adopted in all the European Union since March 2013 and confirmed in December 2013. Another reason is the contraction of the European market (-42% approximately, from 17.5 GW in 2012 to 10.2 GW in 2013), which decreased the import of products from Asia, as they cost less than European PV manufactures.

Focusing more specifically, the market however displayed a different trend for the different technologies: an increase in the average price (between 8 and 9%) for the silicon mono and poly-crystalline technology; the price of CdTe modules was substantially stable; a decrease of 7% for amorphous silicon technology. Products from Europe, the US and Japan have shown a reduction in the average price between 12 and 15%, far from previous years (-26% on 2012 and -38% in 2011). The price of mono and poly-crystal silicon made in China even increased about 10%, for the effects of anti-dumping.

Anyway the slowed collapse of prices has not brought great relief to Italian producers of modules: the average levels of profits are still negative, due to the difficulties to reduce more production costs. In particular, regarding silicon modules it is difficult to reach again sustainable values of profit, or at least comparable to the values of 2010. For CdTe and a-SI (amorphous) modules the state results a little bit better as the cost of production dropped down due to higher conversion efficiency of the modules (in some cases more than 12%). That was possible by the results obtained from researches made in 2012.

Important reductions have been recorded on prices in storage electrochemical technologies, especially in reference to lead-acid batteries, which are the best solution for residential and small commercial (<20 kWp) applications and presenting a storage capacity between 2.5 and 15 kWh.

With today's prices, and tax deductions up to 50%, a plant produces energy at a cost of about 0.06 €/kWh, and without tax deductions at about 0.11 €/kWh. This is the actual real value of the energy produced by the PV.

The **trend** expected till 2020 for the price of modules forecasts a reduction for each year between -2% (in the first years) and -8% (from 2016). This reduction is much more restrained than the -26% in 2012 and -40% in 2011. A reasonable forecast for 2020 seems to assume values below the 0.50 €/Wp in the case of silicon modules and near 0.40 €/Wp for the thin film according to the Energy & Strategy Group.

These price forecasts are based on three main factors. The first is the way out of the state of oversupply for the upstream stages of the production chain, also due to the phenomenon of industry consolidation; the second is the lower incidence of the modules on the European market from China, caused by compensation measures for anti-dumping and less use of aggressive pricing policies by Asian operators on international markets due to result of their internal market growth. The third factor is the increase in global demand.

In Italy there was a big boost for PV systems in the past years. That led to a FiT (feed-in tariff). A feed-in tariff is a policy mechanism designed to accelerate investment in renewable energy technologies, which is achieved by offering long-term contracts to renewable energy producers, typically based on the cost of generation of each technology, which for PV are the highest. They pay an equal amount for energy and moreover, if they require energy, they have access with a discount price, named self-consumption.

For a long time Italy had one of the best FiT in Europe according to CONTO ENERGIA, due to the unlimited resource of sunlight. Below are shown the feed-in tariffs and self-consumption tariffs for most typical PV technologies.

Table 10 Italian Fit for rooftop and grounded PV plant

Size	Term	Rooftop/BIPV		Ground-mounted	
		Feed-in tariff €/kWh	Self-consumption tariff €/kWh	Feed-in tariff €/kWh	Self-consumption tariff €/kWh
1-3kW	20 years	0.182	0.100	0.176	0.094
3-20kW	20 years	0.171	0.089	0.165	0.083
20-200kW	20 years	0.157	0.075	0.151	0.069
200kW-1MW	20 years	0.130	0.048	0.124	0.042
1MW-5MW	20 years	0.118	0.036	0.113	0.031
5MW+	20 years	0.112	0.030	0.106	0.024

Table 11 Italian Fit for concentrating and innovative PV plant

Size	Term	Concentrating PV plants		PV plants using innovative technology	
		Feed-in tariff €/kWh	Self-consumption tariff €/kWh	Feed-in tariff €/kWh	Self-consumption tariff €/kWh
1-20kW	20 years	0.242	0.160	0.215	0.133
20-200kW	20 years	0.231	0.149	0.201	0.119
>200kW	20 years	0.217	0.135	0.174	0.092

For PV plants with a nominal power over 1MWp, the GSE pays a feed-in premium that is determined as the difference between the feed-in tariff above and the applicable average electricity market price.

The feed-in premiums in the table are increased by the following increments:

- €0.02/kWh for plants using modules and inverters produced in the European Union or European Economic Area if they enter into operation on or before 31 December 2013; €0.01/kWh if they enter into operation on or before 31 December 2014; and €0.005/kWh if they enter into operation after 31 December 2014.
- €0.03/kWh for plants up to 20 kW nominal power installed on rooftops with simultaneous complete removal of asbestos and €0.02/kWh for plants above 20 kW nominal power if they enter into operation on or before 31 December 2013; €0.02/kWh up to 20 kW nominal power and €0.01/kWh above 20 kW nominal power if they enter into operation on or before 31 December 2014; and €0.01/kWh up to 20 kW nominal power and €0.005/kWh above 20 kW nominal power if they enter into operation after 31 December 2014.

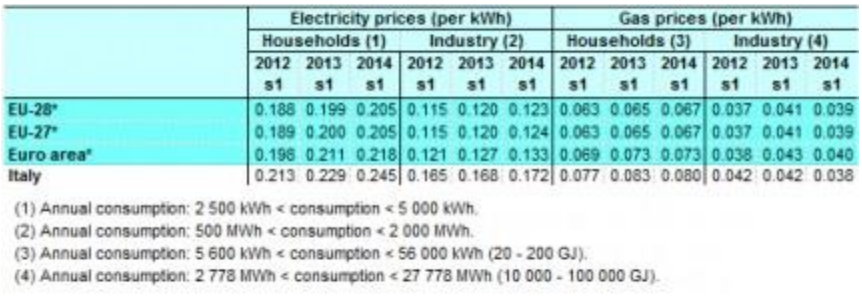
As on July 5, 2013, Italy ceased offering FIT payments because its 6.7 G€ cap was reached, which led to a review of the feed-in tariffs.

Art. 26 of the Law 116/2014 (the Spalma Incentivi provision) applies a reduction to the tariffs that have been awarded before to PV plants with a nominal peak power exceeding 200 kW, with the following options:

- **Option A** provides for a solution that was already contemplated by the Law-Decree: i.e., a reduction of the tariff by a ratio ranging from 17% to 25% depending on the residual incentivized period compensated by an extension of the incentivized period to 24 years starting from the date of entry into operation of the relevant plant (instead of the current 20 years).
- **Option B** provides that, without modifying the duration of the incentivized period (i.e.,20 years), during a first part of the remaining incentivized period, the tariff will be reduced and that, during a second part of the remaining incentivized period, the FIT will be increased. The re-modulation ratios will be established by the Italian Ministry for Economic Development.
- **Option C** provides for a flat reduction of the tariff, for the remaining incentivized period without modifying the duration of the same, equal to 6% for plants with a capacity between 200 and 500 kW, 7% for plants with a capacity between 500 and 900 kW, 8% for plants with a capacity above 900 kW.

Prices of electricity and gas for normal use of the grid in Italy is summed up below:

Table 12 Italian retail energy and gas prices



	Electricity prices (per kWh)						Gas prices (per kWh)					
	Households (1)			Industry (2)			Households (3)			Industry (4)		
	2012 s1	2013 s1	2014 s1	2012 s1	2013 s1	2014 s1	2012 s1	2013 s1	2014 s1	2012 s1	2013 s1	2014 s1
EU-28*	0.188	0.199	0.205	0.115	0.120	0.123	0.063	0.065	0.067	0.037	0.041	0.039
EU-27*	0.189	0.200	0.205	0.115	0.120	0.124	0.063	0.065	0.067	0.037	0.041	0.039
Euro area*	0.198	0.211	0.218	0.121	0.127	0.133	0.069	0.073	0.073	0.038	0.043	0.040
Italy	0.213	0.229	0.245	0.165	0.168	0.172	0.077	0.083	0.080	0.042	0.042	0.038

(1) Annual consumption: 2 500 kWh < consumption < 5 000 kWh.
(2) Annual consumption: 500 MWh < consumption < 2 000 MWh.
(3) Annual consumption: 5 600 kWh < consumption < 56 000 kWh (20 - 200 GJ).
(4) Annual consumption: 2 778 MWh < consumption < 27 778 MWh (10 000 - 100 000 GJ).

As we can notice there was an increase from 2012, either for household and industry. If we compare this data with the actual Italian LCOE (Levelized cost of electricity) for PV system we can notice that it is higher for sure. It means that the electricity produced by PV systems is cheaper than the electricity purchased from the normal grid.

7.2.3 Focus on Hungarian situation

As we said previously, the main reason behind the slow market expansion is imputable to the low FIT (11 eurocents), roughly equal to the average electricity price and therefore with little incentive. Feed-in tariffs in Hungary in 2013 (in HUF/kWh):

Table 13 Hungarian Fit

General, two zone time tariff		Tariff for public institutions		Seasonal (controlled) tariffs
Peak-time	Off-peak time	Peak-time	Off-peak time	23,04
41,44	30,97	35,12	24,56	

FIT is set annually and is adjusted to the rate of inflation. 1 Euro is approximately 310 Forints.

The solar investments of companies and institutions depend on difficulties and EU funding. Problems have been the low support source and short period for application. There are several EU and Hungarian government direct and non-refundable funds available to support PV installations:

- for private households usually 30% of the total system cost can be refunded
- for companies, organizations and local governments 40-70% can be refunded

The access to the grid for solar systems in Hungary is guaranteed by law, but systems of capacity higher than 500 kWp need to obtain a permit from the Hungarian Energy Office. Small installations are subject to utility operator permit. There are six utility operators in Hungary, the most important is ELMÜ. It is a pathfinder, introducing simplified procedure for PV grid connection. Most of the on-grid PV systems are located in the central region which ELMÜ is also situated. Other utilities try to harmonize their procedures with this operator.

The electricity introduced through the grid must not exceed 2/3 of the electricity consumed. If it is not the case, then such installation would be considered like a small electric power station and stricter grid connecting technical requirements would apply, which means less profits and more money to pay. The Hungarian Certificate of the inverters is one of the main problems with PV plants. It is a big obstacle in grid connecting process in Hungary, and hits every size of systems. This certificate is required by utilities operators before opening the access to their grid. Certificates are issued by the Hungarian Testing Laboratory. This requirement results in extra costs for investors. Furthermore the lack of capital and effective governmental support cut the chance to build physical installations. Experiences have shown that without governmental granting support the sector development simply is on halt.

Moreover the levy of HUF 114/kg (0.36 €/kg) was introduced to cover the cost of disposing the panels when they reach the end of their life according to an official rule from the agriculture ministry quoted in local media reports.

Despite this unlikely situation, there has been a growing interest in solar PV from municipalities, not only in investments, development and design but on eco fields too. Almost 170 applications were ordered to the Solar Corona Championship in 2012 from local governments. The winner had the highest proportion of solar PV or collector. One of the winner was Nagypáli, second was Újszilvás with the biggest solar PV system, and the third was Csitár-Nógrádgárdony.

The recent rise in the demand for solar PV is due to the increase electricity bills becoming too expensive for Hungarians, while the progress is partly supported by growing environmental concerns.

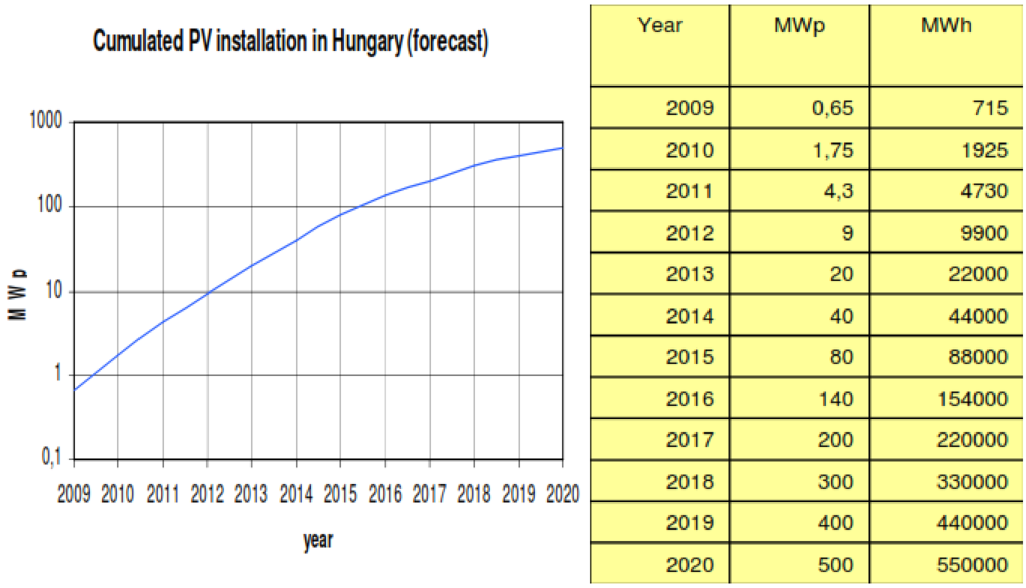
Table 14 Hungarian retail electricity and gas prices

	Electricity prices (per kWh)						Gas prices (per kWh)					
	Households (1)			Industry (2)			Households (3)			Industry (4)		
	2012 s1	2013 s1	2014 s1	2012 s1	2013 s1	2014 s1	2012 s1	2013 s1	2014 s1	2012 s1	2013 s1	2014 s1
EU-28*	0.188	0.199	0.205	0.115	0.120	0.123	0.063	0.065	0.067	0.037	0.041	0.039
EU-27*	0.189	0.200	0.205	0.115	0.120	0.124	0.063	0.065	0.067	0.037	0.041	0.039
Euro area*	0.198	0.211	0.218	0.121	0.127	0.133	0.069	0.073	0.073	0.038	0.043	0.040
Hungary	0.155	0.140	0.120	0.095	0.096	0.091	0.048	0.043	0.037	0.044	0.041	0.040

(1) Annual consumption: 2 500 kWh < consumption < 5 000 kWh.
(2) Annual consumption: 500 MWh < consumption < 2 000 MWh.
(3) Annual consumption: 5 600 kWh < consumption < 56 000 kWh (20 - 200 GJ).
(4) Annual consumption: 2 778 MWh < consumption < 27 778 MWh (10 000 - 100 000 GJ).

From the studies previously reported it emerges that the **LCOE** is still less than the price of retail electricity. The difference is not remarkable as for Italy, but it is anyway a positive data. That means, as well as for Italy, a PV system appears cheaper than purchasing the energy from the grid.

The PV market in Hungary is growing, slowly but stable. Some forecast were made by Solar Experts, in which they expected around 500 MW of capacity. Below is displayed the trend.



Year	MWp	MWh
2009	0,65	715
2010	1,75	1925
2011	4,3	4730
2012	9	9900
2013	20	22000
2014	40	44000
2015	80	88000
2016	140	154000
2017	200	220000
2018	300	330000
2019	400	440000
2020	500	550000

Figure 50 Forecasts for cumulated installed capacity in Hungary

8 Montalto di Castro Photovoltaic Power Station

The biggest large-scale PV plant in Europe is in Italy in Montalto di Castro. The total output is 85 MWp. This is enough to supply a city with a population of about 24,000 with electrical energy around-the-clock using solely the power of the sun. In the case of the PV power station in Montalto di Castro this saves 78,000 tonnes of CO2 emissions every year.

The photovoltaic park of Montalto di Castro is in the region of Lazio, near Viterbo. The project was designed by the Sunray Company, and then bought by the SunPower Company.

The project was developed through several phases. In the first phase the capacity of the plant was about 24 MW, and it was completed at the end of 2009.

The second one was commissioned in 2010 (8 MW), the third and the fourth were finished at the end of 2010, for an amount of 44 MW.

At the beginning of 2011 the company SunPower sold the whole park to an association of international investors. As SunPower designed and built the solar photovoltaic park it will continue to provide assistance and maintenance.

Perfectly integrated into the landscape, the solar farm is not a problem for the population that considered the energy, generated from modules of the photovoltaic park, an opportunity for development and growth. The plant provides clean energy and reduction of pollutants in the atmosphere.

Figure 51 View of the Montalto di Castro Power Plants

8.1 Principal data

The main data of the PV power plant are:

- **Inverters**: 124 x SC 630HE
- **Developer**: SunPowerCorp
- **SunPower Product:** SunPower E18 / 305W panels , SunPower T0 tracker
- **Site area:** 166 acres (1.7 km^2)
- **Units operational:** 276,156
- **Nameplate capacity:** 84.23 MW (DC)
- **Capacity factor**: 19%
- **Annual generation**: 140 GW

8.2 Costs of the plant

- **First and second phase:** 255 millions of euros (51 MW)
- **Third and fourth phase:** 195,2 millions of euros (to achieve 84 MW)
- **Sun power E18:** 400 Euros
- **Sc 630HE:** 150000 Euros
- **SunPower T0 tracker:** 4 Euros/Watt

9 Software SMA: Sunny Design 3

9.1 Introduction

Sunny Design 3 is a software developed from the SMA Solar Technology, a big company established in the USA. The software allows to plan and design PV plants. It is a free software and it is available in every language. It permits, after choosing the main parameters of your PV plants, to find a good combination for the PV array and for the inverter, in relation to the performance class. In the end it is able to estimate your potential self-consumption of the energy generated by the PV plant and show it in a chart.

8.2 Overview of the software

Some of the characteristics of this software are:

- **Easy to use**
  (Optimal design for grid-connected PV systems, tips for system optimization, easy interface)
- **Comprehensive**
  (Database of current PV modules, use of high-resolution meteorological data, design of PV systems with polystring, design of PV hybrid projects, creation of design proposals, energy analysis over an operating year, forecast of projected self-consumption, custom calculation of optimum dimensioning for inverters)
- **Flexible**
  (Worldwide location support, import of your own load profiles and meteorological data, regular online updates)

Principal functions are:

- Plan project with all industrial requirements and according to all current laws
- Use different layouts and choose from all SMA inverters
- Use different types of arrays
- Give specific input for a country or a city, e.g. electric voltage, min and max temperature
- Create project documentation with standard values for projects

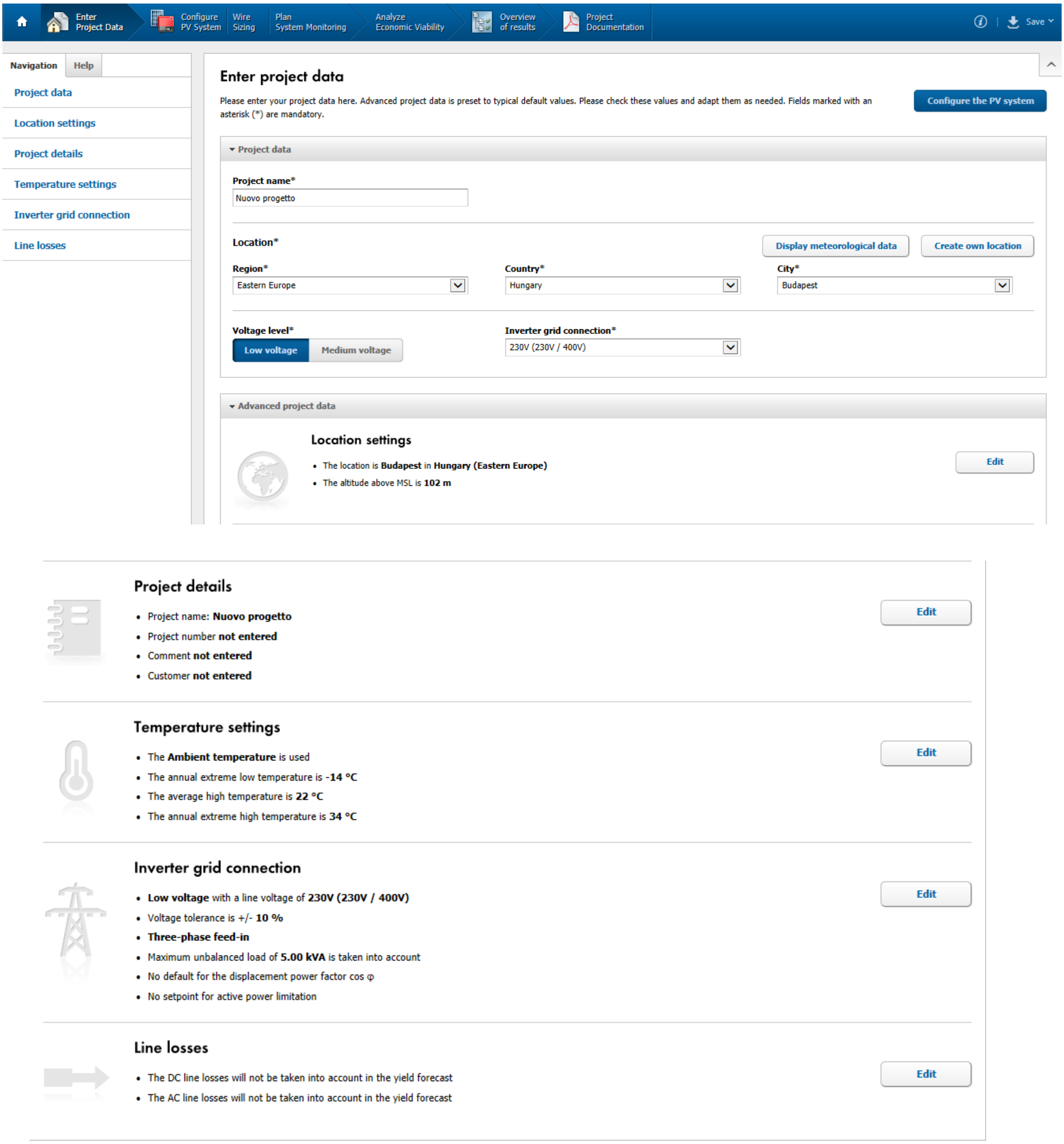
- Detect potential self-consumption of PV energy
- Create an own site with accurate meteorological data
- Create own PV modules
- Automatically check operation data of the planned PV plant
- Cable dimensioning

The software is mainly divided into 7 sections:

1. **First section**

   In the first section we can choose main data of project. We can choose the name, costumers, the location and type of electric voltage. After choosing the location the program loads automatically common data for that position, like temperatures and electric voltage for that state, example Budapest (min -22°, max 34°, voltage 230V). It is also possible to modify meteorological data. The parameters are 3: annual extreme low and high temperature, average high temperature. Changing these parameters make some effects:

   - decreasing the minimum temperature causes an increasing of the maximum voltage value of the PV modules
   - increasing the parameter called "annual extreme high temperature" causes a decrease of the minimum voltage value of the power plant



Enter project data

Please enter your project data here. Advanced project data is preset to typical default values. Please check these values and adapt them as needed. Fields marked with an asterisk (*) are mandatory.

Project name*: Nuovo progetto

Location*

Region*: Eastern Europe

Country*: Hungary

City*: Budapest

Voltage level*: Low voltage

Inverter grid connection*: 230V (230V / 400V)

Location settings

- The location is **Budapest** in **Hungary (Eastern Europe)**
- The altitude above MSL is **102 m**

Project details

- Project name: **Nuovo progetto**
- Project number **not entered**
- Comment **not entered**
- Customer **not entered**

Temperature settings

- The **Ambient temperature** is used
- The annual extreme low temperature is **-14 °C**
- The average high temperature is **22 °C**
- The annual extreme high temperature is **34 °C**

Inverter grid connection

- **Low voltage** with a line voltage of **230V (230V / 400V)**
- Voltage tolerance is +/- **10 %**
- **Three-phase feed-in**
- Maximum unbalanced load of **5.00 kVA** is taken into account
- No default for the displacement power factor cos φ
- No setpoint for active power limitation

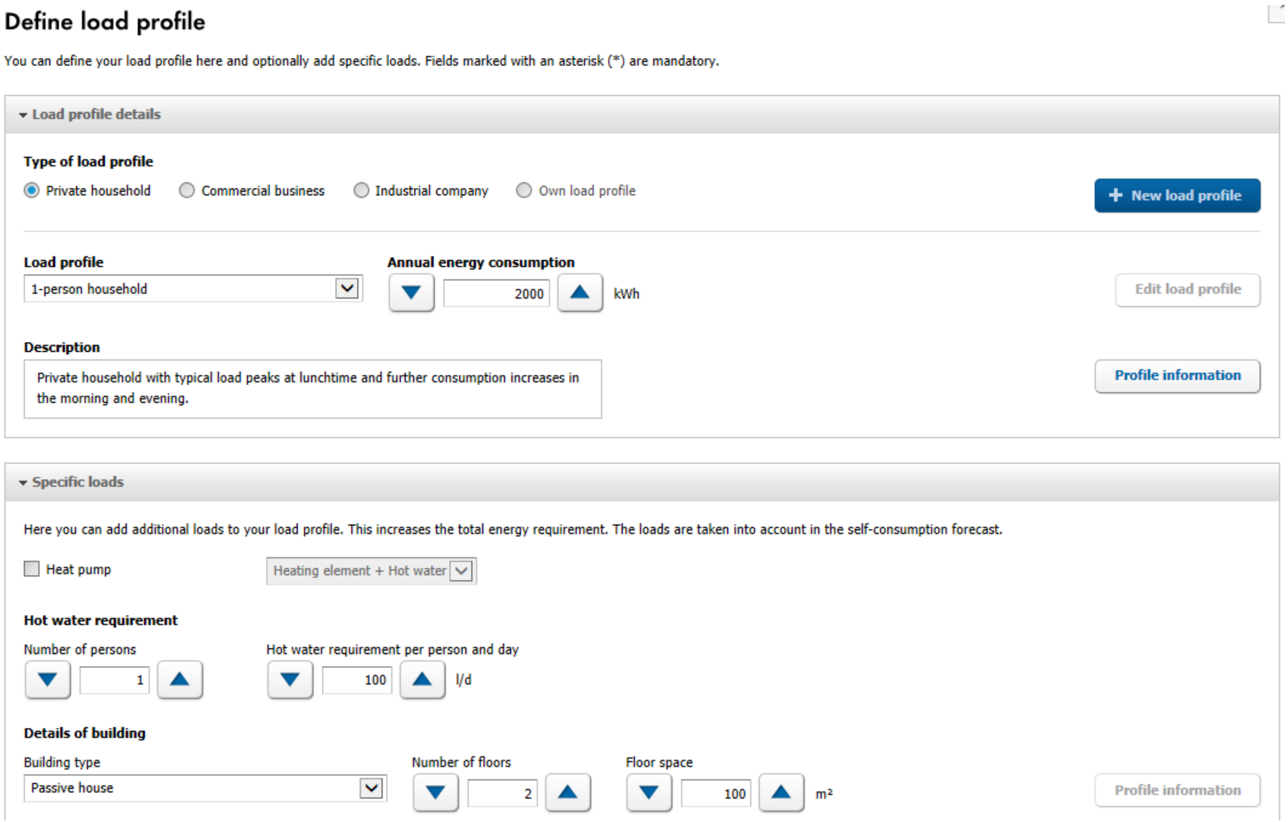
Line losses

- The DC line losses will not be taken into account in the yield forecast
- The AC line losses will not be taken into account in the yield forecast

Figure 52 First secton of Sunny Design 3

2. Second section

In this section we can define our load profile here and optionally add specific loads. We can decide from household to industrial company or our own profile. The software automatically loads the annual energy consumption from its database, but we can change according our request. Then we can also specify number of person, hot water consumption and if we are using a heat pump. In addition we can also give some specifications about the building, like building type, number of floor and floor space.



Define load profile

You can define your load profile here and optionally add specific loads. Fields marked with an asterisk (*) are mandatory.

Load profile details

Type of load profile

● Private household ○ Commercial business ○ Industrial company ○ Own load profile

Load profile: 1-person household

Annual energy consumption: 2000 kWh

Description: Private household with typical load peaks at lunchtime and further consumption increases in the morning and evening.

Specific loads

Here you can add additional loads to your load profile. This increases the total energy requirement. The loads are taken into account in the self-consumption forecast.

☐ Heat pump — Heating element + Hot water

Hot water requirement

Number of persons: 1

Hot water requirement per person and day: 100 l/d

Details of building

Building type: Passive house

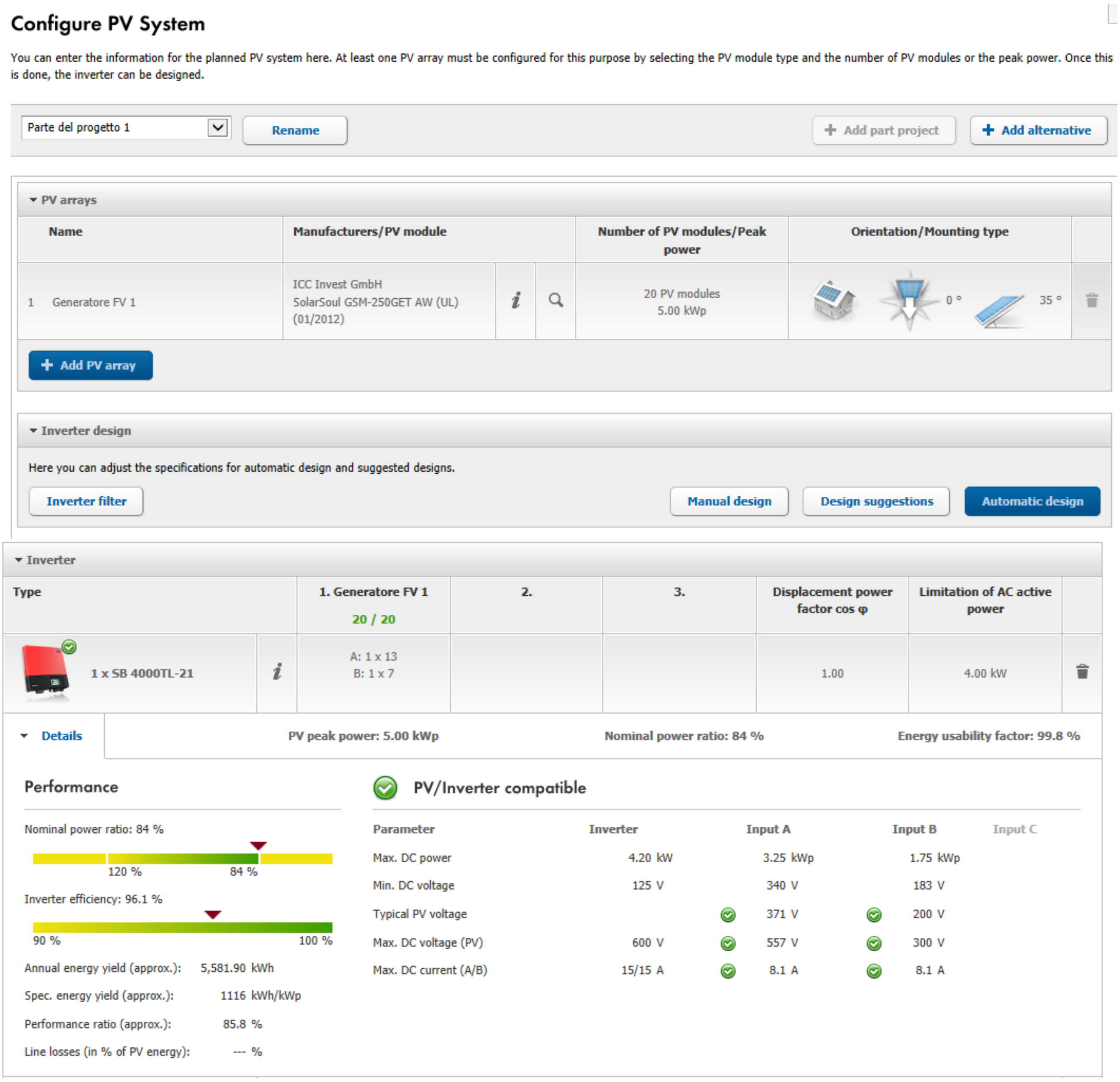
Number of floors: 2

Floor space: 100 m²

Figure 53 Second secton of Sunny Design 3

3. Third section

In this section we can configure the plant. We can choose the type of PV modules from a big database already inside the software, or even create our own module. Subsequently we can select the number of PV modules, orientation and mounting type. We can notice that the software chooses automatically the best orientation and mounting type for the selected place. After that there is the choice of the inverters. The software permits us the manual design of the inverter choosing from a hundreds of SMA products or making a suggestion. It is advisable to use the suggestion of the software because it can find the best combination for the PV plants. Rapidly it shows main parameters (voltage, electricity, power and nominal ratio performance) of the inverter and the best array for the plant.



Configure PV System

You can enter the information for the planned PV system here. At least one PV array must be configured for this purpose by selecting the PV module type and the number of PV modules or the peak power. Once this is done, the inverter can be designed.

Parte del progetto 1

Name	Manufacturers/PV module	Number of PV modules/Peak power	Orientation/Mounting type
1 Generatore FV 1	ICC Invest GmbH SolarSoul GSM-250GET AW (UL) (01/2012)	20 PV modules 5.00 kWp	0 ° 35 °

Here you can adjust the specifications for automatic design and suggested designs.

Type	1. Generatore FV 1 20 / 20	2.	3.	Displacement power factor cos φ	Limitation of AC active power
1 x SB 4000TL-21	A: 1 x 13 B: 1 x 7			1.00	4.00 kW

PV peak power: 5.00 kWp
Nominal power ratio: 84 %
Energy usability factor: 99.8 %

Performance

Nominal power ratio: 84 %
120 % 84 %
Inverter efficiency: 96.1 %
90 % 100 %

Annual energy yield (approx.):	5,581.90 kWh
Spec. energy yield (approx.):	1116 kWh/kWp
Performance ratio (approx.):	85.8 %
Line losses (in % of PV energy):	--- %

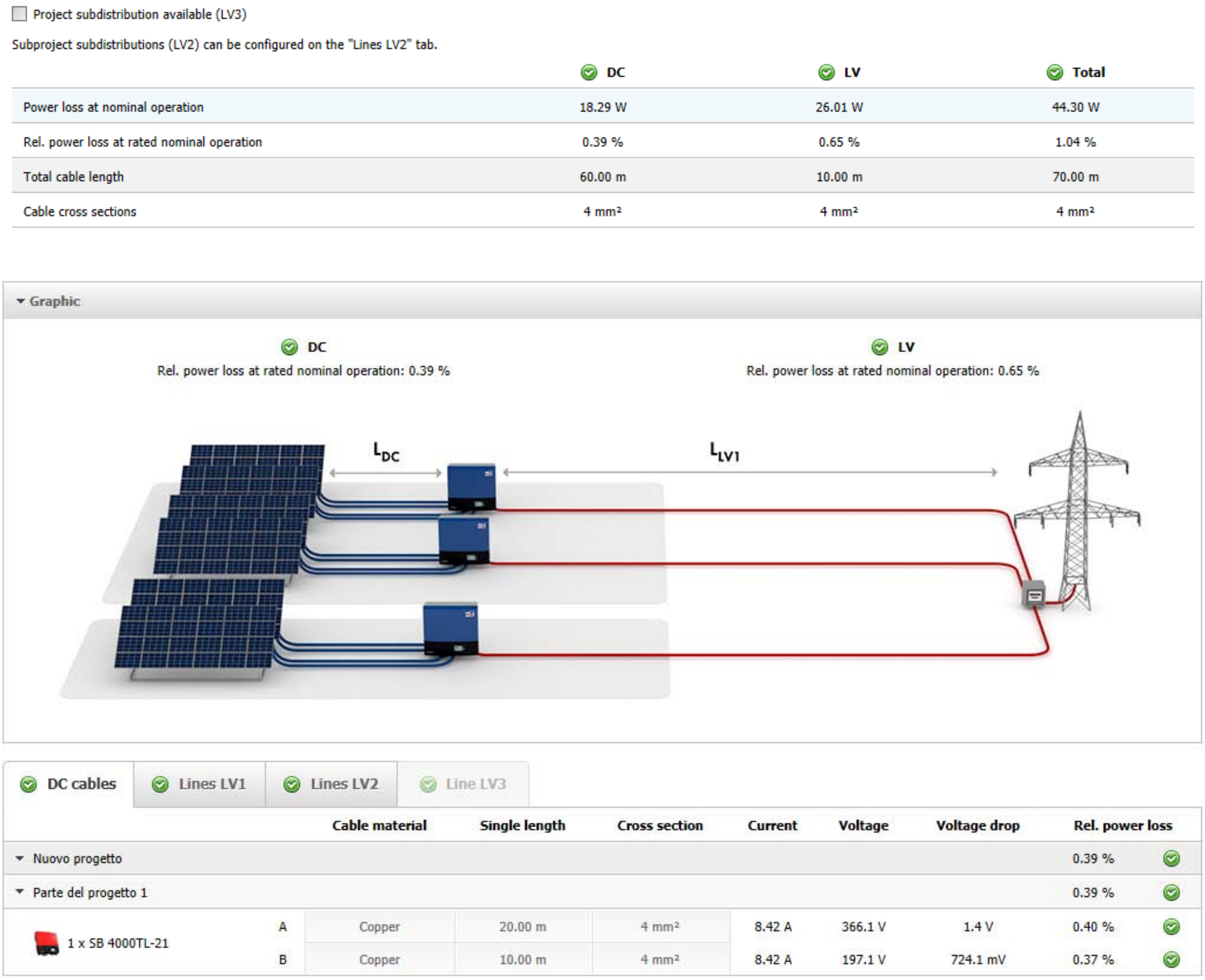
PV/Inverter compatible

Parameter	Inverter	Input A	Input B	Input C
Max. DC power	4.20 kW	3.25 kWp	1.75 kWp	
Min. DC voltage	125 V	340 V	183 V	
Typical PV voltage		✓ 371 V	✓ 200 V	
Max. DC voltage (PV)	600 V	✓ 557 V	✓ 300 V	
Max. DC current (A/B)	15/15 A	✓ 8.1 A	✓ 8.1 A	

Figure 54 Third secton of Sunny Design 3

4. Fourth section

In this section the software automatically shows the best option for wire material, length and the section. It also allows the selection of these parameters. After that it calculates the power losses of the selected line.



☐ Project subdistribution available (LV3)

Subproject subdistributions (LV2) can be configured on the "Lines LV2" tab.

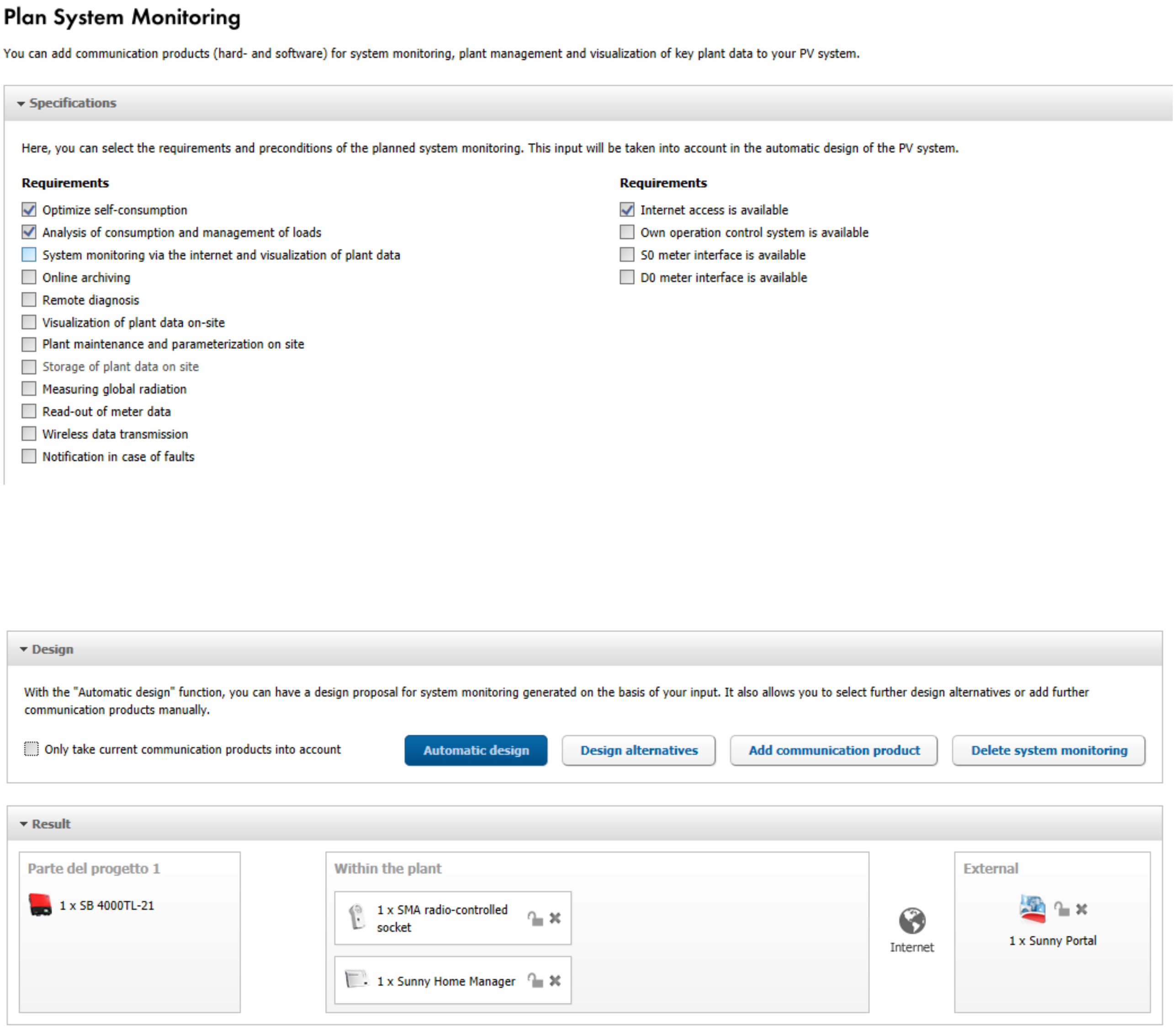
	✓ DC	✓ LV	✓ Total
Power loss at nominal operation	18.29 W	26.01 W	44.30 W
Rel. power loss at rated nominal operation	0.39 %	0.65 %	1.04 %
Total cable length	60.00 m	10.00 m	70.00 m
Cable cross sections	4 mm²	4 mm²	4 mm²

		Cable material	Single length	Cross section	Current	Voltage	Voltage drop	Rel. power loss	
▾ Nuovo progetto								0.39 %	✓
▾ Parte del progetto 1								0.39 %	✓
1 x SB 4000TL-21	A	Copper	20.00 m	4 mm²	8.42 A	366.1 V	1.4 V	0.40 %	✓
	B	Copper	10.00 m	4 mm²	8.42 A	197.1 V	724.1 mV	0.37 %	✓

Figure 55 Fourth secton of Sunny Design 3

5. Fifth section

In this section we can choose a plan system monitoring giving as input some requirements. Then we can decide whether to use the manual design or the automatically design (best option automatically). The software will choose the correct hardware for monitoring our plant.



Plan System Monitoring

You can add communication products (hard- and software) for system monitoring, plant management and visualization of key plant data to your PV system.

Here, you can select the requirements and preconditions of the planned system monitoring. This input will be taken into account in the automatic design of the PV system.

Requirements

- ☑ Optimize self-consumption
- ☑ Analysis of consumption and management of loads
- ☐ System monitoring via the internet and visualization of plant data
- ☐ Online archiving
- ☐ Remote diagnosis
- ☐ Visualization of plant data on-site
- ☐ Plant maintenance and parameterization on site
- ☐ Storage of plant data on site
- ☐ Measuring global radiation
- ☐ Read-out of meter data
- ☐ Wireless data transmission
- ☐ Notification in case of faults

Requirements

- ☑ Internet access is available
- ☐ Own operation control system is available
- ☐ S0 meter interface is available
- ☐ D0 meter interface is available

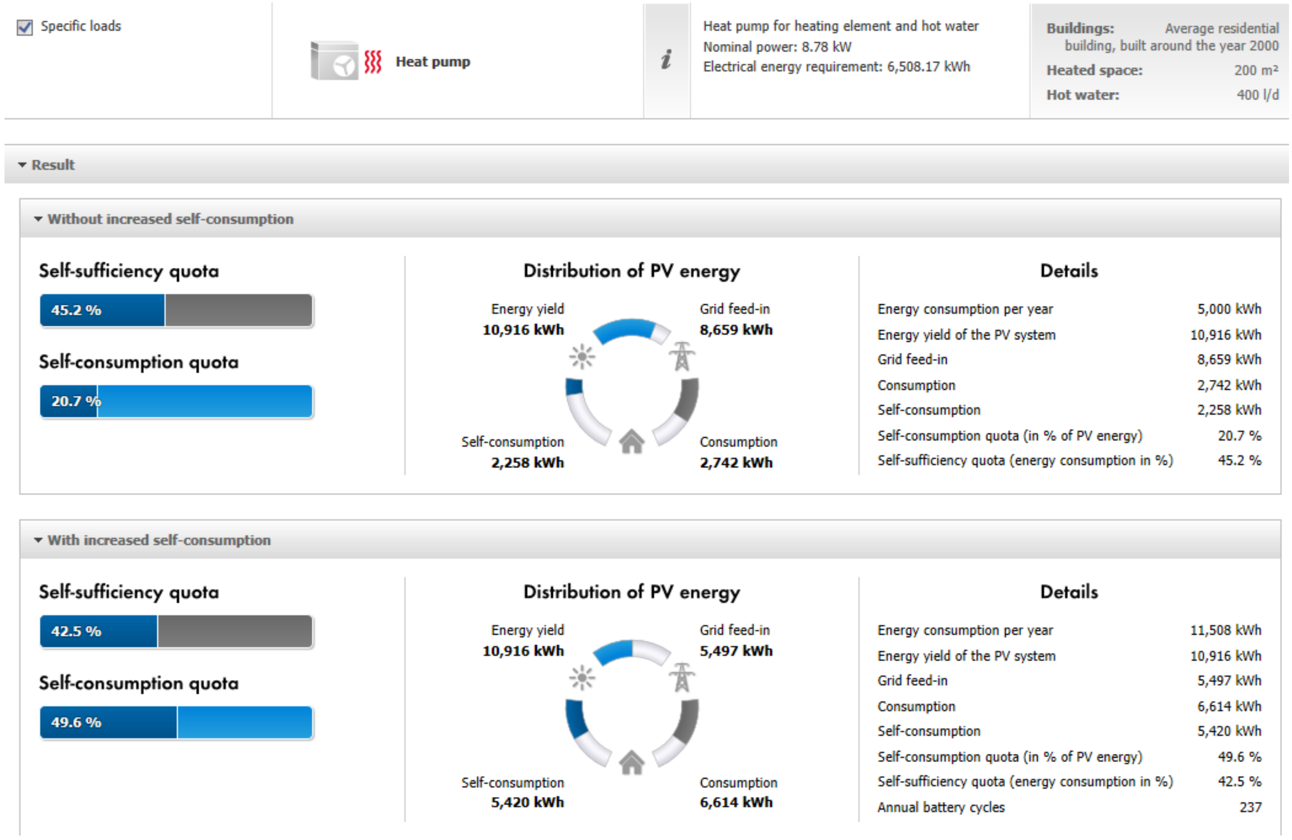
With the "Automatic design" function, you can have a design proposal for system monitoring generated on the basis of your input. It also allows you to select further design alternatives or add further communication products manually.

☐ Only take current communication products into account

Figure 56 Fifth secton of Sunny Design 3

6. Sixth section

Here we can determine our possible self-consumption of the produced PV energy. We can choose if we want to use a battery to storage the temporary surplus of solar power, and also we can generate graphic and data for the use of a heat pump.



☑ Specific loads

Heat pump

Heat pump for heating element and hot water
Nominal power: 8.78 kW
Electrical energy requirement: 6,508.17 kWh

Buildings: Average residential building, built around the year 2000
Heated space: 200 m²
Hot water: 400 l/d

▾ Result

▾ Without increased self-consumption

Self-sufficiency quota: 45.2 %

Self-consumption quota: 20.7 %

Distribution of PV energy

Energy yield **10,916 kWh**
Grid feed-in **8,659 kWh**
Self-consumption **2,258 kWh**
Consumption **2,742 kWh**

Details

Energy consumption per year	5,000 kWh
Energy yield of the PV system	10,916 kWh
Grid feed-in	8,659 kWh
Consumption	2,742 kWh
Self-consumption	2,258 kWh
Self-consumption quota (in % of PV energy)	20.7 %
Self-sufficiency quota (energy consumption in %)	45.2 %

▾ With increased self-consumption

Self-sufficiency quota: 42.5 %

Self-consumption quota: 49.6 %

Distribution of PV energy

Energy yield **10,916 kWh**
Grid feed-in **5,497 kWh**
Self-consumption **5,420 kWh**
Consumption **6,614 kWh**

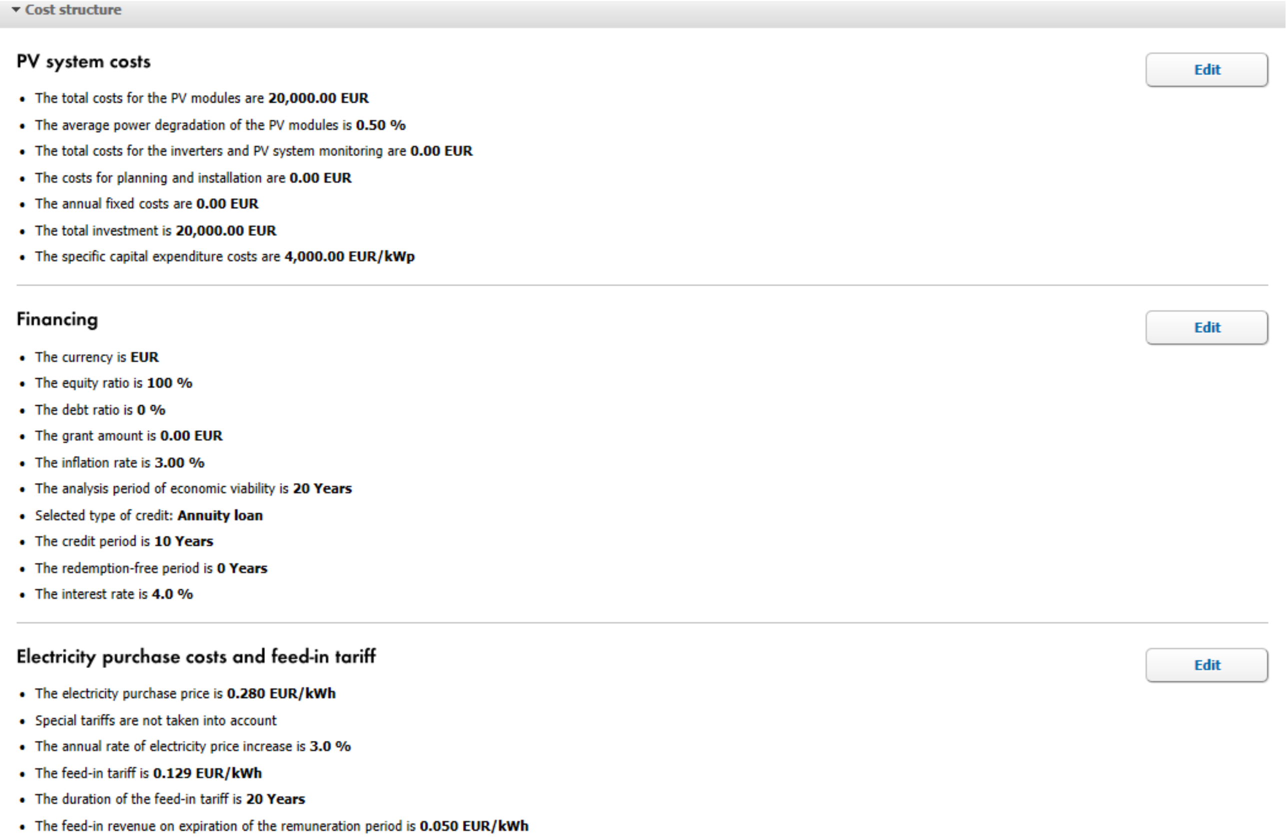
Details

Energy consumption per year	11,508 kWh
Energy yield of the PV system	10,916 kWh
Grid feed-in	5,497 kWh
Consumption	6,614 kWh
Self-consumption	5,420 kWh
Self-consumption quota (in % of PV energy)	49.6 %
Self-sufficiency quota (energy consumption in %)	42.5 %
Annual battery cycles	237

Figure 57 Sixth secton of Sunny Design 3

7. Seventh section

In this section we can edit details on the cost structure and consider an analysis of the economic viability of the PV project.



PV system costs

- The total costs for the PV modules are **20,000.00 EUR**
- The average power degradation of the PV modules is **0.50 %**
- The total costs for the inverters and PV system monitoring are **0.00 EUR**
- The costs for planning and installation are **0.00 EUR**
- The annual fixed costs are **0.00 EUR**
- The total investment is **20,000.00 EUR**
- The specific capital expenditure costs are **4,000.00 EUR/kWp**

Financing

- The currency is **EUR**
- The equity ratio is **100 %**
- The debt ratio is **0 %**
- The grant amount is **0.00 EUR**
- The inflation rate is **3.00 %**
- The analysis period of economic viability is **20 Years**
- Selected type of credit: **Annuity loan**
- The credit period is **10 Years**
- The redemption-free period is **0 Years**
- The interest rate is **4.0 %**

Electricity purchase costs and feed-in tariff

- The electricity purchase price is **0.280 EUR/kWh**
- Special tariffs are not taken into account
- The annual rate of electricity price increase is **3.0 %**
- The feed-in tariff is **0.129 EUR/kWh**
- The duration of the feed-in tariff is **20 Years**
- The feed-in revenue on expiration of the remuneration period is **0.050 EUR/kWh**

Figure 58 Seventh secton of Sunny Design 3

8. Eighth section

In this section there is the overview of the entries, results and current information on the design of the PV system.

9. Ninth section

This is the last section. Here we can modify and print our project documentation.

9.3 Purpose of the project

With the help of the SMA software we will study two different situations, Italy and Hungary.

These are the main features of our work:

Table 15 Data for SMA Sunny Design project

Location	Venice	Budapest
Azimut Angle	0	0
Tilt Angle	45°	45°
Type of load	Ground mount	Ground mount

Other important data to mention for our study is the annual total of global radiation. For Venice it results 1326.29 kWh/m²a, instead for Budapest 1203.99 kWh/m²a. Already from this little difference we can expect more production of energy in Italy then in Hungary.

The grid voltage was set for 230V, which is the normal setting for Italy and Hungary. The photovoltaic peak power was chosen for 84.23 MW, which is the same power of the Montalto di Castro Photovoltaic Power Station.

For each region 4 different types of photovoltaic panels were chosen. Then with the software we tried to find the best solution with inverters maximizing the energy yield.

Types of photovoltaic panels are:

- SMA Demo Poly 240
- Schott Solar PV Inc Perform Mono 250 (UL)
- Sharp ND-R250A5
- Suntech Power STP300-VRM-1

Companies that produce these panels are the most famous around the world and they supply more than the 90% of PV. First the software shows us the quantity of modules and inverters.

Table 16 Data for alternatives in SMA Sunny Design

		pv modules	# of pv modules	inverters	# of inverters
alternative 1	**venice**	**SMA Demo Poly 240**	**350958**	**STP25000TL-30 +**	**3375**
	budapest			**MLX 60 +**	**1394**
alternative 2	**venice**	**Schott Solar PV Inc Perform Mono 250 (UL)**	**336920**	**STP25000TL-30**	**3438**
	budapest				**3438**
alternative 3	**venice**	**Sharp ND-R250A5**	**336920**	**STP25000TL-30**	**3336**
	budapest			**MLX 60 +**	**1460**
alternative 4	**venice**	**Suntech Power STP300-VRM-1**	**280767**	**STP25000TL-30**	**3424**
	budapest			**MLX 60 +**	**1202**

We can notice how for different types of pv modules correspond different types of inverters. That is because every type of module has different characteristics, so to achieve the best solution we need to use different type of inverters. We can also notice that for the same module we need to use different types of inverters depending on the region we choose. The purpose of our plant is not supplying the energy consumption for a household, but it is supplying the electric web. So different countries imply different rules. In Italy, PV systems with a power of more than 6 kWp must be of a three-phase design in accordance with CEI 0-21 and must be able to provide reactive power in accordance with the specifications of the grid operator. Additionally, an external SPI (grid and plant protection) must be installed. The displacement power factor of the inverter used is automatically adjusted to 0.9 overexcited.

This is the main reason for different type of inverters. Anyway the software lets us choose different types of pv modules from a lot of companies, but inverters just from its company, so we cannot be sure this will be the best solution.

We made different diagrams which show our results from the software. They show the AC active power, the annual energy yield, the performance ratio and the specific energy yield.

The AC active power (MW) is the power that we introduce in the electric web after inverters.

The annual energy yield is the total amount of energy that is supposed to be produced and feed the grid in one year. It is usually expressed in GWh.

The performance ratio is the ratio between the nominal yield and the target yield of the PV systems. It thus shows the proportion of the energy that is actually available for export to the grid after deduction of energy losses and energy consumption for operation.

The specific energy yield shows how much power a PV system can supply for each kW of peak power installed.

9.3.1 Venice

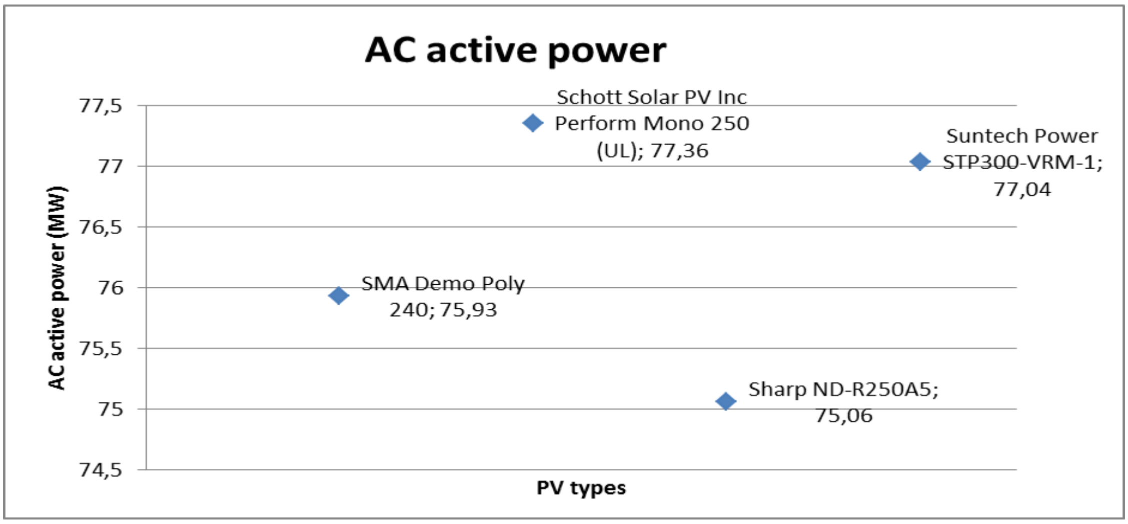


Figure 59 AC active power for Venice

In this first diagram we cannot notice big differences. The AC active power is similar for every type of PV modules. Differences are just given from the type of inverter.

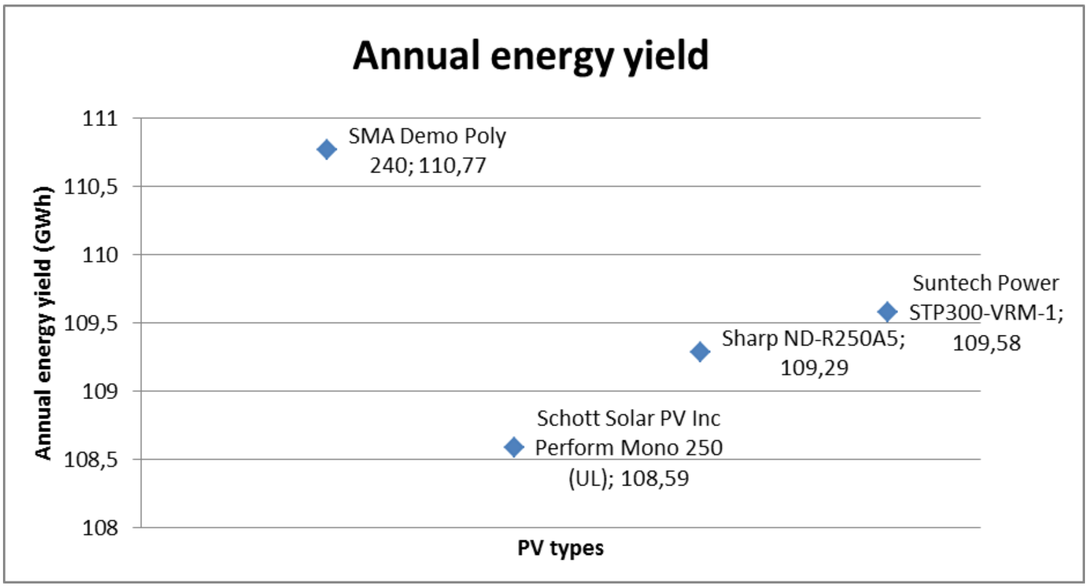


Figure 60 Annual energy yield for Venice

In this diagram we can notice some differences. The annual energy yield is one of the most important parameter to consider. We can see how the first type of PV module gives a remarkable increase of energy than other pv modules. So SMA Demo poly is the best modules among those we have chosen. Schott Solar module instead seems the worst choice for this type of plant. It is expected that SMA is the best because the software is provided from the same company, so it is optimized for their products.

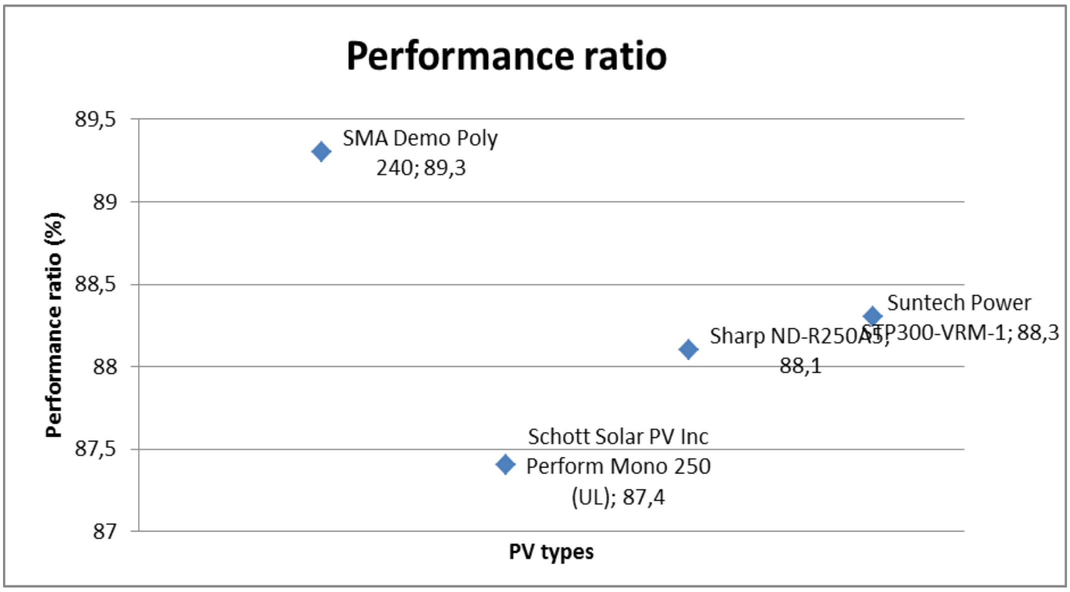


Figure 61 Performance ratio for Venice

Also in this diagram we can notice that the best performance is from SMA Demo Poly, with an amount of 89,3% , which is a good amount. Schott Solar is still the worst.

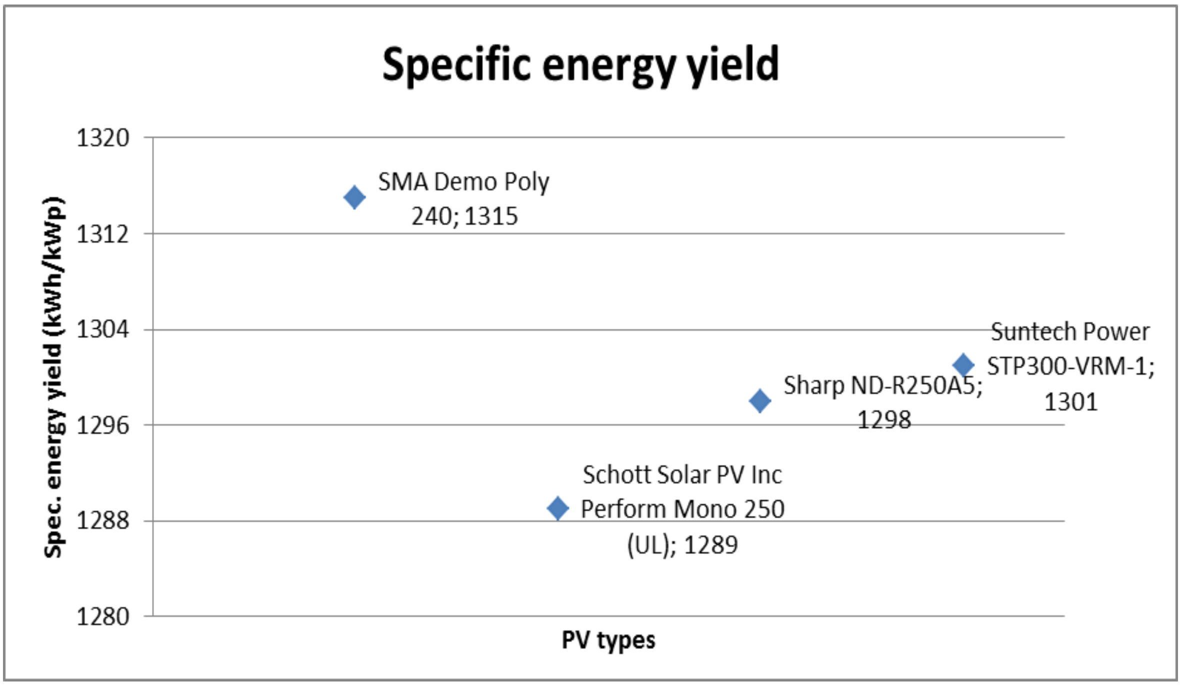


Figure 62 Specific energy yield for Venice

Also here we can see that the SMA Demo Poly is the best. The reasons are the same as before.

9.3.2 Budapest

Underneath there are results for Hungary-Budapest:

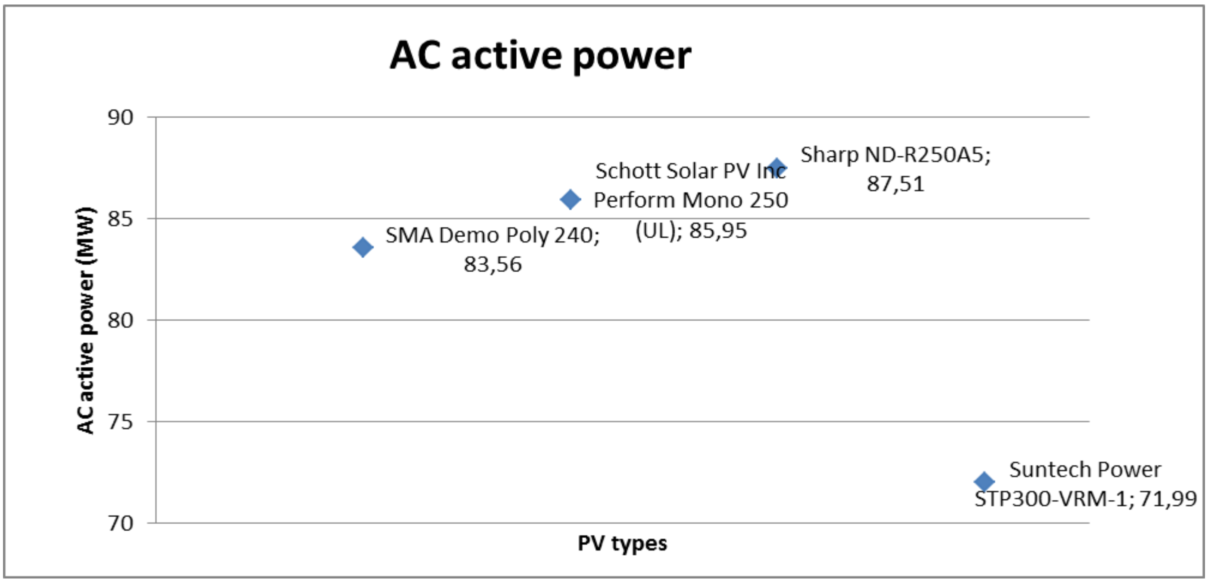


Figure 63 AC active power for Budapest

Here we can notice that the AC active power is similar for all kind of pv modules, except for SUNtech Power. It has a big difference compared to others. This is due to the fact that we chose to minimize the number of inverters. Number of inverters does not influence the annual energy yield, so the cost of the plant will be much more less in this way. We can also notice how the AC active power is higher than in Italy. If we take in case the Schott Solar, we notice that we used the same type of inverters. So the difference is due to the fact that in Italy there is the law (CEI 0-21) that forbiddens to put completely active power into the grid.

Table 17 active power ratio for various alternatives

		pv modules	active power ratio
alternative 1	Venice	SMA Demo Poly 240	90,01
	budapest		99,2
alternative 2	Venice	Schott Solar PV Inc. Perform Mono 250 (UL)	91,8
	budapest		102
alternative 3	Venice	Sharp ND-R250A5	89,1
	budapest		103,9
alternative 4	venice	Suntech Power STP300-VRM-1	91,5
	budapest		85,5

In fact from this table if we compare Italy to Hungary we can notice how the active power ratio is totally different. The active power ratio is ratio between maximum active power and the installed peak power. That is because in Hungary the grid can be fed with the total amount of power that modules can produce. Anyway the ratio is not 100% because we need to consider some losses with wires.

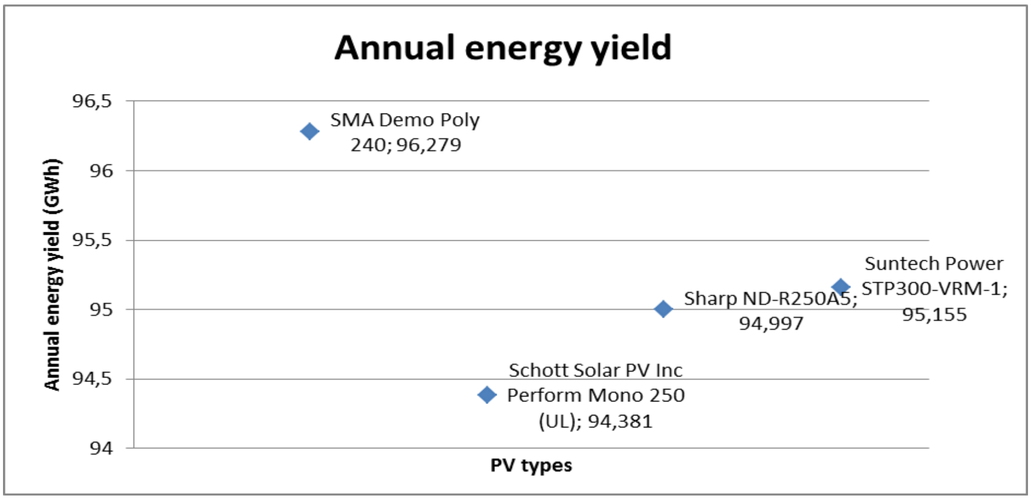


Figure 64 Annual energy yield for Budapest

Also here we can notice how SMA Demo Poly has the best annual energy yield. The reason is the same of the Italian case. Inverters we can choose in the software are just made by SMA, so it is obvious they have the best matching. Schott Solar still remains the worst choice for this type of plant.

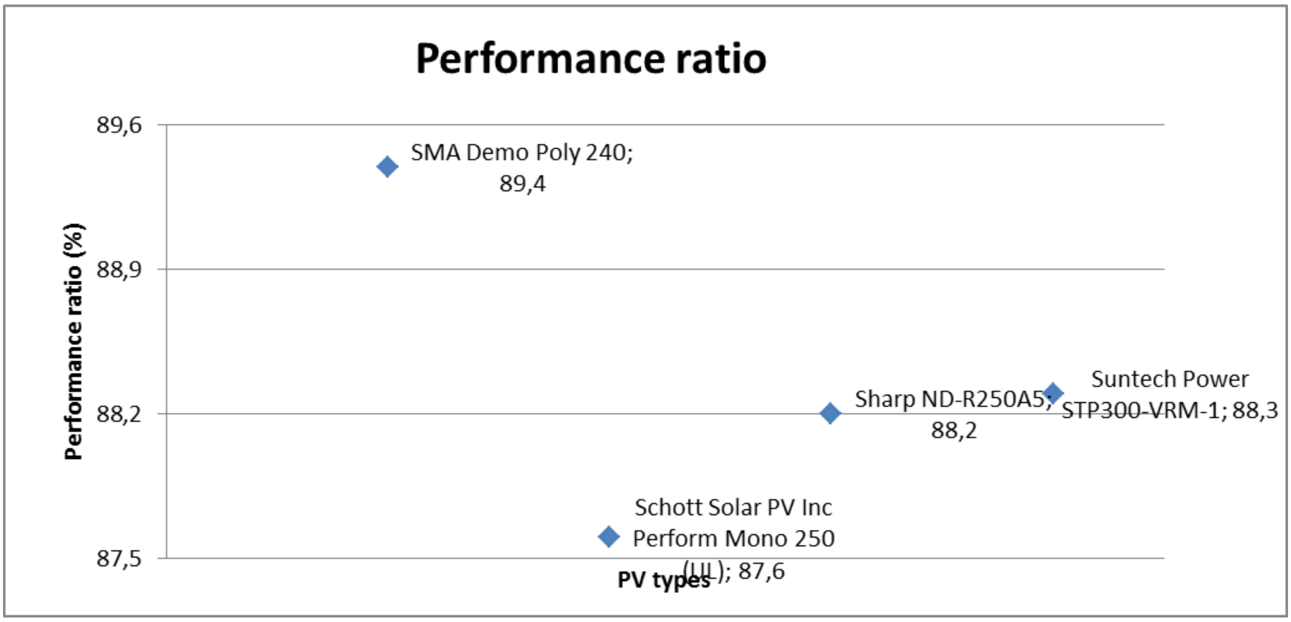


Figure 65 Performance ratio for Budapest

Same as before, the best permormace is given by SMA Demo Poly, which has 89,3%. This amount is a good result.

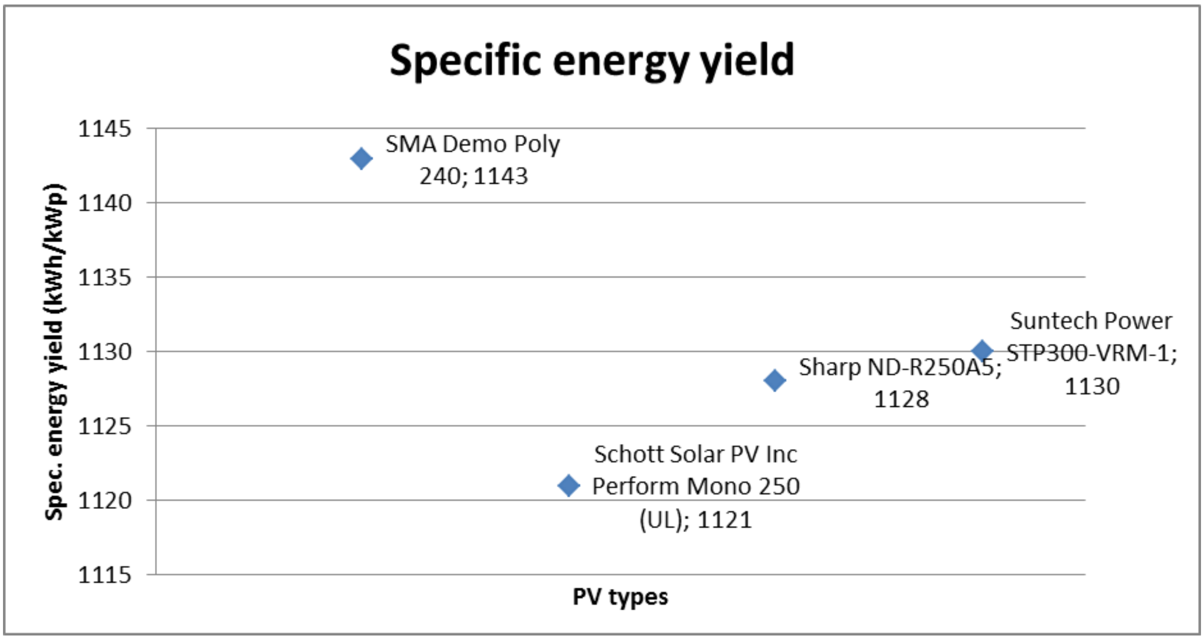


Figure 66 Specific energy yield for Budapest

SMA Demo Poly is the best also in this case. It means that with the same amount of energy from the light modules convert into electric energy in the best way, with minus losses than other types of modules.

9.4 Costs of the plants

For each alternative case examined above we tried to estimate the initial investement required to build the plants. Besides we tried to figure out annual fixed costs and consider the payback time for the plants.

We begin by reporting some market prices for modules, inverters and other hardware stuffs.

Modules

SMA Demo Poly 240: 340 €

Schott Solar PV Mono 250: 320 €

Sharp ND-R250A5: for this module we found two market prices, one for West Europe, precisely from Germany, and one from a company established in Hungary. We quote the two prices because the difference is remarkable, as well as the price of retail electricity with average European price. The price from the German factory is 352 €, while from the Hungarian factory is 246 €, both comprehensive of taxes.

Suntech Power STP300-VRM-1: 280 €

Inverters:

MLX60: 9590 €

STP25000TL-30: 5127 €

Miscellaneous components:

SMA sensor box monitoring: 412 €

SMA CLCON-10 Cluster Controller: 1339 €

Speedwire/Webconnect: 150 €

Some prices were in dollars; they were converted in Euro using the exchange rate of 1 €= 1.18 $

Due to the big amount of materials we use economy of scale for each component. We decide to apply a discount between 20% and 40% in order to reach the actual standard cost for a whole PV system, which is essentially 1.5 €/Wp.

Besides, as we found a remarkable difference in the price between Italy and Hungary, we decided to cut prices for each component for the Hungarian plant.

Furthermore, to calculate costs of planning and installation and annual fixed costs we used the percentage shown in the previous graphic in the cost analysis chapter.

The sum of costs for the Italian plant is shown below for every alternative.

Table 18 Sum of costs for Italian plant

Italy	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Cost of the PV modules (M€)	66.682	64.014	67,384	46.326
Cost of inverters (M€)	10.122	10.314	10.008	10.272
PV system monitoring (M€)	7425	7.102	7.218	6.954
Planning and installation (M€)	38.855	37.061	39.011	26.820
Total investment (M€)	122.558	118.490	123.603	90.372
Specific capital expenditure (k€/kWp)	1.455	1.406	1.467	1.072
Annual energy yield (GWh)	110.77	108.59	109.29	109.58
Annual fixed costs (M€)	4.611	4.611	4.611	4.611

For Hungary instead costs are the following

Table 19 Sum of costs for Hungarian plant

Hungary	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Cost of the PV modules (M€)	46.677	44.809	47.168	32.428
Cost of inverters (M€)	7.08540	7.219	7.005	7.190

PV system monitoring (M€)	**5.197**	**4.971**	**5.052**	**4.867**
Planning and installation (M€)	**27.198**	**25.942**	**27.307**	**18.774**
Total investment (M€)	**89.386**	**86.171**	**89.762**	**66.488**
Specific capital expenditure (k€/kWp)	**1.061**	**1.023**	**1.065**	**0.789**
Annual energy yield (GWh)	**96.279**	**94.381**	**94.997**	**95.155**
Annual fixed costs (M€)	**2.305**	**2.305**	**2.305**	**2.305**

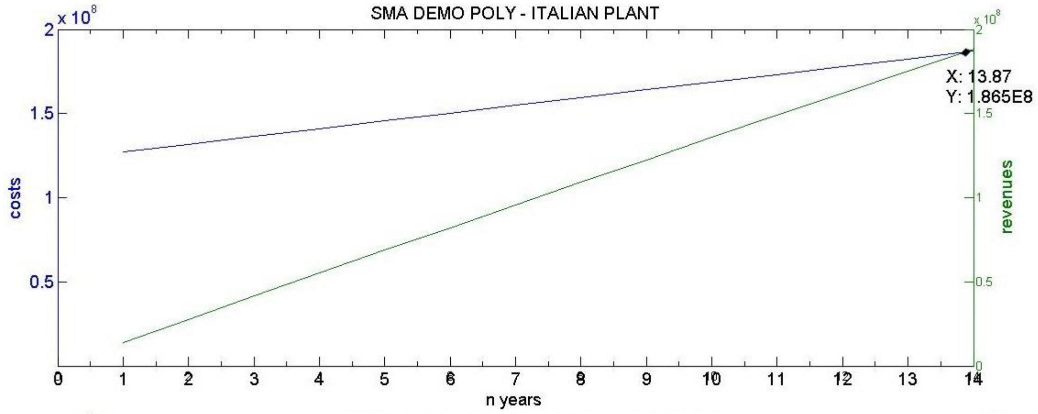
Thanks to the software Matlab we found the total revenue from grid feed-in and the payback time of the plant by this script:

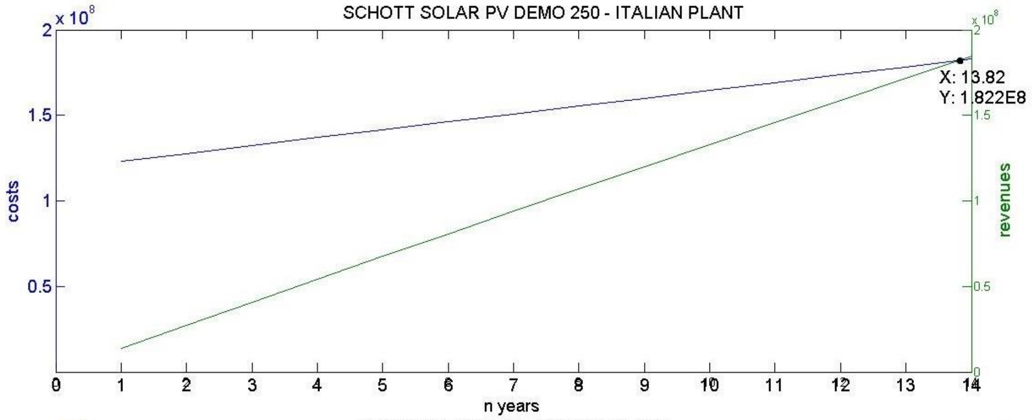
```
%Revenues and payback time for a PV plant%

fit=input ('insert feed-in tariff (€/KWh) ')
tic=input('insert total investment costs (M€) ')
afc=input('insert annual fixed costs (M€) ')
initialany=input('inserire annual energy yield (GWh) ')
any=0
n=1
y=0
any1=0
 while y<1

     if any1==0
         any1=0
     else any=any1
     end

     any1=any+initialany*0.995^n

     afc1=afc*n

     revenue=fit*any1*1000000

     costs=afc1*1000000+tic*1000000

     e1=(revenue-costs)

     if e1<0
         y1=0

     else
         y1=1
     end
     y=y1
rev (n)=[revenue]
cost (n)=[costs]
e (n)=[e1]
ns (n)=[n]
```

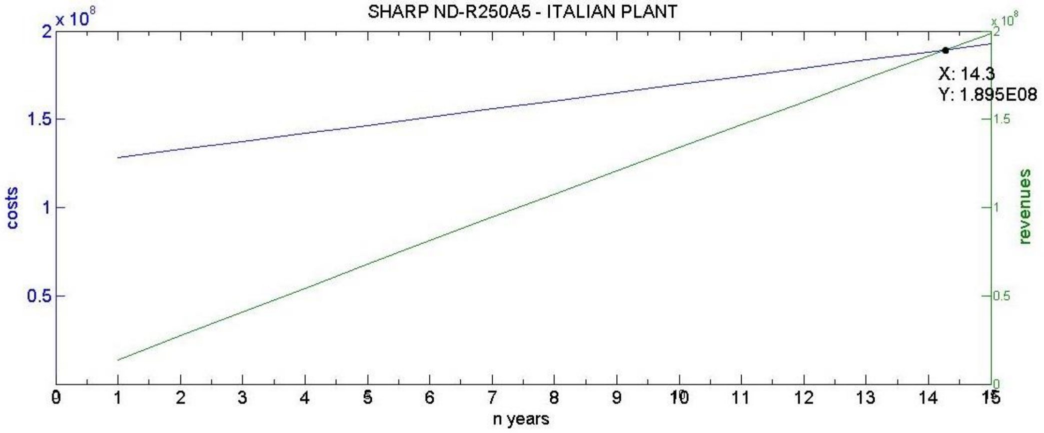
```
 n=n+1
 end

plotyy(ns,cost,ns,rev)
xlabel('n')
ylabel('costs')
```

To calculate the revenue for each year we considered an average annual power degradation of the PV modules of 0.5%.

Results for both countries are shown below:







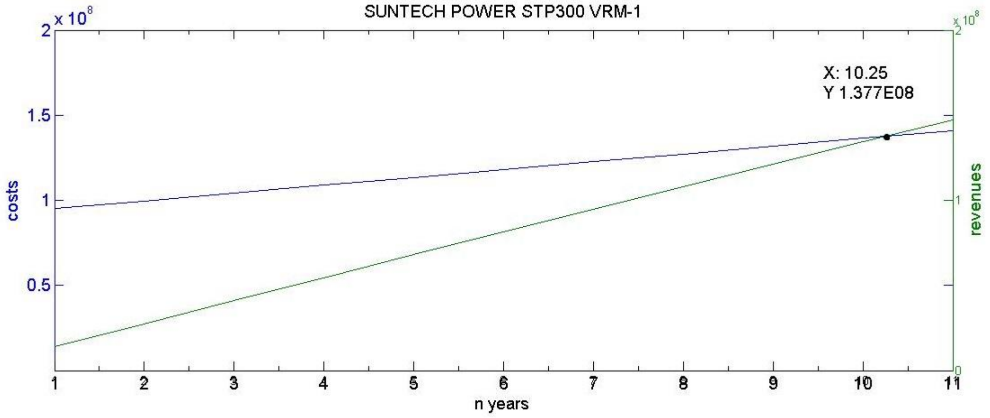
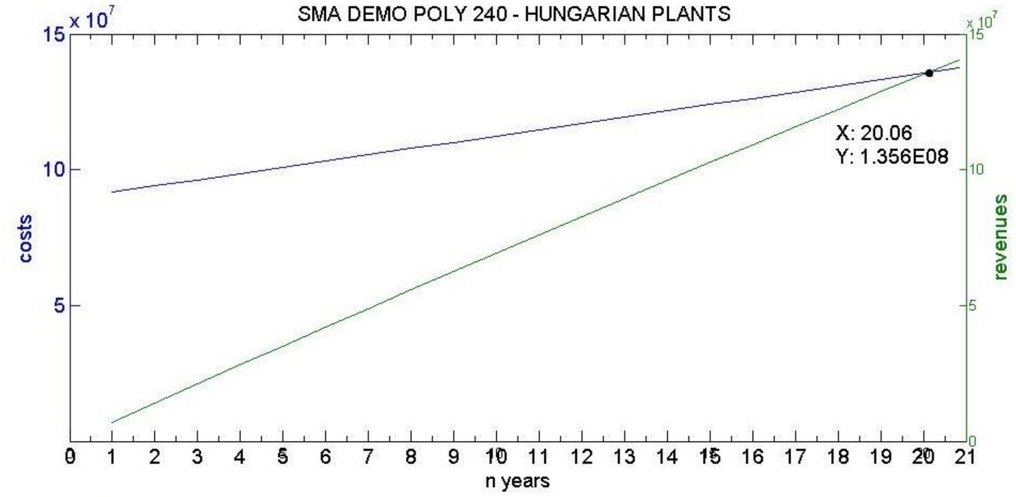
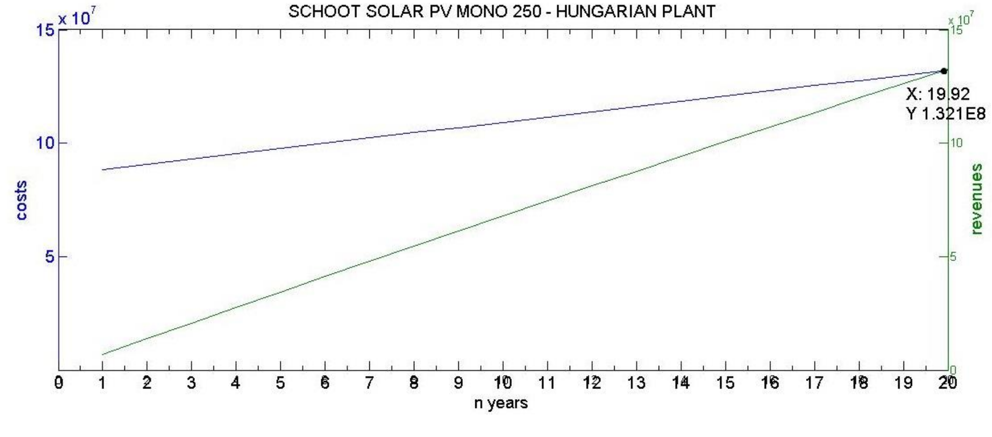


Figure 67 Payback time for Italian plants





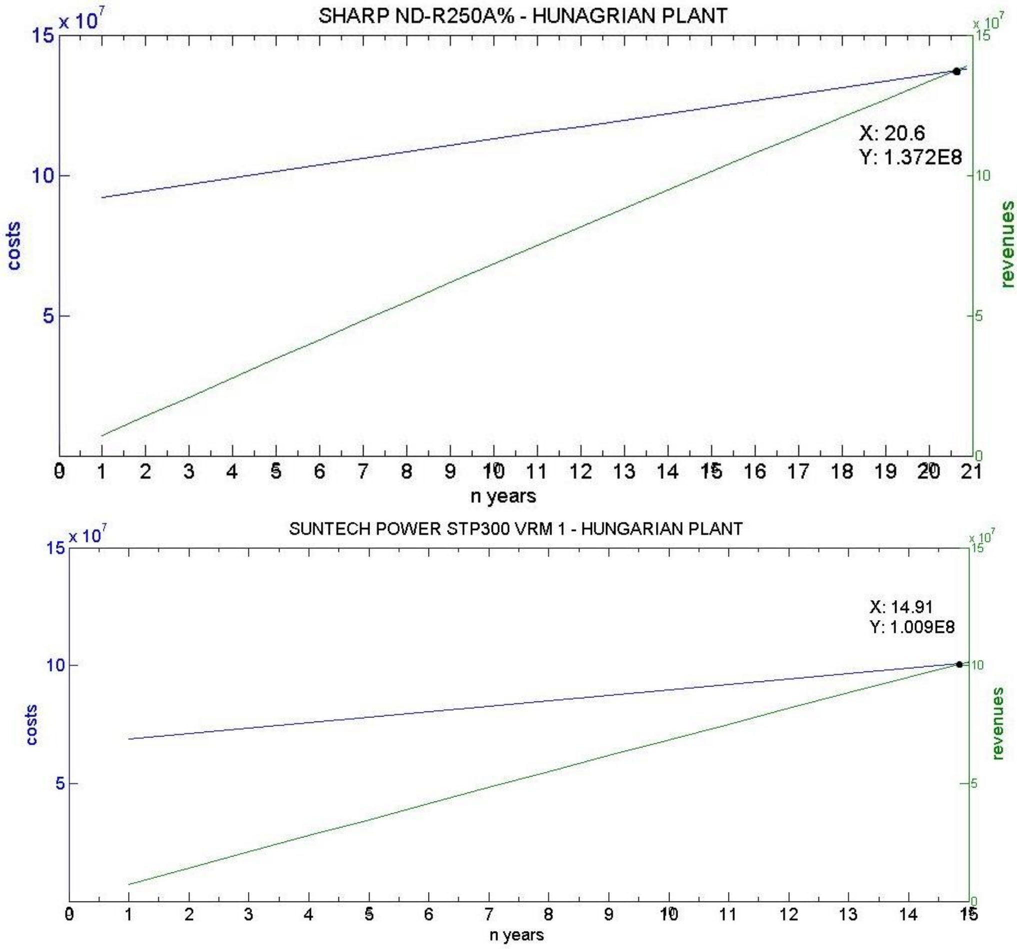


Figure 68 Payback time for Hungarian plants

The sum of results is:

Table 20 Sum of payback time period for each alternative

	Venice				Budapest			
	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 1	Alt. 2	Alt. 3	Alt. 4
Payback time (years)	13.87	13.82	14.3	10.25	20.06	19.92	20.6	14.91

9.5 Differences between Venice and Budapest

First of all we need to say that these cities are situated in different parallels. In fact Venice is in the 45° parallel, Budapest is 47°. That means **different temperature** during the year, but most **important different global radiation**. Hereunder we can see differences in these diagrams.

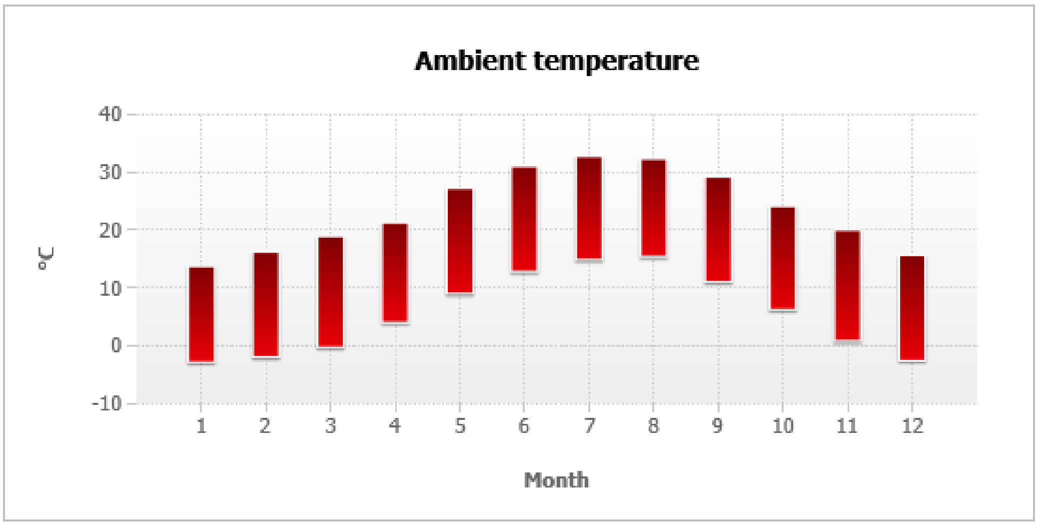


Figure 69 Average ambient temperature for Venice

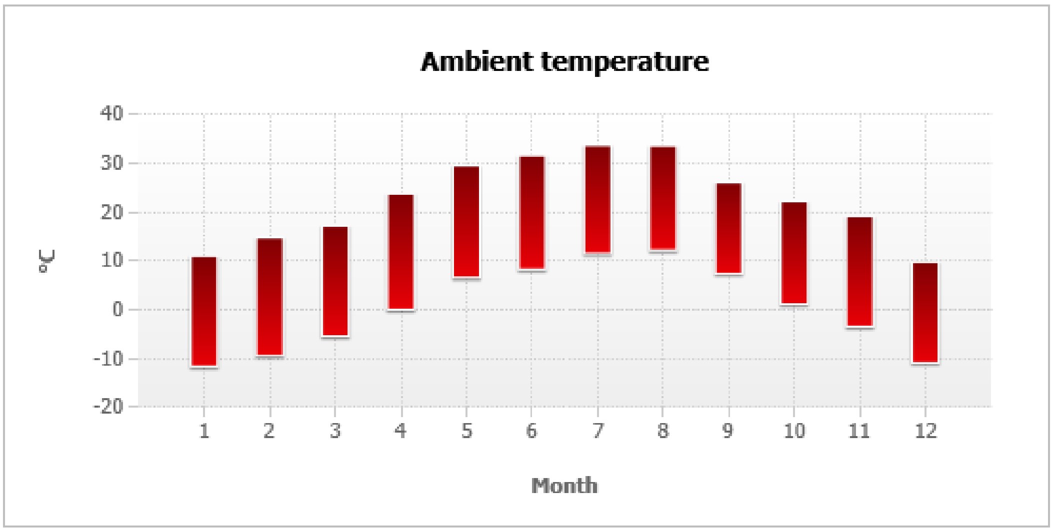


Figure 70 Average ambient temperature for Budapest

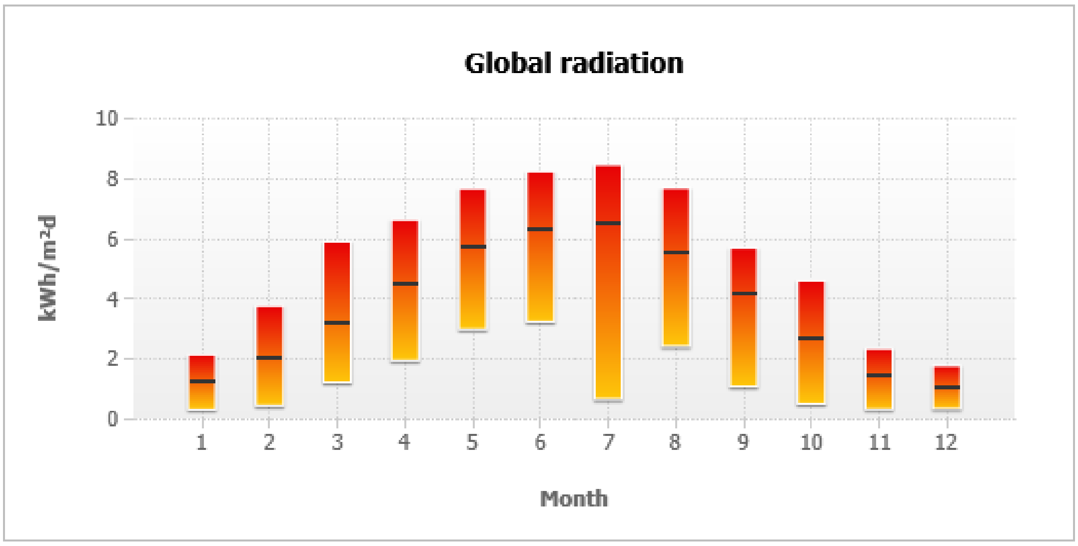


Figure 71 Average global radiation for Venice

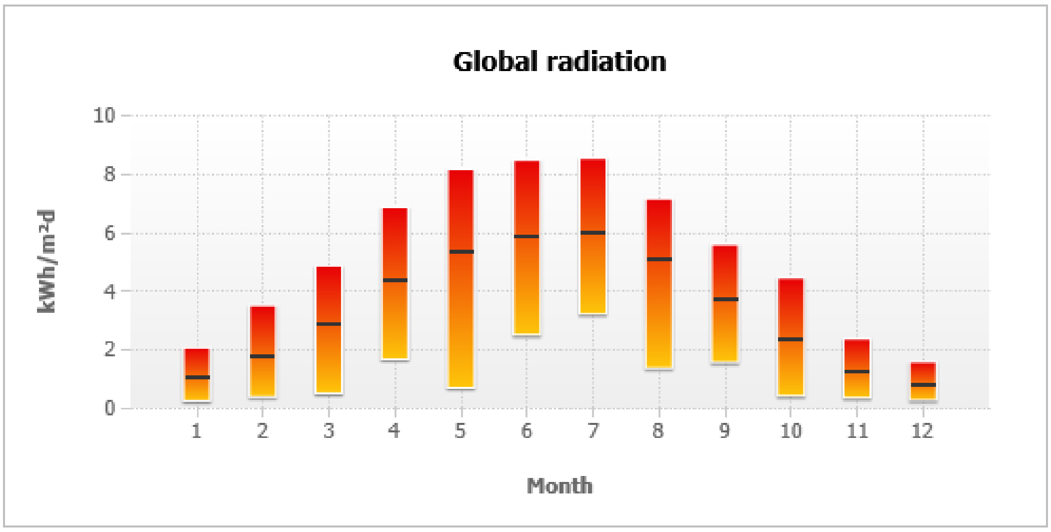


Figure 72 Average global radiation for Budapest

For temperature we can notice that in Venice it is generally higher than in Budapest. In fact, temperature parameters commonly used are 3:

- Annual extreme low temperature (Venice:-4° , Budapest:-14°)
- Average high temperature (Venice:23° , Budapest:22°)
- Annual extreme high temperature (Venice:33° , Budapest:34°)

This is reflected in the annual global radiation. In Venice it is 1,326.29 kWh/m²a, whereas in Budapest it 1,203.99 kWh/m²a. This means that there is less energy available in Budapest.

We can notice this in the graphic of annual energy yield and specific energy yield. For example if we take the SMA modules the annual energy yield for Venice is 110.77 GWh and for Budapest is 96,279 GWh. There is a difference of 14,491 GWh and it is a considerable amount. In Budapest we can collect the 86.9 % of energy that we can take in Venice. Also if we consider the case of Schott Solar PV INC modules in which we used the same type of inverter the annual energy yield is totally different: for Venice is 108,94 and for Budapest is 94,38 GWh. Same reason is for the specific energy yield.

Another difference between the two cities is the **current regulations**. As I quoted before in Italy there is a rule named CEI 0-21 that prohibits the use of inverters for more than 6 KWp. This rule does not exist in Hungary, so we can use different types of inverters there. That allows money saving and use of fewer inverters. One example is with SMA modules. For Italy we had to choose the STP25000TL-30 inverter, instead of MLX 60 inverter for Budapest. In Italy we had to use 3375 of that type of inverter, counter just 1394 in Budapest. The first costs 7300 $, the second 9800 $. In this way in Hungary we can save a lot of money and space also. Probably this rule is used just for private users who have a small amount of extra energy to feed the grid, but our software cannot recognize differences between types of installation. Another consideration is that for a big plant like that we do not use this type of inverters, but usually we use central like SC 630HE which is functionally in the Montalto di Castro power plant. Its nominal power DC reaches 642 KW, more than 10 times of MLX60 and 25 times of STP25000TL-30. In this way we can achieve better results, in terms of both economy and energy. We do not know why the software does not take into account this possibility, but for our purpose it is not necessary.

Another interesting aspect to notice is that the **performance ratio** is a little bit higher for Budapest.

Table 21 Performance ratio for various alternatives

		pv modules	performance ratio
alternative 1	**venice**	**SMA Demo Poly 240**	**89,3**
	budapest		**89,4**
alternative 2	**venice**	**Schott Solar PV Inc Perform Mono 250 (UL)**	**87,4**
	budapest		**87,6**
alternative 3	**venice**	**Sharp ND-R250A5**	**88,1**
	budapest		**88,2**
alternative 4	**venice**	**Suntech Power STP300-VRM-1**	**88,3**
	budapest		**88,3**

From the table above we can notice really small differences, except for the Suntech Power modules. Probably the reason resides in the choice of inverters. Laws in Hungary are less restrictive and they allow to feed the grid with 100% of the power that came from modules and using a displacement power factor equal to cosϕ=1. As we said before, that permits the use of bigger capacity inverters which results in a better performance.

Another interesting point to focus is the use of **mounting degree**. To calculate the best degree we need to consider essentially two factors: latitude and energy demand.

With latitude we can estimate the best angle for summer, winter, spring and autumn season. A simple way, but not the most accurate, is the following. For the 21 of March and for the 21 of

September, the operation to find the best angle is 90°-latitude°, and this corresponds to spring and autumn. Instead for 21 of June and 21 of December the operation is this: 90°-latitude°+23° for the 21 of December, and that is for the winter period 90°-latitude°-23 for the 21 of June, and this is for the summer.

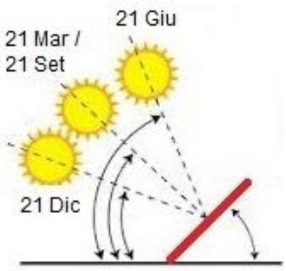
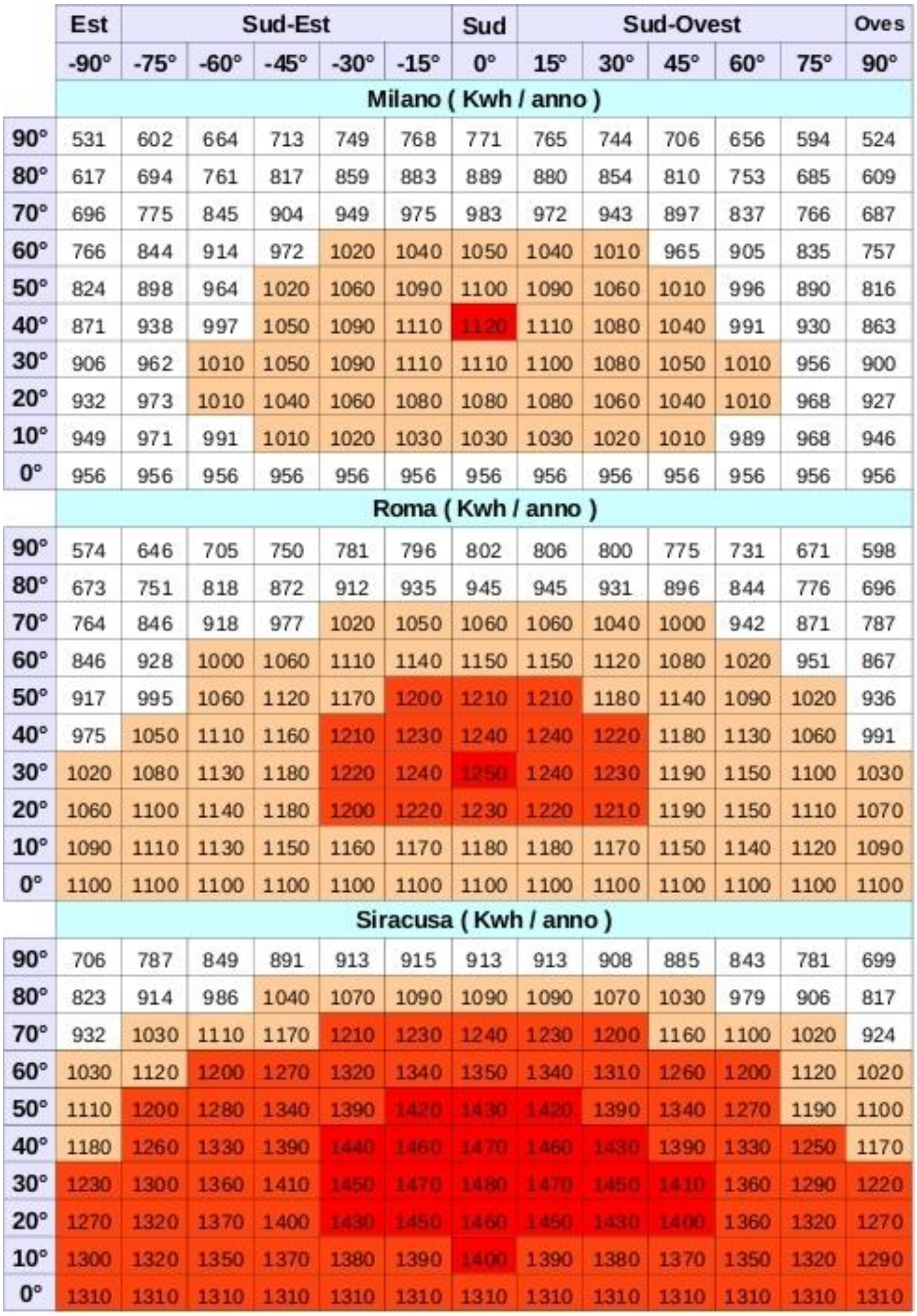


Figure 73 Angle of incidence during the year

For example if we take Venice, which is at 45° of latitude, the best angle for spring and autumn will be 45°, for winter 68° and for 22° for summer. This is a simple but effective way to calculate the angle.

To make better calculations we need to analyze previous data taken from other panels. An example is in the chart below:

Table 22 best mounting angle for different cities



	Est	Sud-Est					Sud	Sud-Ovest					Oves
	-90°	-75°	-60°	-45°	-30°	-15°	0°	15°	30°	45°	60°	75°	90°
	Milano (Kwh / anno)												
90°	531	602	664	713	749	768	771	765	744	706	656	594	524
80°	617	694	761	817	859	883	889	880	854	810	753	685	609
70°	696	775	845	904	949	975	983	972	943	897	837	766	687
60°	766	844	914	972	1020	1040	1050	1040	1010	965	905	835	757
50°	824	898	964	1020	1060	1090	1100	1090	1060	1010	996	890	816
40°	871	938	997	1050	1090	1110	1120	1110	1080	1040	991	930	863
30°	906	962	1010	1050	1090	1110	1110	1100	1080	1050	1010	956	900
20°	932	973	1010	1040	1060	1080	1080	1080	1060	1040	1010	968	927
10°	949	971	991	1010	1020	1030	1030	1030	1020	1010	989	968	946
0°	956	956	956	956	956	956	956	956	956	956	956	956	956
	Roma (Kwh / anno)												
90°	574	646	705	750	781	796	802	806	800	775	731	671	598
80°	673	751	818	872	912	935	945	945	931	896	844	776	696
70°	764	846	918	977	1020	1050	1060	1060	1040	1000	942	871	787
60°	846	928	1000	1060	1110	1140	1150	1150	1120	1080	1020	951	867
50°	917	995	1060	1120	1170	1200	1210	1210	1180	1140	1090	1020	936
40°	975	1050	1110	1160	1210	1230	1240	1240	1220	1180	1130	1060	991
30°	1020	1080	1130	1180	1220	1240	1250	1240	1230	1190	1150	1100	1030
20°	1060	1100	1140	1180	1200	1220	1230	1220	1210	1190	1150	1110	1070
10°	1090	1110	1130	1150	1160	1170	1180	1180	1170	1150	1140	1120	1090
0°	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100
	Siracusa (Kwh / anno)												
90°	706	787	849	891	913	915	913	913	908	885	843	781	699
80°	823	914	986	1040	1070	1090	1090	1090	1070	1030	979	906	817
70°	932	1030	1110	1170	1210	1230	1240	1230	1200	1160	1100	1020	924
60°	1030	1120	1200	1270	1320	1340	1350	1340	1310	1260	1200	1120	1020
50°	1110	1200	1280	1340	1390	1420	1430	1420	1390	1340	1270	1190	1100
40°	1180	1260	1330	1390	1440	1460	1470	1460	1430	1390	1330	1250	1170
30°	1230	1300	1360	1410	1450	1470	1480	1470	1450	1410	1360	1290	1220
20°	1270	1320	1370	1400	1430	1450	1460	1450	1430	1400	1360	1320	1270
10°	1300	1320	1350	1370	1380	1390	1400	1390	1380	1370	1350	1320	1290
0°	1310	1310	1310	1310	1310	1310	1310	1310	1310	1310	1310	1310	1310

We can see that the best angle to give the maximum KWh/year differs for cities that are really close (between 42° and 47° parallel).

The second factor is also important. If we do not have a photovoltaic panel with a tracked mount, like in the common use, we need to decide just one angle which meets our energy requirements.

The software loads automatically 35° degrees for Budapest. The best angle for spring and autumn is 43° degrees. It probably means that in Budapest energy requirements are a little bit higher during the summer period, instead of in Venice, in which the software chooses 45° degrees. Also the weather during the year contributes to the choice.

So in our case we used 45° for both cities, maximizing Venice. If we had used the best mounting angle for Budapest we could have noticed a small difference in the annual energy yield, but still remarkable. The amount would be 2 GWh more and less, which are enough to meet the energy needs of two average Swedish towns with a population of 100,000 for 8 hours.

One last consideration to make is about **costs, revenues and payback time**.

As we said before, Hungary is cheaper than Italy. A discount was required otherwise there would be no market for PV in Hungary, due to the small economy and the cost of life, which is lower than in Italy. Therefore, it seemed reasonable to apply a discount up to 25% for each component. Besides, it seemed reasonable to reduce the annual fixed costs to 50% because manpower is very cheap in Hungary.

As we can imagine, also the Fit in Hungary is lower than in Italy. This means the revenue is lower for an equal power of the plant. In fact, the Fit used for Italy was 0.126 €/KWh, for Hungary was 0.074 €/kWh.

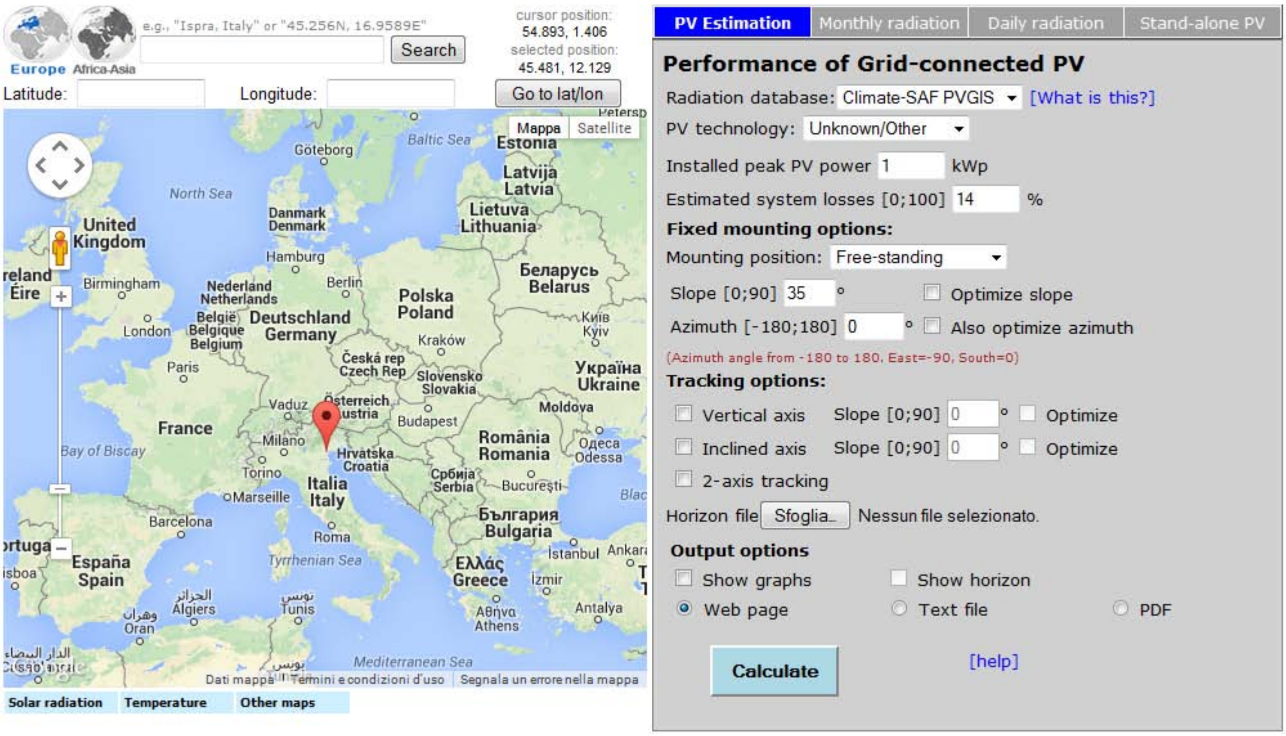
Anyway results showed what we expected. In Italy, due to laws, economic benefits and higher sunlight, PV plants are cheaper. This emerges from the payback time; in Italy the average of payback time is 14 years, without considering the exceptional value for the technology of the company SUNTECH POWER (11 years), whereas in Hungary it is 20 years.

The SUNTECH POWER alternative is an exceptional value, due to the 300W modules, instead of common 240/250W ones, and the cheap price offered to purchase them.

10 Software Photovoltaic Geographical Information System

10.1 Overview of the application

This is not a real software, but this is more an interactive map of Europe in which we can estimate performance of grid-connected photovoltaic. We can also calculate the monthly radiation and the daily radiation of a precise place.



cursor position: 54.893, 1.406
selected position: 45.481, 12.129
Latitude:
Longitude:

Performance of Grid-connected PV
Radiation database: Climate-SAF PVGIS
PV technology: Unknown/Other
Installed peak PV power 1 kWp
Estimated system losses [0;100] 14 %
Fixed mounting options:
Mounting position: Free-standing
Slope [0;90] 35 ° ☐ Optimize slope
Azimuth [-180;180] 0 ° ☐ Also optimize azimuth
(Azimuth angle from -180 to 180. East=-90, South=0)
Tracking options:
☐ Vertical axis Slope [0;90] 0 ° ☐ Optimize
☐ Inclined axis Slope [0;90] 0 ° ☐ Optimize
☐ 2-axis tracking
Horizon file Nessun file selezionato.
Output options
☐ Show graphs ☐ Show horizon
● Web page ○ Text file ○ PDF

Figure 74 Photovoltaic Geographical Information System Web application

The System provides 2 different types of climate database.

They are the Climate-SAF PVGIS or the Classic PVGIS. PVGIS needs data on solar radiation in order to make estimates of the performance of PV systems and to do the other calculations possible in the web application. There exist a number of different sources of solar radiation data, but none of them are perfect, so it is important to understand the strengths and weaknesses of each data source.

Types of solar radiation data sources

The two main sources of data on solar radiation on the surface of the earth are:

- Ground measurements

- Calculations based on satellite data

10.1.1 Ground measurements of solar radiation

Direct measurements of the solar radiation at ground level can be made with a number of different instruments. A widely used instrument is the pyranometer. Typically, the instrument measures all the radiation coming from the sun and from the sky or clouds. When you want to know the solar radiation at a specific place, ground station measurements give the best results. It is also possible to measure with a high time resolution, typically every minute or even more often.

Anyway, problems with the measurements could arise, when for example the sensor may be covered with dirt, frost, snow, or it is shadowed by nearby trees or buildings for some time during the year. These problems can be removed by careful siting and maintenance, but it makes it more uncertain to use data where you do not have direct experience with the measurements.

10.1.2 Solar radiation estimates from satellite

There are a number of methods to estimate the solar radiation at ground level using data from satellites. Typically the satellites measure the light (visible or infrared) coming from the Earth. This light is mainly the light reflected from the ground or from clouds. The calculation of the solar radiation at ground level must therefore be able to take into account the radiation absorbed by the atmosphere as well as that reflected by clouds.

Different types of satellites can be used to estimate solar radiation. *Geostationary* weather satellites take pictures of the Earth at short intervals (every 15 or 30 minutes) so they have a very good time resolution. However, each pixel in the picture typically represents a rectangle a few km on each side, so the estimate of solar radiation for each pixel will be the average of such an area. *Polar-orbiting* satellites fly closer to the Earth, so the space resolution is better. However, they do not stay permanently above a particular area, so they are normally able to take only a couple of pictures a day of a given area. The data used for PVGIS come mainly from geostationary satellites.

The main advantage of satellite-based methods is that they give a fairly uniform coverage of large areas while ground stations are often very far apart. On the other hand, there are potential problems also with the satellite methods:

- Snow on the ground is a special problem for satellite methods, since snow will look very much like clouds in the satellite images. There are methods to overcome this problem, but the uncertainty is higher in areas with snow.
- In mountain areas one pixel may cover an area with strongly varying altitude. The solar radiation dependence on altitude is not well represented in the satellite-based calculations.
- When the sun is very low in the sky the calculation from satellite data becomes very difficult. This can cause problems, in particular in winter at high latitudes.

The quality of satellite-based estimates must be checked by comparison with high-quality ground station measurements.

10.1.3 PVGIS classic

The original PVGIS radiation database is based on data from the European Solar Radiation Atlas. The data consist of ground station measurements from about 560 stations in Europe, over the period 1981 to 1990. Thus, the data are rather old, and there are strong indications that the climate has changed in the last 25-30 years, affecting also the solar radiation. The station data have then been used for a mathematical interpolation to give solar radiation values also for the areas between stations. However, this interpolation is subject to uncertainties. The density of stations varies strongly in Europe, and the uncertainty can be very high in areas with few stations.

10.1.4 PVGIS-CMSAF

The new database in PVGIS has been calculated from solar radiation data made available by the Climate Monitoring Satellite Application Facility (CM-SAF). The solar radiation values have been estimated from satellite images. The data are fairly recent, from 1998 to mid-2010, so there should not be strong effects of climate change. However, the use of satellite data has its own problems. The pixel size in the satellite images is about 3-5km, so smaller features such as narrow mountain valleys cannot be resolved. The computer algorithm that calculates the solar radiation on the ground may have difficulties in telling the difference between snow and clouds, which can have a large influence on the result. The CM-SAF team has worked hard to minimize these errors, but there are still uncertainties.

Types of photovoltaic technology

The three types of photovoltaic modules are:

- Crystalline Silicon
- CIS
- CdTe

With the web application we can choose the installed PV peak power and the estimated system losses, which, in order to simplify our job, we leave at 14%.

Afterwards we can select the mounting position, mounting angle and the azimuth. We can also select if we want a tracked angle, but for our job and our purpose this is not necessary.

10.2 Purpose of the project

Our purpose with this application is similar to that of the software SMA Sunny Design, that is to estimate the power produced from a PV plant about 84,23 MW.

As we did before, we choose two different places to put our PV plant.

The first is near Venice and precisely 45°20'48" North, 12°11'36" East, elevation: 0 m a.s.l. The place is near the beach, in the Laguna of Venice, in which there is a big empty field.

The second is in Budapest 47°13'31" North, 18°45'7" East, elevation: 136 m a.s.l.

The main data for both places are:

- Climate-SAF PVGIS
- Power plant: 84,23 MW
- Angle slope 45°
- Angle Azimuth 0
- Free-standing mounting
- No tracking positions

We select for each place every type of modules, to show the differences between them.

10.3 Venice

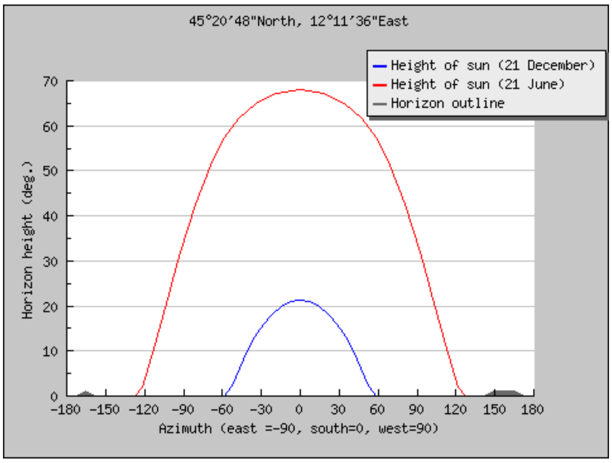


Fig 75 Outline of horizon with sun path for winter and summer solstice

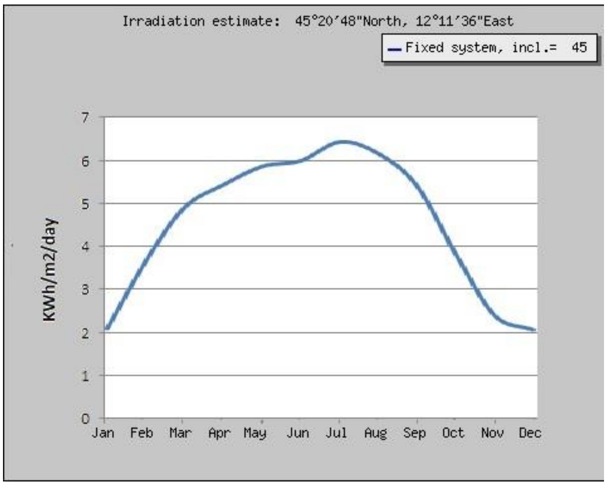


Fig 76 Daily in-plane irradiation for 45°

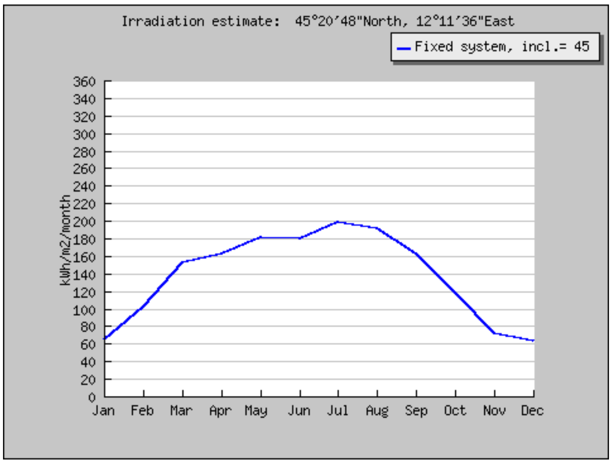


Fig 77 Monthly in-plane irradiation for 45°

10.3.1 Crystalline Technology

10. TABLE 23 Results for crystalline silicon pv system in Venice

	Fixed system: inclination=45 deg., orientation=0 deg.			
Month	**Ed**	**Em**	**Hd**	**Hm**
Jan	144000	4460000	2.09	64.9
Feb	249000	6970000	3.66	102
Mar	323000	10000000	4.91	152
Apr	350000	10500000	5.43	163
May	367000	11400000	5.86	182
Jun	365000	11000000	5.99	180
Jul	390000	12100000	6.43	199
Aug	376000	11700000	6.16	191
Sep	336000	10100000	5.40	162
Oct	248000	7680000	3.82	119
Nov	159000	4780000	2.39	71.8
Dec	141000	4370000	2.06	63.9
Average Year	288000	8750000	4.52	138
Total for year		105000000		1650

Ed: Average daily electricity production from the given system (kWh)

Em: Average monthly electricity production from the given system (kWh)

Hd: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m2)

Hm: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m2)

In this table the 4 main data of our calculations are shown.

The most important is the total power per year, which is 105 GWh in this case.

Another interesting data is the total sum of global irradiation per square meter received, which is 1650 KWh/m2.

Estimated losses due to temperature and low irradiance: 9.5% (using local ambient temperature)

Estimated loss due to angular reflectance effects: 2.7%

Other losses (cables, inverter etc.): 14.0%

Combined PV system losses: 24.3%

Below we can see the trend in graphics of performances of our plant.

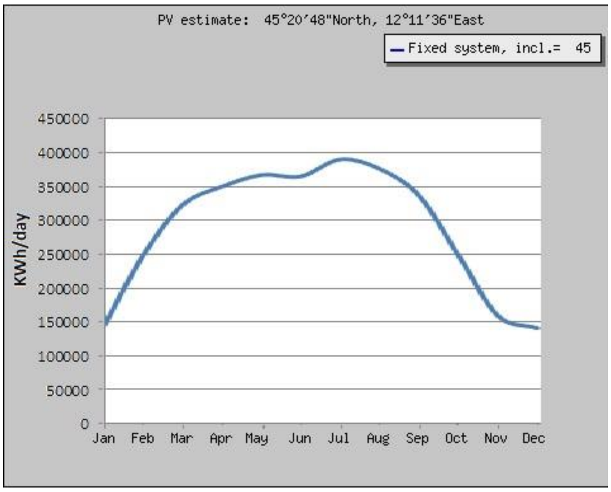


Fig 78 Daily energy average output for 45°

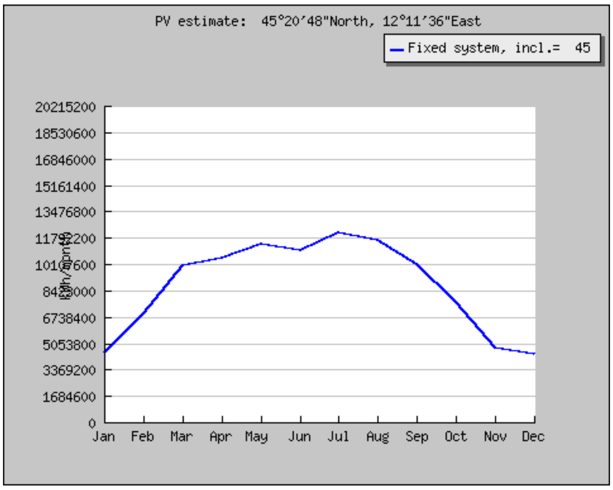


Fig 79 Monthly energy output for 45°

We can notice how the trend from January to July more and less rises, after that it starts to lower. This is completely normal and makes sense, because we select a place in the northern hemisphere, which means seasons with the summer as the most irradiated. The top of accumulated energy is in July, when the maximum monthly irradiation occurs.

10.3.2 CIS technology

Estimated losses due to temperature and low irradiance: 8.0% (using local ambient temperature)

Estimated loss due to angular reflectance effects: 2.7%

Other losses (cables, inverter etc.): 14.0%

Combined PV system losses: 23.0%

Table 24 Results for CIS pv system in Venice

	Fixed system: inclination=45 deg., orientation=0 deg.			
Month	**Ed**	**Em**	**Hd**	**Hm**
Jan	144000	4480000	2.09	64.9
Feb	250000	7010000	3.66	102
Mar	327000	10100000	4.91	152
Apr	356000	10700000	5.43	163
May	374000	11600000	5.86	182
Jun	373000	11200000	5.99	180
Jul	399000	12400000	6.43	199
Aug	385000	11900000	6.16	191
Sep	343000	10300000	5.40	162
Oct	251000	7790000	3.82	119
Nov	161000	4830000	2.39	71.8
Dec	142000	4390000	2.06	63.9
Average Year	292000	8890000	4.52	138
Total for year		107000000		1650

Here we can notice an increase of the annual energy yield due to lower losses of temperature and low irradiance. Here we have 8% instead of 9.5% of the previous case.

The total power energy is 107 GWh, which is a good result. The average daily sum of global irradiation per square meter received and the average sum of global irradiation per square meter received by the modules of the given system remain unchanged.

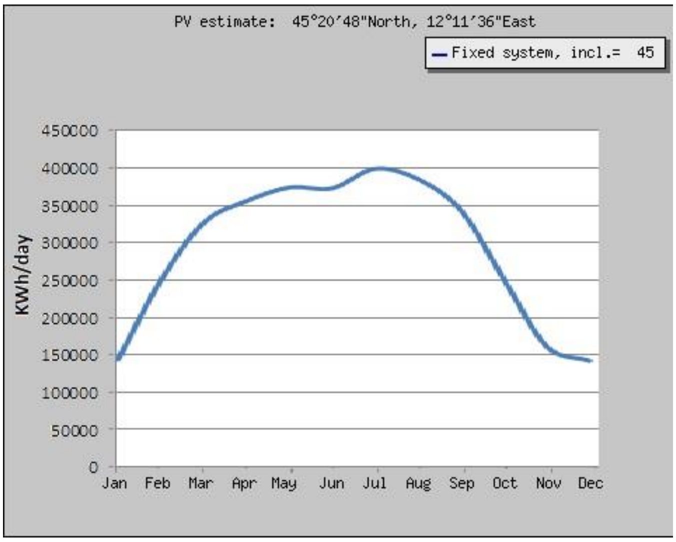


Fig 80 Daily energy average output for 45°

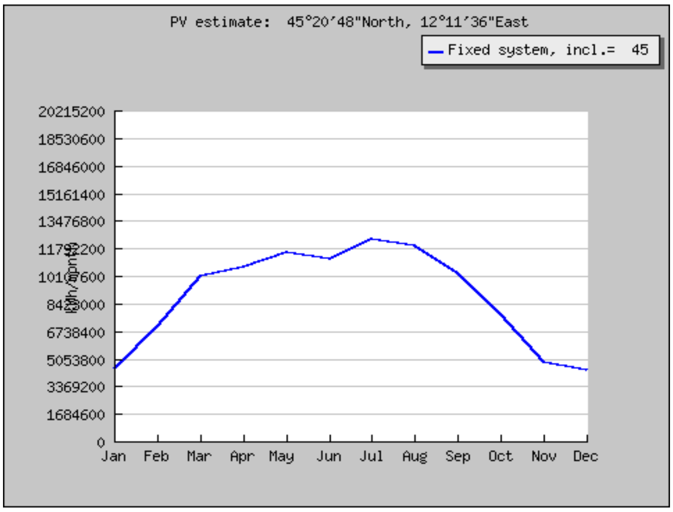


Fig 81 Monthly energy output for 45°

10.3.3 CdTe technology

Estimated losses due to temperature and low irradiance: 1.2% (using local ambient temperature)

Estimated loss due to angular reflectance effects: 2.7%

Other losses (cables, inverter etc.): 14.0%

Combined PV system losses: 17.4%

TABLE 25 Results for CdTe pv system in Venice

	Fixed system: inclination=45 deg., orientation=0 deg.			
Month	**Ed**	**Em**	**Hd**	**Hm**
Jan	152000	4710000	2.09	64.9
Feb	264000	7380000	3.66	102

Mar	345000	10700000	4.91	152
Apr	380000	11400000	5.43	163
May	405000	12600000	5.86	182
Jun	409000	12300000	5.99	180
Jul	437000	13600000	6.43	199
Aug	419000	13000000	6.16	191
Sep	370000	11100000	5.40	162
Oct	271000	8400000	3.82	119
Nov	172000	5150000	2.39	71.8
Dec	149000	4620000	2.06	63.9
Average Year	315000	9570000	4.52	138
Total for year		115000000		1650

Losses due to temperature and low irradiance are really low in this case. They are just 1.2% and combined PV system losses are 17.4%. That provides a very good amount of energy produced in one year. It is 115 GWh. The average daily sum of global irradiation per square meter received and the average sum of global irradiation per square meter received by the modules of the given system remain unchanged.

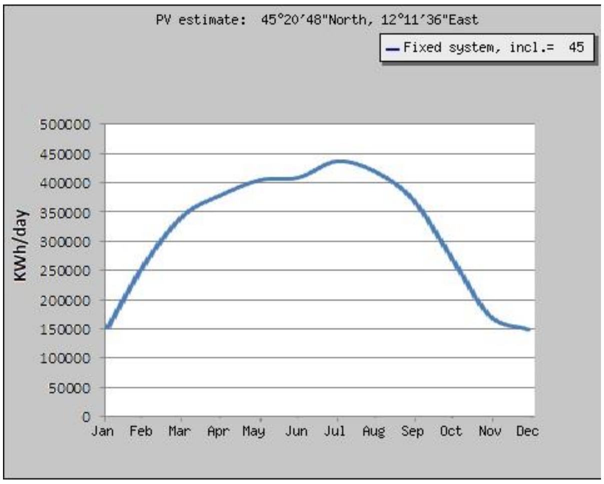


Fig 82 Daily energy average output for 45°

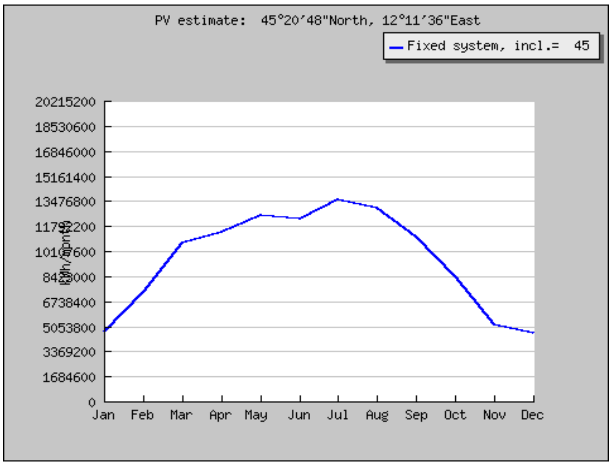


Fig 83 Monthly energy output from fixed-angle PV system

10.4 Budapest

Now we will analyze the situation in Budapest:

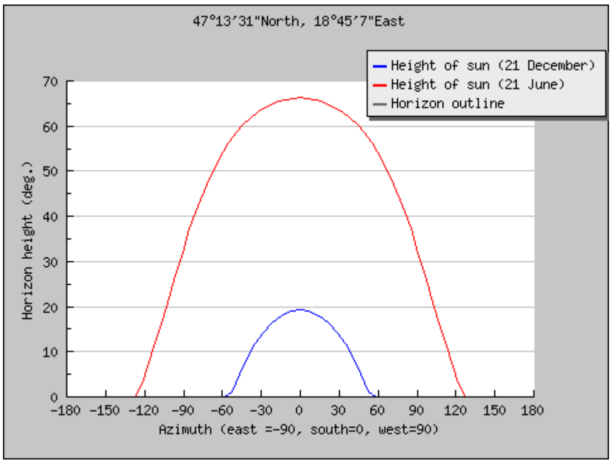


Fig 84 Outline of horizon with sun path for winter and summer solstice

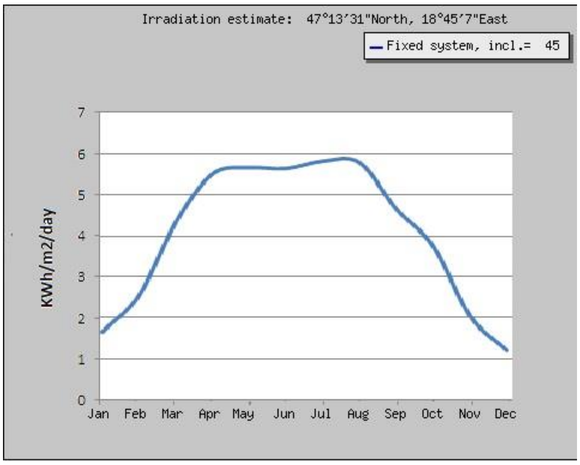


Fig 85 Daily in-plane irradiation for 45°

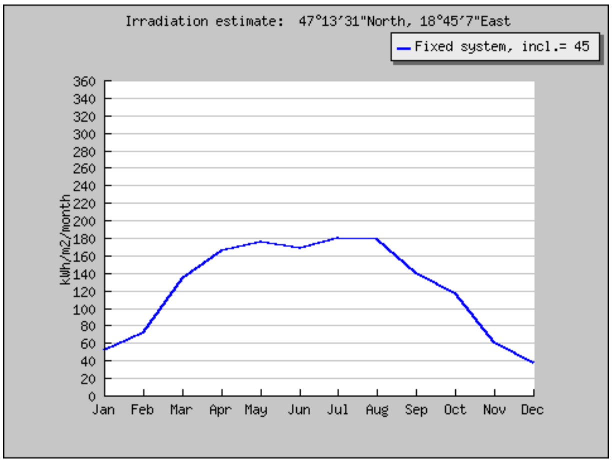


Fig 86 Monthly in-plane irradiation for 45°

10.4.1 Crystalline silicon technology

Table 26 Results for crystalline silicon pv system in Budapest

	Fixed system: inclination=45 deg., orientation=0 deg.			
Month	**Ed**	**Em**	**Hd**	**Hm**
Jan	118000	3660000	1.66	51.5
Feb	178000	5000000	2.55	71.5
Mar	289000	8970000	4.33	134
Apr	353000	10600000	5.50	165
May	351000	10900000	5.65	175
Jun	346000	10400000	5.63	169
Jul	354000	11000000	5.81	180
Aug	354000	11000000	5.77	179
Sep	295000	8850000	4.64	139
Oct	247000	7650000	3.74	116
Nov	139000	4180000	2.04	61.2
Dec	85500	2650000	1.21	37.4
Average Year	260000	7900000	4.05	123
Total for year		94700000		1480

Estimated losses due to temperature and low irradiance: 8.8% (using local ambient temperature)

Estimated loss due to angular reflectance effects: 2.8%

Other losses (cables, inverter etc.): 14.0%

Combined PV system losses: 23.7%

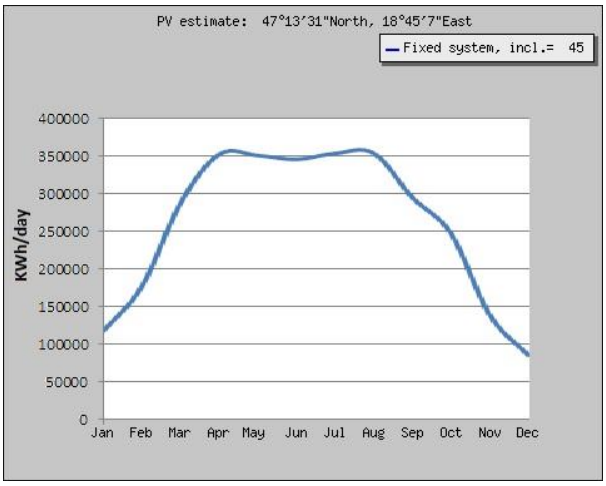


Fig 87 Daily energy average output for 45°

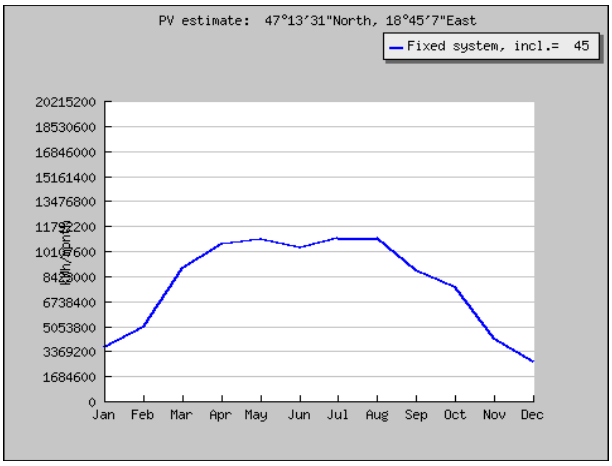


Fig 88 Monthly energy average output for 45°

10.4.2 CIS technology

Estimated losses due to temperature and low irradiance: 7.4% (using local ambient temperature)

Estimated loss due to angular reflectance effects: 2.8%

Other losses (cables, inverter etc.): 14.0%

Combined PV system losses: 22.6%

Table 27 Results for CIS pv system in Budapest

	Fixed system: inclination=45 deg., orientation=0 deg.			
Month	**Ed**	**Em**	**Hd**	**Hm**
Jan	118000	3650000	1.66	51.5
Feb	179000	5000000	2.55	71.5
Mar	292000	9060000	4.33	134
Apr	359000	10800000	5.50	165
May	359000	11100000	5.65	175
Jun	353000	10600000	5.63	169
Jul	361000	11200000	5.81	180
Aug	362000	11200000	5.77	179
Sep	300000	9010000	4.64	139
Oct	250000	7740000	3.74	116
Nov	140000	4200000	2.04	61.2
Dec	85200	2640000	1.21	37.4
Average Year	264000	8020000	4.05	123
Total for year		96200000		1480

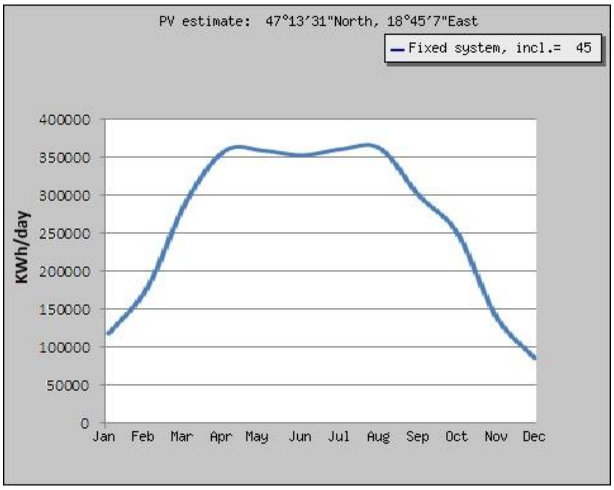


Fig 89 Daily energy average output for 45°

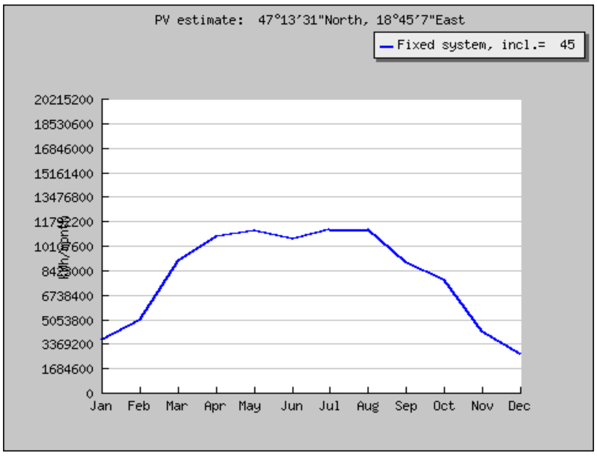


Fig 90 Monthly energy average output for 45°

10.4.3 CdTe technology

Estimated losses due to temperature and low irradiance: 0.4% (using local ambient temperature)

Estimated loss due to angular reflectance effects: 2.8%

Other losses (cables, inverter etc.): 14.0%

Combined PV system losses: 16.7%

Table 28 Results for CdTe pv system in Budapest

	Fixed system: inclination=45 deg., orientation=0 deg.			
Month	**Ed**	**Em**	**Hd**	**Hm**
Jan	123000	3810000	1.66	51.5
Feb	187000	5230000	2.55	71.5
Mar	308000	9550000	4.33	134
Apr	384000	11500000	5.50	165
May	390000	12100000	5.65	175
Jun	387000	11600000	5.63	169
Jul	397000	12300000	5.81	180
Aug	396000	12300000	5.77	179
Sep	325000	9760000	4.64	139
Oct	268000	8320000	3.74	116
Nov	148000	4450000	2.04	61.2
Dec	89700.00	2780000	1.21	37.4
Average Year	284000	8640000	4.05	123

Total for year		104000000		1480

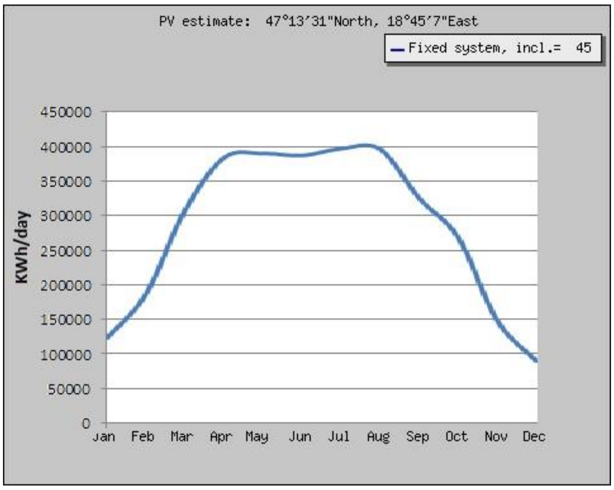


Fig 91 Daily energy average output for 45°

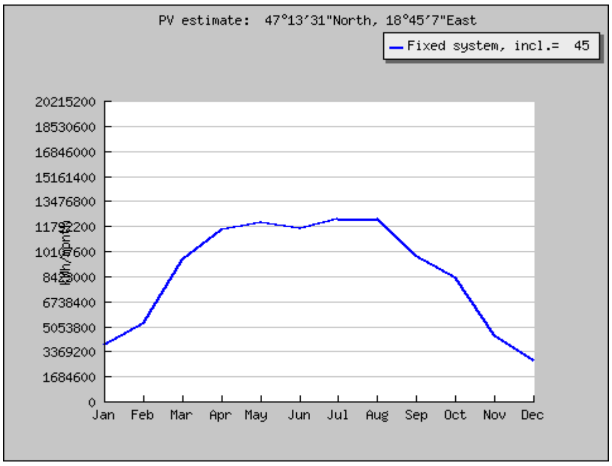


Fig 92 Monthly energy average output for 45°

Also for Budapest we can notice the same difference between various types of technology. The worst is the Silicon crystalline technology, because it has bad performance comparing to other technologies.

The total energy yield per year for Crystalline technology is 94,7 GHh. For CIS is 96,2 GHh and for CdTe is 104 GWh. Like for Venice there is a remarkable increase using the CdTe technology. This is due to the small losses (just 0,4%) due to temperature and low irradiance.

As in Italy the maximum of irradiance is in July, which is 5.81 Kwh/m2 per day, and the average sum of global irradiation per square meter received per month is 180 KWh/m2. The reason is due to the presence of seasons, and July is the pick during the summer, when the sun reaches the maximum angle with the surface.

10.5 Comparison between Budapest and Italy

The first consideration to make is the difference of radiation. As we supposed the radiation in Italy is higher. The table below shows the different amount per month.

TABLE 29 Comparison between Venice and Budapest irradiation (kwh/m2)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Total for year
Venice	64.9	102	152	163	182	180	199	191	162	119	71.8	63.9	138	1650
Budapest	51.5	71.5	134	165	175	169	180	179	139	116	61.2	37.4	123	1480

The total amount for Venice is 1650 kWh/m2, instead for Budapest it is 1480 kWh/m2.
The immediate effect is on the production of energy.
Modules can store more energy in Venice.

Another difference, albeit small, is in losses.

For Venice the estimated loss due to angular reflectance effects is 2,7%, instead for Budapest it is 2,8%. This is a really small difference, which probably has not a remarkable effect in the total energy yield. Something interesting to note instead is the estimated losses due to temperature and low irradiance.

Table 30 Comparison between Venice and Budapest losses due to temperature and low irradiance

	Crystalline Silicone	CIS	CdTe
Italy	9,50%	8%	1,20%
Budapest	8,80%	7,40%	0,40%

As we can see there is a small amount of difference, but still remarkable. This is reflected in combined PV system losses.

Table 31 Comparison between Venice and Budapest combined PV system losses

	Crystalline Silicone	CIS	CdTe
Italy	24,30%	23%	17,40%
Budapest	23,70%	22,60%	16,70%

The smallest difference is in the CIS technology, just 0,4%, but for CdTe technology the difference is 0,7%, which is not something to give up. CdTe technology is the best technology available, and also the most inexpensive, so we need to pay more attention to it than to other technologies.

We can say that Budapest has better performance, but this is not enough to contrast the amount of energy received in Venice. In the end Venice still produces more energy than Budapest.

Another consideration to make, as we made for the software SMA Sunny Design, concerns the mounting angle. As we said before, the best angle for Venice is about 45°, Budapest around 35°.

We made the same situation in Budapest, changing just the mounting angle with 35°. These are the results:

Table 32 Results for Silicon Crystalline pv system in Budapest with 35° angle

	Fixed system: inclination=35 deg., orientation=0 deg.			
Month	**Ed**	**Em**	**Hd**	**Hm**
Jan	112000	3460000	1.57	48.7
Feb	172000	4820000	2.46	68.8
Mar	286000	8850000	4.27	132
Apr	359000	10800000	5.59	168
May	368000	11400000	5.91	183
Jun	366000	11000000	5.96	179
Jul	372000	11500000	6.12	190
Aug	364000	11300000	5.93	184
Sep	294000	8820000	4.62	139

Oct	238000	7390000	3.61	112
Nov	132000	3960000	1.93	57.9
Dec	81000	2510000	1.14	35.5
Average Year	262000	7980000	4.10	125
Total for year		95800000		1500

We can see that the total energy yield is 95.8 GWh, which has increased of 1,1 GWh compared to the previous situation. It is small, but it is remarkable.

Last consideration is about the web application. The software is warning us when we use a peak power higher than 20 KWp.

The PVGIS interface is very simple to use and is free for all. But there are a lot of possible complications in PV system design that it cannot handle. Local shadows are not taken into account, nor the problem of one row of modules shadowing the row behind (this problem is even worse with tracking systems). It is also assumed that all the PV modules will be mounted facing the same way, and if this is not, like for big plants, we can have problems with string mismatch. The application does not know anything about the inverter we are going to use or its efficiency. For these reasons developers of the application cannot assure accurate results for big plants of PV system.

11 Conclusions

As we have seen the use of a PV system of any capacity size is not only economically convenient but it produces clean energy from renewable source as well. The PV system is environment friendly due to the fact that it does not produce any CO_2 differently from the common fossil fuels. In fact, during the combustion fossil fuels produce millions of tons of CO_2 each year thus polluting and damaging the Earth through the greenhouse effect. Unfortunately, the fuel based technologies are still widespread.

However, governments and industry have changed policies so that we can say that nowadays they aim at producing energy from PV by raising the cumulated capacity of PV plants more and more. They are trying to reach a higher and higher share of clean energy.

On the other hand, the production of this energy is still considered quite expensive as the overall efficiency is low. The photovoltaic working system was discovered long time ago (1950s), but this technology entered the global market view only a few decades ago. It is still a fresh technology, its development being just at the beginning.

In the next years with advanced researches and investments this field will achieve a full spread in the world, using more and more conversion efficiency and reducing the costs of plants.

The price of a plant is already competitive, as we showed above (Ch.8) both for residential, commercial and industrial fields.

It is obvious that a key parameter is the average radiation for a selected zone. In our study we chose to compare Italy to Hungary, precisely Venice to Budapest. As we know, the average radiation in Venice is higher than in Budapest due to the latitude, which is lower in Venice than in Budapest.

As our study demonstrated the annual energy yield, which is the most important data for a PV power plant, is higher in Venice, and that is solely due to the latitude. The average difference is 14 GWh, which is a remarkable value. Italy has an incredible amount of sunlight and this is one of the reasons why Italy is the second country in Europe with major installed capacity nowadays. For a long time Italy brought about a good policy and great FiTs to encourage the use of PV systems. An important effect was the rapid decrease of the price for a whole PV system, which saw a cut of half of its price in just 3 years.

Taking into account the data from the Montalto di Castro power plant, which was finished in 2010, we tried to design another one with the same capacity. The total initial investment for our plant was estimated between 90 and 120 million Euros current price, which is half of the investment in Montalto di Castro. The payback time is between 11 and 14 years, which is a sustainable value.

For Hungary we did the same study. The total investment was estimated between 65 and 90 million Euros, as the average level of richness is lower than in Italy. The annual fixed costs were valued in 2.3 million Euros, which are half of the Italian value. Due to the slow policies and not encouraging FiTs and the less amount of sunlight the payback time in Hungary is between 15 and 20 years, which is estimated too much high, also because FiTs are usually guaranteed for 20 years. Hungary market in fact seems to be still unsustainable for large scale PV production.

As for the annual energy yield, using the Web application (Ch.9) we could notice basically the same situation in the two cities. We saw instead differences in the technology used for PV modules. In fact, for Venice we recorded an annual energy yield of 105 GWh for crystalline silicon, 107 GWh for CIS technology and 115 GWh for CdTe technology, thus making the efficiency of the latter much higher than the other two.

12 References

- Practical handbook of photovoltaics; Fundamentals and applications. Second edition, AUGUSTIN MCEVOY, TOM MARKVART, LUIS CASTAÑE. 2012 Elsevier Ltd.
- Környezettechnika, TERC Kft.Budapest, 2013; Dr. Csoknyai Tamás, Dr. Kircsi Andrea, Dr. Kalmár Ferenc, Talamon Attila.
- National Energy Strategy 2030; Date of Publication: 2012, Publisher: Ministry of National Development, ISBN 978-963-89328-3-9. Ministry of National Development
- Optical gain in silicon nanocrystals L. Pavesi, L. Dal Negro, C. Mazzoleni, G. Franzo, F. Priolo, Nature 408 (2000)
- Renewable Energy Technologies: Cost analysis series, IRENA, 2012
- Photovoltaic electricity costs maps, H. Ossenbrink, T. Huld, A. Jäger Waldau, N. Taylor, European Commission, 2013
- Environment, Health and Safety Issues for Sources Used in MOVPE Growth of Compound Semiconductors. Journal of Crystal Growth
- PV in Hungary 2012 - Status Report. Miklós Pálfy
- Global Market Outlook for Photovoltaics 2014-2018, EPIA 2014
- SUNNY DESIGN 2.20: Software for planning PV plants; User Manual; SDesign-BA-BEN120432 - Version 3.2
- https://solar.org.au
- https://terna.it
- http://www.iea.org
- http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php
- http://www.sma.de/en/products/references/montalto-di-castro.html