Thesis of Doctoral (Ph.D.) Thesis

YIELDS OF PV SOLAR ENERGY SYSTEMS AND OPERATIONAL EFFICIENCY

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1. INTRODUCTION AND OBJECTIVES

The global energy consumption was doubled between 1971 and 2010, by 2020 is likely to increase triple. Meanwhile, the energy intensity - so the amount of energy required to produce one unit of income - decreased steadily. Based on the assessment of the Inter-national Energy Agency, China's energy demand will increase about 30%. We must not forget either about India, with this proportion will reach 40%.

In terms of capabilities, we can say that Hungary has favorable opportunities, environmental energies - except hydropower and wind power - solar energy has great potential.

Member States of the European Union is committed to the European Union need to integrate the Central and Southern European gas markets, diversify sources and routes. Most important things in these program are energy efficiency and support those who produce a marketable product or service.

However, there are significant differences between the plans and objectives of the Member States. Germany has a very serious action so they will withdraw all nuclear power from electricity by 2022. Currently, only 10 EU member countries plan a new nuclear plant, there are four reactors under construction in three countries (Finland, France, Slovakia) while in three countries (Finland, Hungary, UK) are licensing phase. Nowadays five countries (Bulgaria, Czech Republic, Lithuania, Poland, Romania) prepare nuclear plants. *(PINC, 2016).*

Germany favors solar and biomass energy production in contrast with nuclear energy. This is a generally in EU, although there are some exception such as Hungary.

Renewable energy sources

The climate change is a great global ecological problem, for which the energetic processes can be made responsible for about 80% *(Pálvölgyi, 2000).* That's why sustainability gets increasing rolein these days (*Bulla, 2006) which means* humanity satisfies the needs while preserving the environment and natural resources for future generations.

Sustainability as energetically can be reached as we need to minimize energy consumption and this lowest consumption should be produced as much as possible from environmental energy. Furthermore, the energy will be used to create value not only for temperate our building.

Sustainable energy management „energy production, storage, transport, social, economic and ecological aspects of implementation of the complex process of integrating use; the classic power management conversion matched sustainable development" *(Dinya, 2010).*

In this energy management the environmental energy sources has a key role which are able to renew *(Barótfi, 1993)*. Its importance to the use of renewable energy because it does not pollute for the environment furthermore humanity can satisfy the needs. Renewable energy sources such as solar energy, hydropower, wind power, geothermal energy and biomass in its various forms (*Farkas et al., 2003*).

Aims of the doctoral thesis

Hungary use less renewable energy than neighboring countries. However across Europe, the number and size of solar systems are growing dynamically. It promotes the spread of solar power plants to significantly reduce the investment costs these system helps to decentralizing energy supply system, furthermore more forecasted the production, such as wind turbines.

It is very important that we can predict the expected production because these resources not always be available when it is in use. With “smart-grid systems” we have a chance to connect to the existing power grid while we use as much energy as necessary.

In my research work one of the main aims to find out that the capacity of the solar sys-tems in our country should be increased or not, and is there any importance of the geo-graphical distri-bution. Main scope of my research is to inspect the yield of already oper-ating solar systems, based on environmental parameters.

For this, I collected solar and meteorological data in three locations, Debrecen, Haj-dúnánás and Hódmezővásárhely. I collected eight different operating PV system data at Debrecen be-tween 2013 and 2015.

Based on the experience of the three-year measurement I was looking for correlation between the energy yield of solar radiation and global radiation. Also I analyzed the effects the deviation of ideal orientation to energy utilization. Finally, I suggested diag-nostic tests to the already operating systems.

HYPOTHESISES OF THE RESEARCH

H1: The operated solar systems need continuous optimization, where operators have to use a working local PV model.

H2: There is a coherent link between the geographical position of the installed solar systems and the global high-radiation areas in Hngary.

H3: The monocrystalline solar cells can be operated with same energy recovery in our region as poly-crystalline solar panels.

H4: With PV cells possible to make a decentralized electricity supply at potentially favorable regions, until all of the current consumption needs can be absorbed with solar system.

H5: PV’s energy efficiency and the average day outside temperature is inversely related.

H6: The energy yield of solar cells well-projected using the PV model at Hungary regions.

2. MATERIAL AND METHOD

In order to analyze the efficiency of the installed solar system or check a proposed investment before the expected energy recover we should collected data by local meteorological stations. This is necessary because of the expected energy recovery is projected on the basis of many years of radiation averages. In the event that you have existing system, it is great importance can be checked the energy yield based on the actual amount of globalradiation.

During operation, when a different amount of strings should be observed as soon as possible to examine. This requires knowledge of the specific characteristics and the current global radiation data in the system, these can accurately calculate expected energy yield.

The primary data collected using qualitative (quality) and quantitative (quantitative) research methods. The qualitative research unstructured, exploratory approach based on a small sample and serves the nature of the problem of understanding (*Malhotra, 2002*). This research is mainly managed to get to know better "Why?", "How?" answers. The quantitative research usually based on a large number of database quantifies the response to various requests protrusion for ("What?", "How much?", "How many?", "Where?", "When?") Responses, which are analyzed mathematical and statistical methods.

We can find a number of theoretical methods where we can expect energy yields of solar systems, however, there were significantly fewer examples to analyze the installed system's energy efficiency.

The primary aim of my research is to look for a correlation between the actual amount of energy utilized and environmental parameters. For this reason, I collected solar and meteorological data from three locations Debrecen, Hajdúnánás and Hódmezővásárhely, (**1.**). After I finished collection I made analysis.

1. foto *Installed monocrystalline and polycrystalline PV cells in No.2 and No.4 system*
Source: Own

Testing expected energy yield of solar photovoltaic systems currently use online calculator on the Geographic Information System (PvGIS), application for example, our PV model should be an alternative application at Hungary, where the monitoring data can be analyzed according to the local meteorological data and the actual energy yields will be assessment.

With PvGIS database in case of grid-connected operation and sealing of the selected type solar cell can be tested in any geographical location in a photovoltaic system operation. You can adjust the solar field orientation, inclination and even days following the layout.

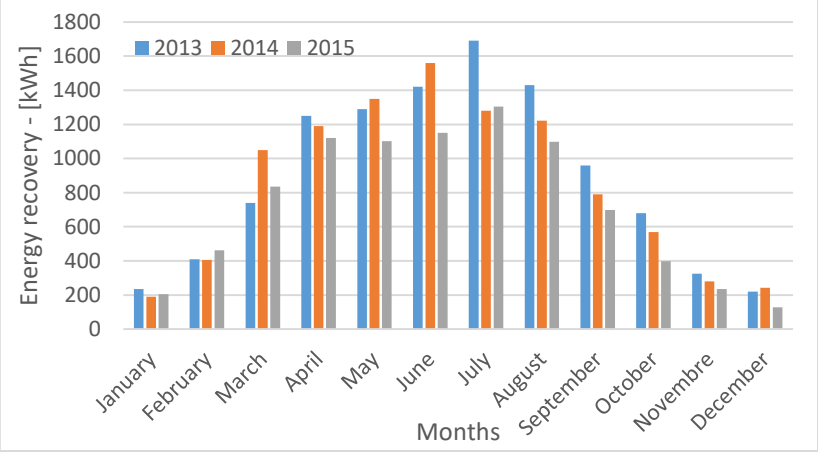
I found that every month the value are same, the standard deviation is between 0.01 ÷ 0.02 energy recovery and the local global radiation quotient operated in various locations in different ways policy-agents, so the global radiation Monthly amount of well described by the expected energy yield.

The model is constructed on the basis of analyzes were performed three new systems one at Hódmezővásárhely, one at Debrecen and one at Hajdúnánás. I found that using the PV model can be predicted energy recovery. Where are significant differences there where a technical error as I discussed it with operators.

3. RESULTS

We should improve the technical and economic efficiency of the already operating solar systems with monthly maintenance and control. My analyzes indicate that nobody has analyzed the collected data and when something was bad they didn't make any technical intervention.

I found that the solar systems are also examined common that there did not happen either cleaning or changing position. The amount of energy utilized in the three years are summarized in the following (**Hiba! A hivatkozási forrás nem található.**).

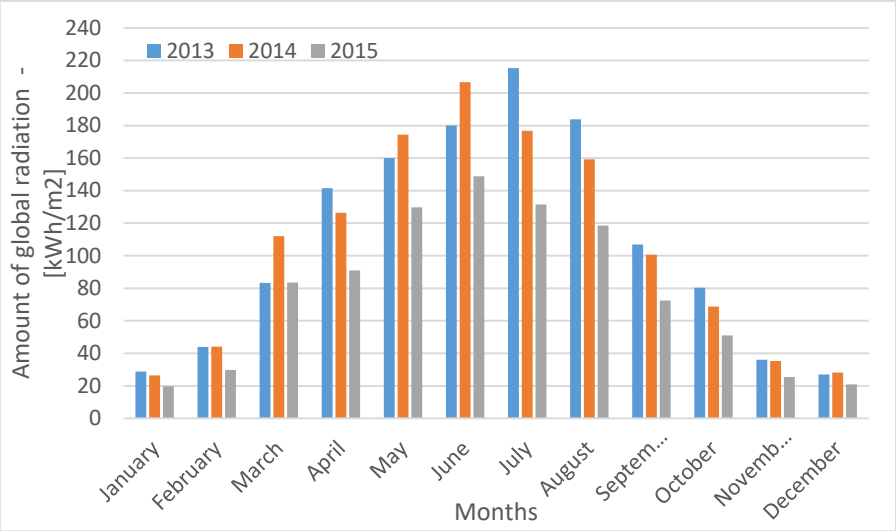


1. chart Monthly energy utilization of No. 4 solar system in Debrecen 2013-2015

Source: *Own edited, 2016*

Concluded that after the commissioning continuous decrease the energy use year after year. 10650 kWh in 2013, 10128 in 2014, the annual amount of electricity utilized in 2015 was 8736 kWh value. I measured a significant drop in the summer time from May to August 1175 kWh observed between 2013 and 2015, reflecting the full-year 1924 kWh downturn more than 60%.

But rate of reduction not be same each month, so the deviation is not caused by technical failure. I have summarized the monthly global radiation amounts in the following (**2. chart**).



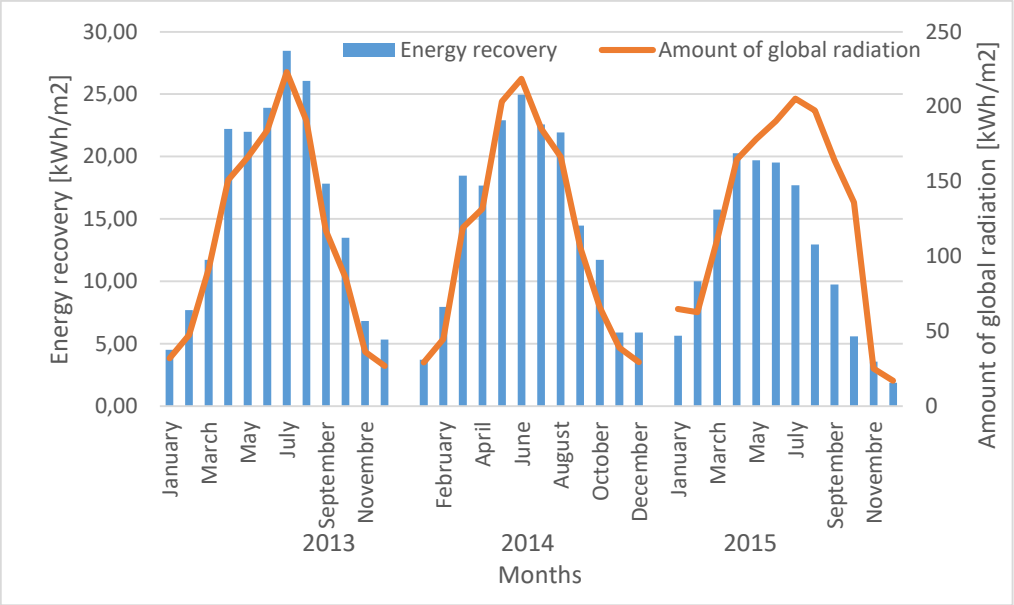
2. chart *Amount of global radiation in Debrecenben 2013-2015*

Source: *Own edited, 2016*

The global radiation amounts are not the same extent over the past three years, with minimal reduction in 2014 was when 1280 kWh / m2 to decreased 1260 kWh / m2, but the 2015 year reached the value at the 2013 year again global radiation amount, so it is not the reason for the reduction in energy utilization.

I found that in 2013 and in 2014. In July the surplus energy utilization due to higher global radiation possible. However, in July of 2015 the global radiation was higher than, in 2014 so the solar system should utilize more.

I present the No. 1 system's annual energy yield and the global amount of radiation measured in the following chart (**3. chart**).



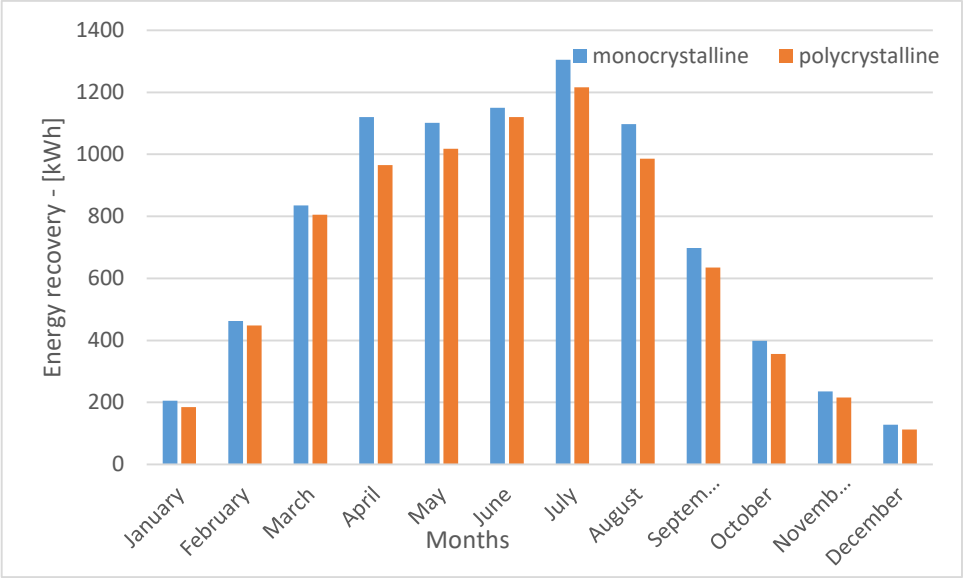
3. chart *Monthly energy yield of the No. 1 solar system and global radiation amount changes is Debrecen 2013-2015*

Source: *Own edited, 2016*

It established the No. 1 system has reduced energy yields even under the three-year operation. The annual energy yield in 2013 was 63840 kWh, in 2014 was 59808 kWh, in 2015 was 47712 kWh. I measured a significantly decline in 2015, then it could utilize the global radiation more fully. The rate of decline in 2014 is virtually identical to the extent of reduction of global radiation.

I had opportunity to compare the mono- and polycrystalline solar panels which are located on the same building. Both systems operate with same SMA inverter. The system area is about 54 m^2, the polycrystalline is about 58 m^2. I summarized the measurement data in **4. chart**.

After processing the data I found that monocrystalline solar panels operate with better annual energy utilization in our region, than the poly-crystalline solar cells. Over the past three years, the monocrystalline system recovered 29514 kWh, while the polycrystalline system only 27425 kWh (4. chart). Calculated with average residential electricity price -44 HUF/kWh it means more than 90.000 HUF.

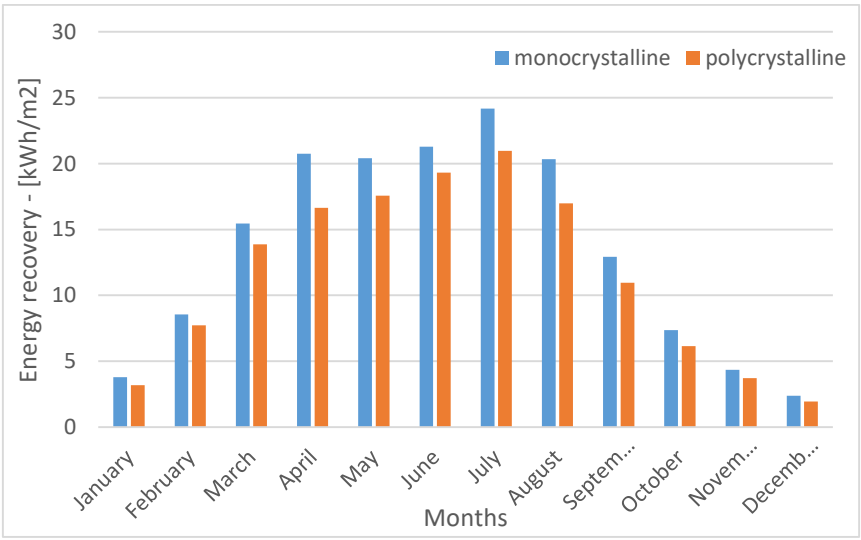


4. chart *Energy recovery of mono and polycrystalline PV cells in Debrecen 2015*

Source: Own edited, 2016

I have to high lighted that the monocrystalline system can be operated with better parameters. The customers are not informed before the investment properly, many times because of the economic interests rather direct the customer towards a weaker technical content. People buy polycrystalline solar panels typically, I could also collect more data from these systems.

If we have limited possibilities with built in area, we should check the energy yield per m^2 (**5. chart**)



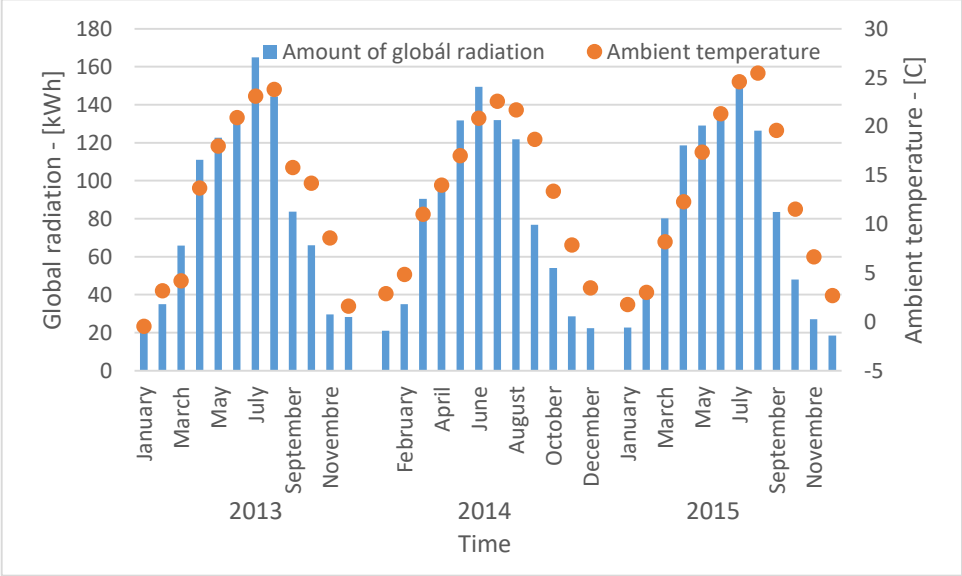
5. chart *Energy recovery of mono and polycrystalline PV cells per m^2 in Debrecen 2015*

Source: Own edited, 2016

I present the energy yields per square meter in 2015 on chart above. I found that the monocrystalline items efficiency better in every month. I measured more than 8,4% surplus annual production output at monocrystalline solar cells. This trend can be observed in all three analyzed year.

It found that higher average temperature was measured during the summer months, from May until September in 2015 than in 2014. The average temperature in July increased 22.6°C to 24.6 °C in August from 21.7°C to 25.5°C, the temperature was registered decline during the winter months, which is an outstanding example in March when it was cooler above 2.8 °C . In my opinion, this change, should be caused this significant loss of performance of the solar system.

The answer to the question of why we operate a system worse in 2015 than in 2014, as further analysis was carried out. I illustrated the global radiation amounts on 6. chart and I added the measured average monthly air temperature data by the day period.

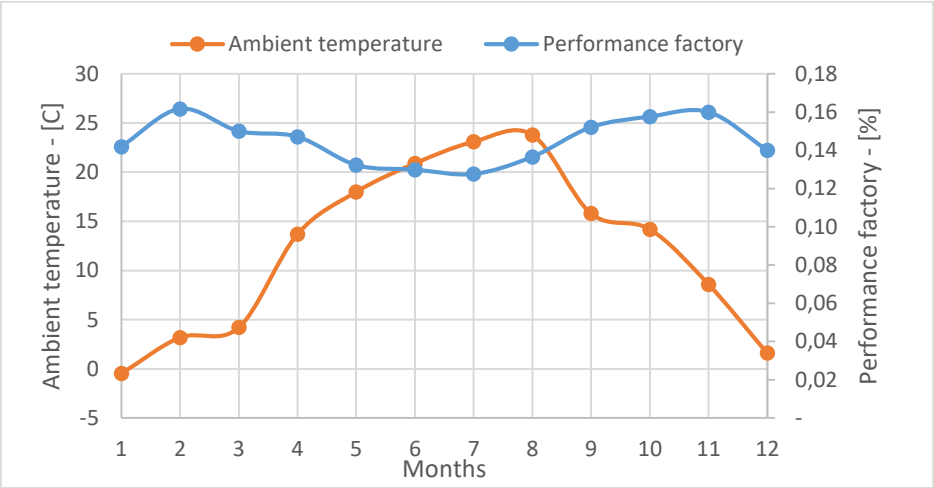


6. chart *Amount of global radiation and avarage ambient temperature in Debrecen 2013-2015*

Source: Own edited, 2016

I found that the solar system is able to make more electricity during the months when the air temperature is lower in addition to radiation similar value, while in the case where the outside

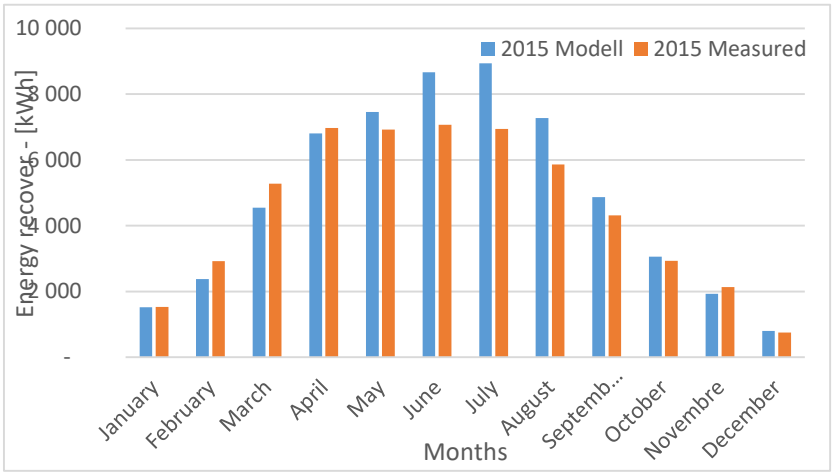
air temperature increases, then decreases the rate of energy utilization rate despite similar irradiation. The following chart is illustrated the performance factory and the measured air temperature during sunny (**7. chart**).



7. chart *Ambient temperature and performance factory in Debrecen 2013-2015*

Source: Own edited, 2016

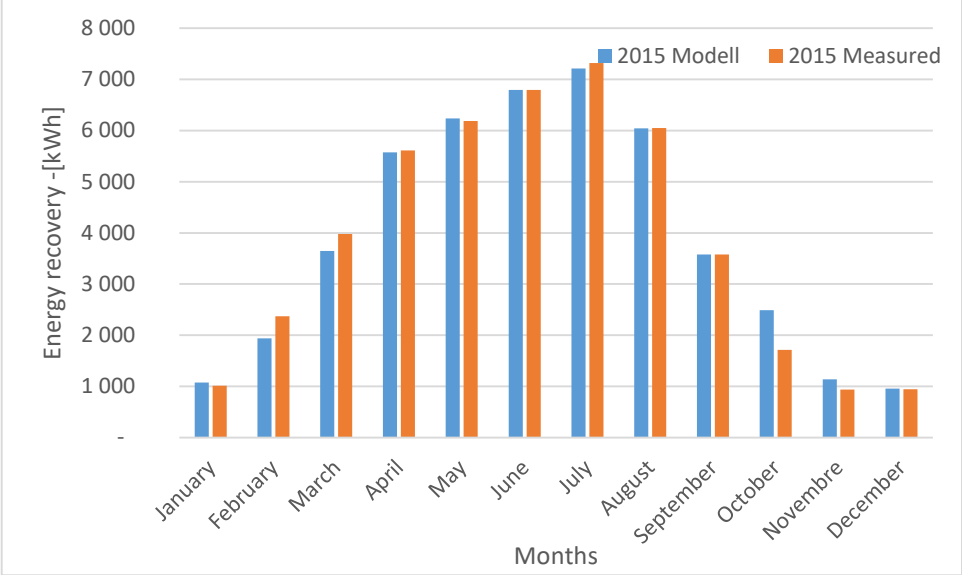
The external environmental parameters under investigation, I found that a large role in the changes in temperature. Examination of the wind speed was the next item, because I think the wind is able to cool the system which cause more efficiently. I made calculations with PV model at operating systems also. In order to apply the model for systems installed in various fields, I chose systems from different areas. For example I made a following calculation at Hódmezővásárhely which is a 50 kWp solar system (**8. chart**).



8. chart *Counted and measured energy recovery at Hódmezővásárhely in 2015*

Source: Own edited, 2016

I summed the monthly energy quantities in 2015 on 9. chart. I illustrated the actual amount of energy with red mark while the blu one is the calculated by PV model. Energy recover of this system is about 55.620 kWh, while according to calculations the amount of energy could be 58.242 kWh. It found that during the summer there is a significant performance loss. This is most likely to occur, such as overheated solar panels – cells are fixed to the hall roof - it can not cool sufficiently. Further enhance the situation, summer season is warmer -local weather station data - in 2015 than in 2014. In order to further increase the reliability I checked energy data recovery at Hajdúnánás (**9. chart**)



9. chart *Counted and measured energy recovery at Hajdúnánás in 2015.*

Source: Own edited, 2016

With this system we can recovery 46689 kWh enegergy as PV model calculated, until I measured 46501 kWh. It looks on a **9. chart**, so the system recover as many energy as PV model calculated.

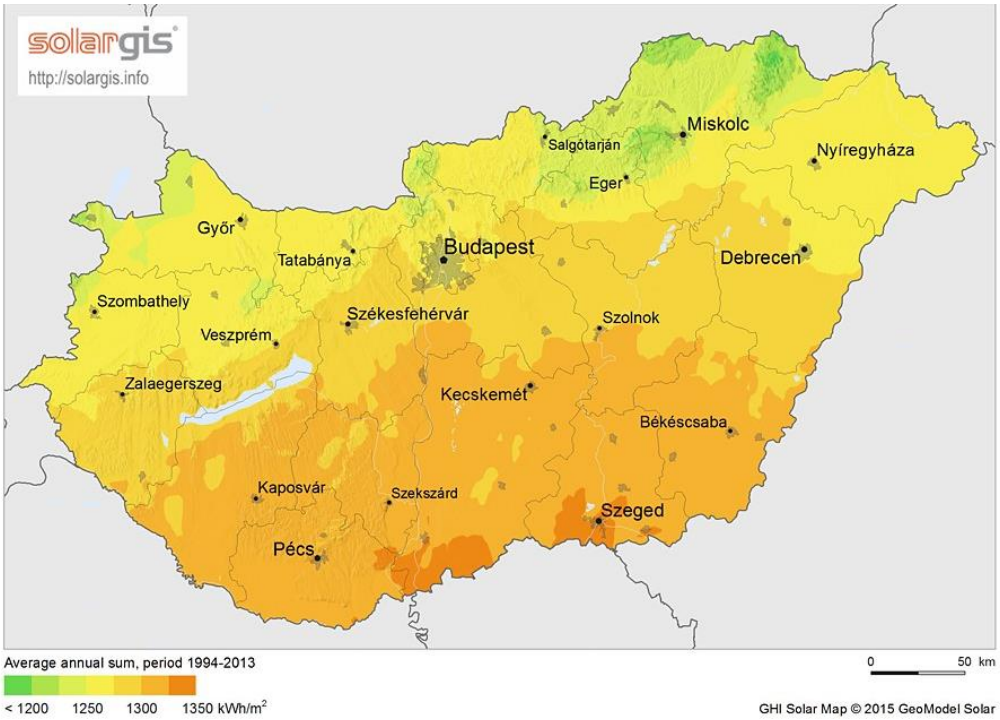
The installed Hungarian solar systems

Analize - data collected by Hungary Energy and Utilities Regulatory Office- distribution of 143.3 MW of installed Hungarian PV capacity, turns out that the 47.7 MW have been installed in Dunántúl region, Tiszántúl region and southern part of about 56.2 MW and the North Hungary has 39,4 MW capacity.

It was found that the distribution of plants a big spread from city to city. Several counties such is Bács-Kiskun county, where is no system installed and has a favorable solar radiation conditions in this area. There is also a county example of Gönczi, where weather conditions were not the most favorable, and even solar power plant is installed.

Based on MVR data in the Észak Alföldi region the average electricity consumption is about 1.030 kWh. In this region lives about 1,5 million people so they use about 1.545 GWh energy *(KSH, 2011).* It means that if all the people use an average of 1 kWp solar system this region would be able to produce electricity demand from environment.

Of course, for this target need many professional and financial support, degree of the fossil fuels could be reduced greatly in the energy mix. You can see the regional distribution of global radiation on (**1**. figure) in Hungary.



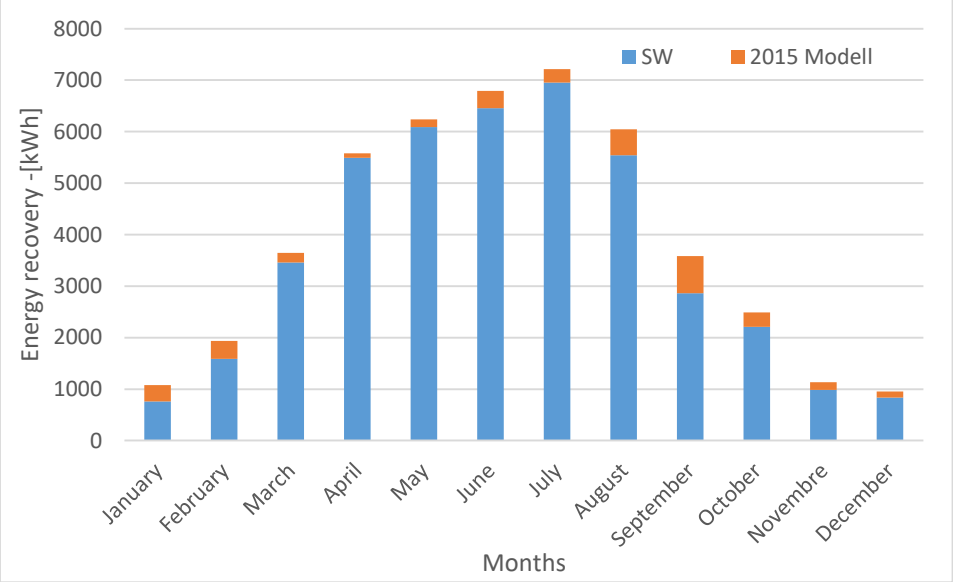
1. figure *Total global radiation regional distribution in Hungary*

Source: Solargis

The above figure is based on meteorological data, which stated that in terms of the overall global radiative capabilities very good potential in the field of Tiszántúl region. Comparing the data of the energy agency also found that this region can be observed more integrated solar capacity than other regions, but it could be more homogeneous distribution per county.

The southern areas worth 1300 kWh/m2 mean radiative very favorable for the operation of solar systems, but also in the northern areas, where 1250 kWh/m2 is less than the value it is favorable.

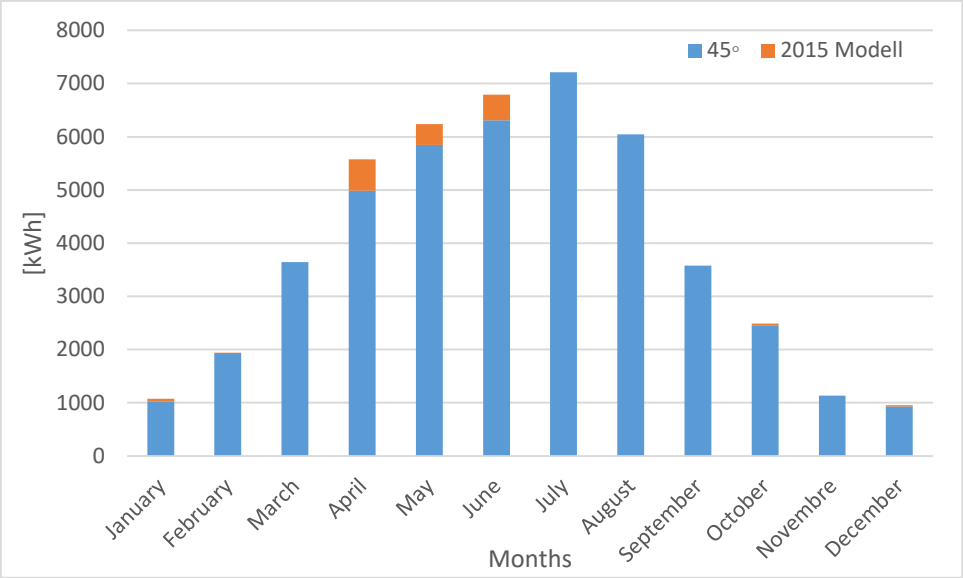
In that case if built in conditions not same as the ideal for the solar modules we can analize what it means in energy efficiency. This calculation is made for two different situation, where one case is the orientation SW, the second case relates 45◦ angle of solar panels (**10. chart**; **11. chart**).



10. chart *Energy recovery of southwest oriented 50 kWp PV cells*

Source: Own edited, 2016

Often happens with the existing buildings that you can not install the modules of south orientation. In this case, this difference makes 7.4% reduction in annual energy yield.



11. chart *Energy recovery of 45˚ titled 50 kWp PV cells*

Source: Own edited, 2016

If the tilt angle is not ideal due to the existing roof structure, this means 3.4%. decrease of an annual energy recover. I conclude that no significant differences are in minimum recovery and it can be compensated by number of pieces of solar modules.

4. RESULTS OF THE THESIS

1. Use My proposed model predicted the PV solar energy yield annual and monthly increments. Operators can verify system based on the current environmental parameters. Based on the control measurements can be calculated to within ± 5% of the expected energy yield.

2. Based on the measurements of three years, in our region the monocrystalline solar cells operated with better annual energy utilization, then the poly-crystalline solar cells. The view that polycrystalline solar cells better utilized with scattered radiation at Hungary climatic conditions, could not be verify with measurements. Both in winter and in the summer months the monocrystalline solar cells have better energy yield 7,6%.

3. The different inclination and orientation of solar cell energy output examining determined rate performance degradation caused by deviations from the ideal. I found that the deviation from the ideal orientation significantly reduce the orientation for example in the southwest of the annual production is 7.4%. Even in the case where only the ideal angle can not be kept in the embodiment, the example case of a 45◦ angle an annual rate less with 3.4%.

4. Use the PV model proved that great importance is the continuous optimization of the operating PV solar systems. With the monthly checks of a technical problem be discovered, and if you manage to correct the problem, you can maximize the annual energy yield.

5. I proved that a high degree of performance degradation in systems which can not sufficiently cool. The solar modules which are fixed to the roof structure are only at a slight breeze, these are able to convert less energy than a free-standing solar panels about 4.7%. I found that the performance factory of solar systems and average ambient temperatures is inversely related.

6. I found the absolute necessity of the solar surface cleaning, surface contamination because of large reductions in solar energy utilization. I measured to 1.5% improvement

when I cleaned the solar cells compared with the solar panel, where the maintenance was not done cleaning.

7. It is possible to decentralize the power supply with solar panel at good natural conditions regions, the current consumption needs would be covered by solar systems, if everybody intall only 1kWp PV system in our region. In addition, preference should be given to energy efficiency programs in the regions where higher than average electricity consumption that can reduce energy consumption, and this reduced volume to produce the greatest extent from renewable energy.

5. PRACTICAL USE OF THE RESULTS

1. Over the past seven years, almost from scratch increased to 140 MW of installed solar capacity in our country and to continue this development. As a regional disparity in the solar potential and therefore needed special support to those regions, in which endowments better.

2. PV model help to the maintenance work which is set Hungarian environmental parameters and we can count monthly energy yields so we can optimalize our operating PV systems.

3. The basic parameters of the global radiation is the most important parameter in terms of production, which is recorded a number of weather stations in the region. The PV model can be integrated into these systems and analysis of computerized geographical information systems.

4. The PV energy yield analysis of model is of great importance to calculate and check. I examined the systems in one common and significant problem of contamination was and the anotherone was the overheating.

5. In the event that a visual inspection may be difficult or impossible comparison with sufficient monitoring data and expected energy yield of PV model, and you only need to visually check the system does not work properly if the environmental parameters of the system.

6. In practice, it is important that the projected energy efficiency of different types of solar systems and take into account the long 20-30 years operating time

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7. List of publications related to the dissertation

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List of publications related to the dissertation

Foreign language international book chapters (1)

1. **Török, I.**, Tóth, J.: Operating experiences of the photovoltaic system of a business center that utilizes environmental energy.
   In: IMT Oradea - 2013 : Proceedings of the annual session of scientific papers : may 30 - june 2013, Felix SPA, Oradea Romania. Ed.: Calin Baban [et al.], Editura Universitatii, Oradea, 187-190, 2013. ISBN: 9786061010844

Hungarian scientific articles in Hungarian journals (3)

2. **Török, I.**: Energiahatékonyság itthon és külföldön.
   Agrártud. közl. 63, 147-150, 2015. ISSN: 1587-1282.
3. **Török, I.**: Egy napelemes rendszer üzemeltetési tapasztalatai.
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Foreign language scientific articles in Hungarian journals (1)

5. **Török, I.**: Renewable energy strategy in Hungary.
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Foreign language scientific articles in international journals (1)

6. **Török, I.**, Tóth, J.: Operating experiences of the photovoltaic system of a business center that utilizes environmental energy.
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Hungarian scientific articles in Hungarian journals (3)

10. **Török, I.**: Megújulók a felsőoktatásban.
Agrártud. közl. 63, 151-154, 2015. ISSN: 1587-1282.

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