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ENERGY ANALYSIS OF THE PV FARM WITH A CAPACITY OF 140 MW

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Abstract: Recently, there has been a large development of photovoltaics in Poland and in the world. This work shows how the energy profit of a high-power photovoltaic farm changes with the change of the angle of inclination of the panels on the example of a PV power plant project in the Siemiatycze districtin the Podlaskie Voivodeship. In order to verify the energy gain, measurements were made in the PVSyst program for panels with a power of 600 Wp, the spacing of 10 m or 6 m for angles from 20 ° to 25 °. Based on the analysis, the results were obtained, which indicate that with an increase in the angle of inclination in the studied range of angles, the annual production of energy by power plants increases. The difference between the production for the angle of 20 ° and the angle of 25 ° is 1010 MWh, which means profits higher by almost 1% per year. on the basis of the selected row spacing and angle, an analysis was carried out, which shows that the average amount of energy generated in a 140 MW installation will be approximately 149 246 MWh. The article also contains an analysis of losses which are generated during the work of PV panels.

Keywords: photovoltaic, renewable source of energy, solar farm, energy

1. INTRODUCTION

Recently, there has been a large development of photovoltaics in Poland and in the world. This fact is due to the lower prices of the panels and the increasing environmental awareness of the people. More and more people start to think about the world around us and want to make it better. So they decide to invest in PV farms. The largest global photovoltaic powers are constantly investing in the further development of this field of energy, using the latest technology achievements to amaze the world. Example that the future of solar energy is really important to the authorities of the world's economic powers is the commissioning of the world's largest solar power plant at the end of September 2020. It was created in China at the amount of about 3 thousand. meters above sea level. and produces 2.2 GW of electricity, and consists of as many as 7 million photovoltaic panels.

The most important element of the farm is PV module which is made up of connected and then laminated photovoltaic cells that they are protected at the top by a glass with anti-reflective properties (fig.1), and at the bottom by an insulating layer. Whole aluminum frame protects. A box with cables and connectors is attached to the rear surface. The optimal operation of photovoltaic panels is ensured by: exposure towards the south, correct angle of inclination and no shading.

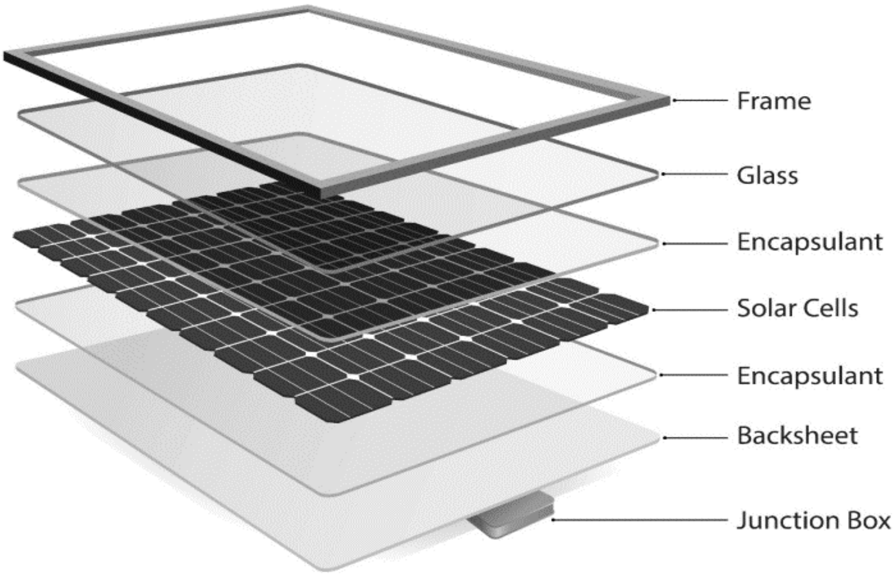

Fig. 1. Solar panel construction (source: https://ae-solar.com/what-pv-modules-made-of)

The production of electricity by photovoltaic panels is possible thanks to a phenomenon called the photovoltaic effect. This phenomenon is that an electromotive force is generated in the semiconductor. It means that simply put, it converts solar energy into direct current, and this happens in photovoltaic cells that make up solar panels. A photovoltaic installation can be installed virtually anywhere. The panels can be placed on flat roofs (flat roofs), slightly sloping and sloping roofs (over 45 degrees of slope). In addition, however, it is also possible to mount it in the ground. This solution is most often chosen by entities that have unused land. The construction of a 1 MW installation is an initial cost of PLN 2 to 3 million, however, within thirty years of operation, such a solar farm will not only pay for itself, but will generate savings of around PLN 5 million.
The practical use of solar energy resources requires the estimation of the potential and real conditions of solar energy resources in a given region and the parameterization of meteorological conditions adapted to the needs of the technology of converting solar energy into electricity. Insolation in Poland is characterized by an uneven distribution of solar radiation throughout the year. Nearly 80% of the total annual amount of sunshine falls on the six months of the spring and summer period (April to September). The time of sun activity in winter is reduced to 8 hours a day, and in summer in the sunny months it reaches 16 hours. The average annual insolation in Poland is about 1000 kWh / m2. On the other hand, the average sunshine duration is 1,600 hours a year (fig. 2).

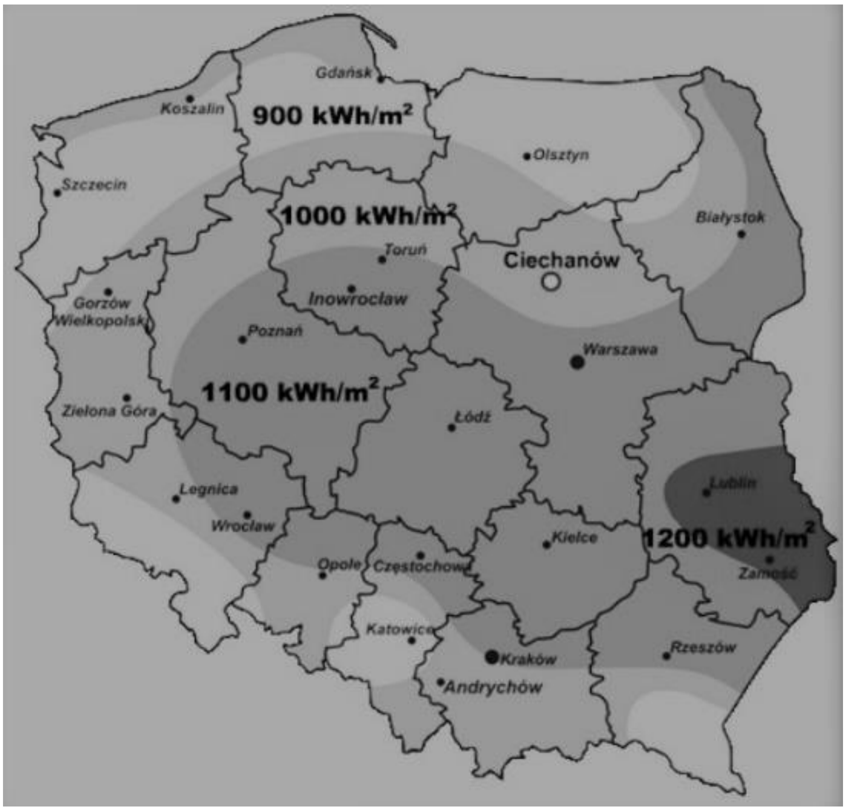

Fig. 2. Insolation distribution in Poland (source: https://teplo.pl/fotowoltaika/)

Continuous technological development and more and more effective photovoltaic cells give hope that in the near future photovoltaics will slowly replace conventional power plants. The energy based on coal combustion is already in a strong retreat, as evidenced by the plans of some European countries assuming a 100% transition to renewable energy by 2050. So, the future of photovoltaics in this respect is very optimistically considered by the countries that already assume now what will be in half a century. Therefore, it is reasonable to try to analyze the productivity of a 140 MW farm in Poland, which will be presented in the article on the basis of the analysis carried out in the PVSyst program, which is a tool for designing and estimating a photovoltaic system. It simulates most of the parameters required by PV system designers and helps generate a comprehensive simulation report. (Caamano et al., 2009; Hammons and Sabnich, 2005; Kaproń et. al, 2015; Klugman, 2010; Ristinen and Kaushaar, 1999; Sarnik, 2008; Wacławek and Rodziewicz, 2011)

2. RESEARCH OBJECT

The object of research is a photovoltaic farm located in Podlaskie voivodeship (north - east of Poland). The solar farm include 234 716 PV panels about with a total capacity of 140 MWp. The power of a single panel is 600 Wp. PV system is mounted on a stainless steel support structure facing south east. The area designated for investment does not have a Local Spatial Development Plan. There are overhead power lines in the vicinity of the investment site. The solar farm will consist of the following elements: photovoltaic panels, internal roads, ground and underground infrastructure, power and fiber optic cable lines, power connections, transformer stations, energy storage, inverters, GPO and other necessary infrastructure elements related to the construction and operation of the farm. This solar farm will be a maintenance-free, closed facility. During its technical condition there will still be no sanitary sewage.

3. The results of the analysis

In the first step of the analysis, the optimal angle and distance between the rows of panels were selected in order to obtain the highest possible annual energy gains.

Table 1
Power generation depending on the angle and distance between the rows (MWh)

Spacing/Angle	20°	22°	23°	24°	25°
7 m	134 912	141 730	141 345	141 012	144 412
8 m	146 110	145 830	145 521	145 219	148 300
9 m	148 980	148 940	148 631	148 739	149 057
10 m	148 988	149 181	149 221	149 246	148 494

Source: own elaboration (PVSyst)

After the analysis, it appears that the farm achieves the highest profits for the row spacing of 10 m and the slope of 24 degrees. If we select these parameters, the average amount of energy produced in a 140 MW installation will be approximately 149 246 MWh (table 1). For the analyzed data, the maximum amount of energy produced was 21693 MWh per month, while the minimum was 2012 MWh per month (table 2).

Table 2
Power generation depending on the angle and distance between the rows (MWh)

Month/ Parameter	Global horizontal irradiation [kWh/m^2]	Energy injected into grid [MWh]	Performance Ratio
January	20,1	3 526	0,740
February	30,8	5 336	0,869
March	74,2	12 574	0,950
April	118,1	17 872	0,930
May	156,1	20 716	0,905
June	164,9	21 123	0,895
July	168,0	21 693	0,889
August	133,8	18 495	0,898
September	89,1	14 107	0,916
October	50,5	8 690	0,897
November	20,2	3 102	0,817
December	12,6	2 012	0,698
Year	1 038,4	149 246	0,896

Source: own elaboration (PVSyst)

Figure 2 shows the Performance Ratio which stands out among the most important variables in assessing the efficiency of a solar farm. The performance index is a measure of the quality of a photovoltaic installation, the value for it depends on the location and therefore is often described as a quality factor. The efficiency factor (PR) is given as a percentage and describes the relationship between the actual and theoretical power of the PV farm. With this indicator, it is possible to show how much of the energy is actually available for export to the grid after deducting energy losses energy consumption for operation. If the index PR for a photovoltaic plant is as close as possible to 100%, the more efficient the farm is. Unfortunately, it is impossible to achieve a value of 100% for PR. Because there are always losses due to the operation of the installation (for example: heat losses due to the heating of PV panels). The indicator is used to compare the energy performance of a power plant with others and to monitor power plants over a period of operating years. The value of PR is influenced by: The following factors may affect the PR value:

a) environmental factors
- solar radiation and power dissipation,
- solar module temperature,
- the measuring instrument is shaded or dirty,
- PV module in the shade or dirty;

b) other factors
- differences in solar cell technologies,
- the efficiency of the inverter,
- conduction losses,
- the efficiency of photovoltaic modules.

The optimum analysis period for calculating the performance ratio is 1 year. Based on the analysis carried out in the PVsyst program, the average PR of the tested farm is 89%. The highest rate is in March and the lowest 70% in December (fig. 2).

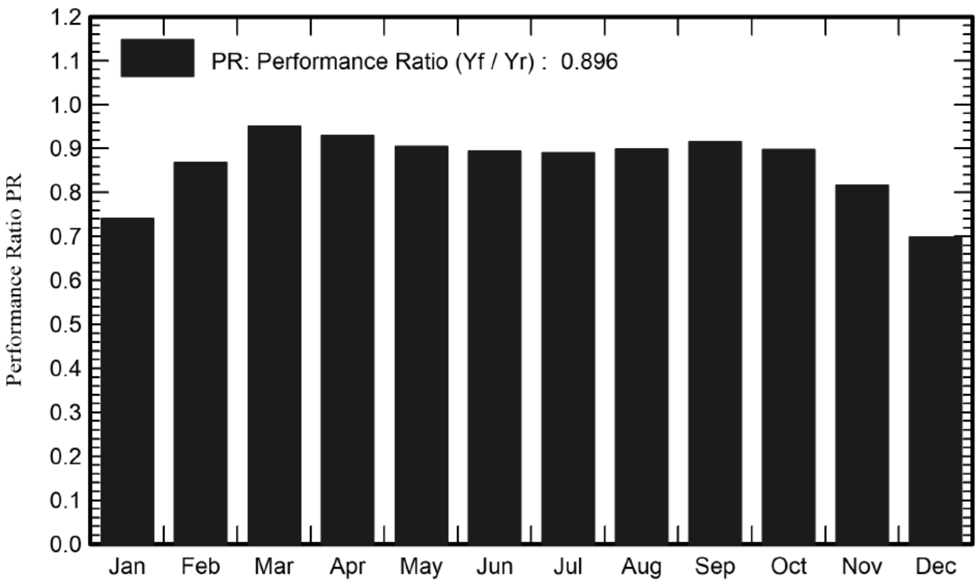

Fig. 2. Performance Ratio (source: own elaboration)

Figure 3 shows the different performance index of the Pv farm obtained during simulation. System yield (Yf) is useful daily energy of the system related to nominal power, shows in kWh / kWp / day. Colletion loss (Lc) is the array losses, which include thermal, wiring, module quality, mismatch. System loss (Ls) include inverter loss in grid-connected systems. In this example energy supplied to the user Yf= 2,9 kWh/kWp/day, collection loss (Lc) is 0,3 kWh/kWp/day and system losses (Ls) is 0,04 kWh/kWp/day (fig. 3).

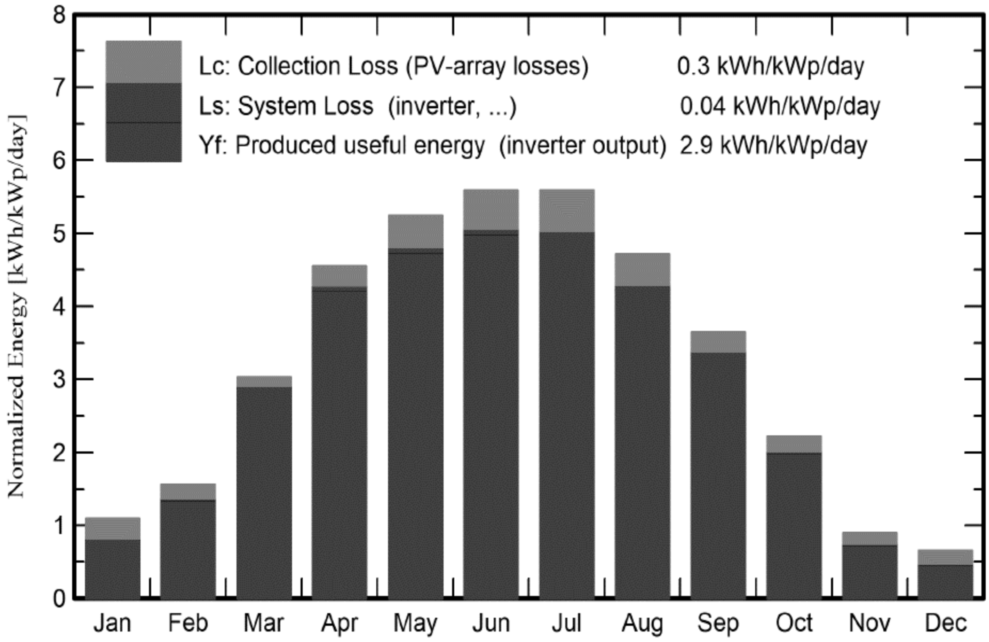

Fig. 3. Normalized productions per installed kWp (source: own elaboration)

The loss diagram is showed at the figure 4. This diagram shows all the losses that occur during the transfer and conversion of solar energy at different stages system. The diagram shows that the available solar energy for the plant site is 1032 kWh/m^2. The actual energy available to the collector plane, considering IAM factor and 21,23% efficiency at STC, is 161129 MWh. Due to the occurring various losses, such as: radiation losses, temperature losses, mismatch losses, the energy available from the power plant is 151479 MWh. Considering different losses which are connected with inverter energy supplied to the user is 149246 MWh. The loss graph provides a helpful picture of the quality of your PV farm project by listing the individual losses and grouping them. (Khorasanizadeh et. al., 2014; Makrides et. al., 2010; Aslani and Wong, 2014)

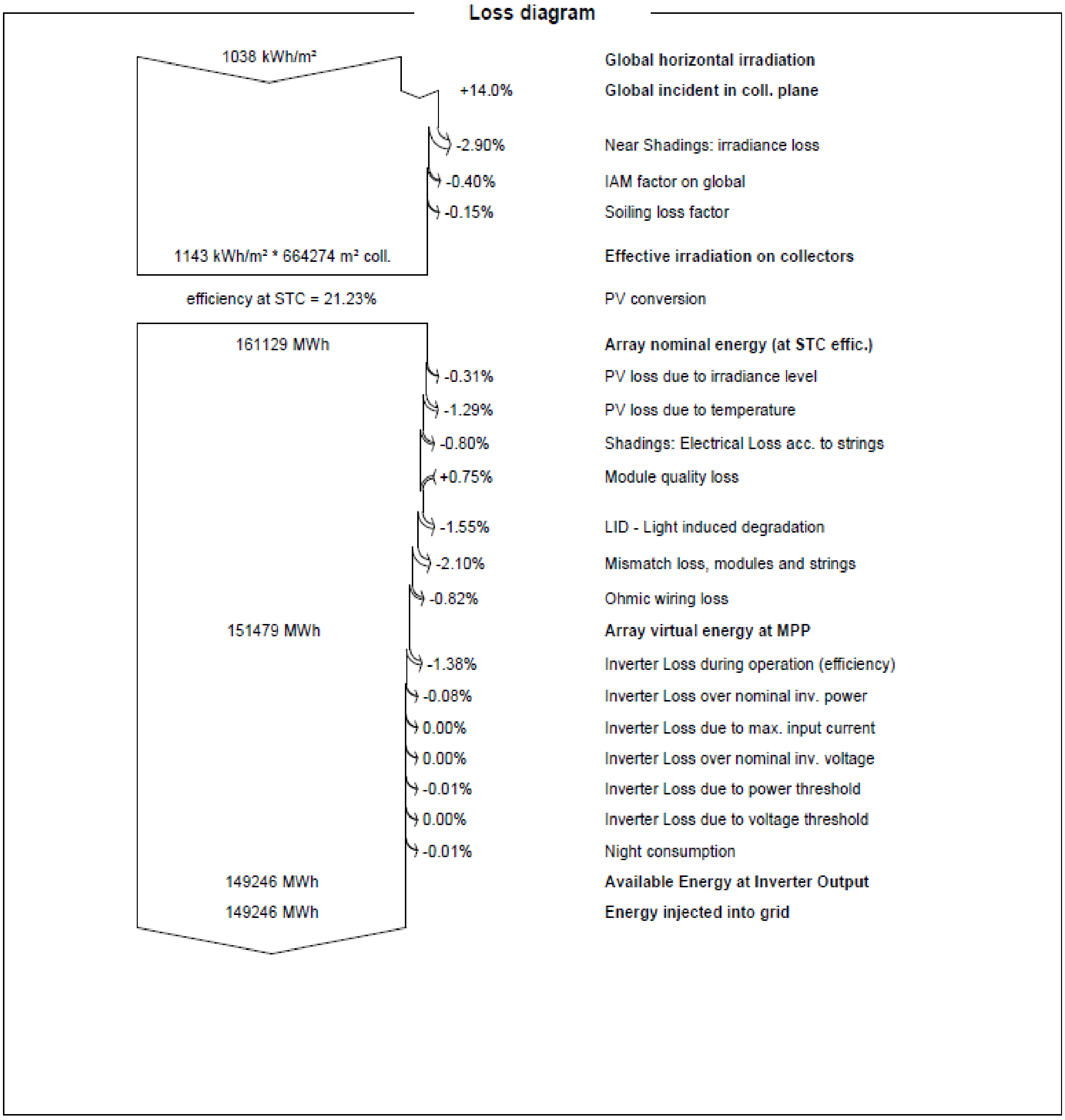

Fig. 4. Loss diagram (source: own elaboration)

4. CONCLUSION

The photovoltaic sector in Europe and in the world is developing very dynamically. In the last few years alone, the power of electricity produced by solar photovoltaic conversion has been doubled. This dynamics is fostered by the legal regulations of most countries, introducing a system of fixed tariffs. Also in Poland, there are more and more PV installations every year. It is important to carry out an analysis before making the farm project, which will indicate the appropriate parameters responsible for the greatest possible profit from the PV farm.

Knowing the amount of energy produced by the PV farm is very important for the planning, design and operation of a solar farm. The most important parameter before starting the construction of the farm is to determine its system efficiency, which is determined by the annual energy production.

On the basis of the analysis, the optimal angle for PV panels was determined. Selecting the optimal angle - 24°, an energy analysis of the entire farm was carried out. The average amount of energy produced in a 140 MW installation will be approximately 149 246 MWh (table 1). For the analyzed data, the maximum amount of energy produced was 21693 MWh per month, while the minimum was 2012 MWh per month. Loss diagram shows that about 10,25% of solar energy falling in the analyzed period is not converted in to usable energy due to factors such as inverter losses, thermal losses and defects in components, etc. Therefore, it is important to take care of the appropriate selection of locations, devices, etc. in order to achieve the highest energy gains. (King et al., 2002; Fiances et. al, 2019; Tryjanowski, 2013)

REFERENCES

Aslani A., Wong KFV, (2014), *Analysis of renewable energy development to power generation in the Unit-ed States. Renewable Energy, vol. 63, 153-161*

Caamaño Martín, E., Masa Bote, D., Gutiérrez Martín, Á., MonasterioHuelin Maciá, F., Castillo Cagigal, M., Jiménez Leube, F. J., & Porro, J. (2009). *Optimizing PV use through active demand side management.*

D. L. King, W. E. Boyson and J. A. Kratochvil: (2002)“Analysis of factors influencing annual energy production of photovoltaic systems,” Photovoltaic Specialists Conference IEEE,

Hammons, T. J. Sabnich, V. (2005), “*Europe Status of Integrating Renewable Electricity Production into the Grids”, Panel session paper 291-0, St. Petersburg*

I. R. Fiances, E. M. Cerón, R. E. Paredes, G. N. and J. de la Casa, (*2019) Analysis of the Performance of Various PV Module Technologies in Peru (Energies)*

Kaproń P., Nagięć A., Sobczyk A.,Bzowski B., Rówiński E.,(2015) *Badanie wpływu kąta nachylenia paneli fotowoltaicznych wykonanych z monokrystalicznego, polikrystalicznego i amorficznego krzemu na przebieg charakterystyki prądowo-napięciowej,*

Khorasanizadeh,K.Mohammadi,and A.Mostafaeipour: *(2014) “Establishing a diffuse solar radiation model for determining the optimum tilt angle of solar surfaces in Tabass, Iran”, Energy Conversion and Management ,Vol 78 ,pp. 805–814*

Klugman-Radziemska, E. (2010) *Fotowoltaika w teorii i praktyce. Legionowo: Wyd. BTC.*

Makrides, G., B. Zinsser, M. Norton, G. E. Georghiou, M. Schubert, and J. H. Werner. (2010) *‘‘Potential of Photovoltaic Systems in Countries with High Solar Irradiation.’’ Renewable and Sustainable Energy Reviews, 14, 754–62.*

Ristinen R.A. and Kraushaar J.J. (1999) Energy and the Environment. John Wiley &sons.

Sarnik M. T., (2008) *Podstawy fotowoltaiki, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa*

Tryjanowski P. (2013) *Wpływ elektrowni słonecznych na środowisko przyrodnicze. Czysta Energia, nr 1/2013*

Wacławek M., Rodziewicz T. (2011) *Ogniwa słoneczne – wpływ środowiska naturalnego na ich pracę. WNT, Warszawa 2011*

https://vosti.pl/aktualnosci/przyszlosc-fotowoltaiki/ (access: 01.10.2021)

https://files.sma.de/downloads/Perfratio-TI-en-11.pdf (access: 01.10.2021)

https://www.solarmango.com/dictionary/performance-ratio/ (access: 01.10.2021)

https://physicsworld.com/a/sunny-superpower-solar-cells (access: 01.10.2021)