Czech University of Life Sciences Prague

Faculty of Engineering

Department of Physics

Diploma Thesis

Impact of pollutants on the efficiency of PV panels in the Czech Republic.

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Engineering

DIPLOMA THESIS ASSIGNMENT

Ivan Ekimov

Technology and Environmental Engineering

Thesis title

Impact of pollutants on the efficiency of PV panels in the Czech Republic.

Objectives of thesis

Evaluate the data from the polluted pv panels in Czech Republic (Prague).
- Compare the data with the clean panel and with the contaminated panel
- Make conclusions according to this data

Methodology

- measure and evaluate the data from the polluted pv panels.
- compare the data with the clean panel and with the contaminated panel, using statistical methods
- Make conclusions according to this data

The proposed extent of the thesis

45 pages

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photovoltaics, pollutants, solar energy, efficiency

Recommended information sources

Behavior of Photovoltaic System during Solar Eclipse in Prague, Libra, Martin; Kourim, Pavel; Poulek, Vladislav, INTERNATIONAL JOURNAL OF PHOTOENERGY, Article Number: 2653560, 2016

EXPERIENCE GATHERED WITH THE PRAGUE NATIONAL THEATRE PV SYSTEM, Libra, Martin; Avramov, Valentyn; Poulek, Vladislav, 5th International Conference on Trends in Agricultural Engineering Location: Prague, TRENDS IN AGRICULTURAL ENGINEERING 2013, pp 386-390

http://re.jrc.ec.europa.eu/pvgis/

Poulek, V., Libra, M., Photovoltaics, theory and practice of solar energy utilization. Kniha-monografie v angličtině, ILSA, Praha, 2010, 169 stran, ISBN 978-80-904311-2-6.

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Declaration

I hereby declare that this Master's Thesis titled "Impact of pollutants on the efficiency of PV panels in the Czech Republic" is my own work, completed with the expert guidance of my thesis supervisor and consultant and all the sources have been cited and acknowledged by means of complete references. As an author of the thesis I declare that, in association with writing it, I did not infringe copyrights of third persons.

Prague, March 23, 2018

Signature: . . . .

Ivan Ekimov

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Summary

Solar energy has huge potential because it is an endless energy source. In recent years this type of energy is becoming more popular; many countries and people are thinking about the ecology and the environment. However, a deterrent is that renewable energy sources such as photovoltaic panels are expensive, and their efficiency are not high. In addition, there are many uncertain and unpredictable factors that can affect efficiency such as (dust, mud, environmental conditions, etc.). In this dissertation, the efficiency of the solar panels will be analysed to determine whether or not the efficiency is affected by external variables.

Key words: pv panel, solar energy, efficiency, pollutants.

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1. Introduction

In the 21st century many countries that currently use nuclear power, are increasing their attention to renewable energy resources that utilize energy from the sun, wind, tides, biofuels, and other alternative sources. The developed technologies have in some capacity been applied actively throughout the world.

Renewable energy sources are in a natural state that can be harnessed from nature, therefore environmental problems are mitigated, and also are virtually an infinite source of energy making them renewable.

In other sectors of renewable energy, there are some negatives. The use of renewable energy sources for the energy supply of various facilities is currently problematic in which demand for energy cannot be met. At present, the efficiency of alternative energy sources, unfortunately, are lower than that of traditional power plants.

Another disadvantage is the cost of equipment. The cost of power plants is very high and without subsidies and government assistance there aren’t cost-effective at current price point projections.

For solar radiation, we could not achieve stable power, due to natural features and limitations of current technologies until future R&D (Research and Development) allow for greater improvement. Moreover, the energy production schedule may not coincide with the graph of energy consumption.

For solar and wind energy the location is of immense importance. In many areas the application of solar and wind will not be cost effective, which makes these installations less attractive. But this energy is incredibly huge in areas that are attractive to solar and wind.

2. Scientific Hypothesis and Objectives of the Work

Objectives of the work.

The objective of this work is to determine the effect of different types of pollution on the efficiency of the solar panel.

Scientific hypothesis.

Expected Hypothesis: Pollution will cause a disruption in the efficiency of solar panels. It is expected that dirt and sand will cause the most disruption while dust will still disrupt but considerably less. Air pollution will most likely not have an impact.

3. Literature Review

3.1 The Sun as an Energy Source

The sun radiates a huge amount of energy - 384.6 yottawatts (3.846×10^{26} W) Williams (2013) .The outer layers of Earth's atmosphere intercept approximately one millionth of the energy emitted by the Sun 174 000 TW. However, due to the reflection, scattering, and absorption by atmospheric gases and aerosols, about 70% of the total energy reaches the Earth's surface Trenberth et al., (2009). The amount of solar energy incident on the surface of the Earth changes due to the movement of the Sun. These changes depend on the time of day and season. Usually at noon, more solar radiation hits the Earth than in the early morning or late evening. At noon the Sun is high above the horizon, and the length of the path of the rays of the Sun through the Earth's atmosphere are reduced. Consequently, less solar radiation is scattered and absorbed, therefore, more reaches the surface. The amount of solar energy reaching the Earth's surface differs from the average annual value: in winter time - by less than 0.8 kWh /m2 per day in Northern Europe and more than 4 kWh /m2 per day in the summer in this same region Huld (2012). The amount of solar energy depends on the geographical location of the site: the closer to the equator, the greater it is. For example, the average annual total solar radiation incident on a horizontal surface is: in Central Europe, Central Asia and Canada - approximately 1000 kWh/m2 Huld (2012) ,Mao-Fen Li (2010); in the Mediterranean - about 1700 kWh/m^2 Huld (2012); in most of the desert regions of Africa, the Middle East and Australia - about 2200 kWh/m^2 Huld (2012), Nematollahi (2016), Imteaz (2018).

Solar energy is one of the directions of alternative energy, which is based on the use of solar radiation to generate energy in some form. Solar energy uses renewable energy sources and is "environmentally friendly", that is, it does not create harmful waste during the active phase, which is important. As the issue of ecology and environmental protection, it is more acute than ever Kabir (2018).

The limited energy resources that people constantly use for their needs are so obvious that they began to think about this problem in the 20th century, thus the development of alternative energy became more active. To date, there are many opinions by different experts about the future of the energy complex of the entire world. But in all opinions it is possible to trace one pattern - in the near future there will come the need to search for and transition to more advanced sources of energy Tsai (2017).

In the near future, humanity is expected to have a strong increase in energy requirements, which can lead to serious problems in the energy sector. A competent solution, which allows to avoid consequences and the crisis itself, is the development of renewable energy Andreas (2017).

At present, there is a worldwide trend that inspires confidence, a growing number of countries using renewable energy sources. Each of the types of non-traditional energy has a number of features that should be considered when using. First of all, it is necessary to take into account geographical features Luz (2018). But, paradoxically, the greatest development and application they have received in countries located in areas with not the best energy potential. In these cases, the main role is played not by energy indicators, but by economic, political, environmental and social factors Nicolini (2017). These examples show us that even in better conditions, with due support, the main problems could be solved.

3.2 Solar Energy in the Czech Republic

Today solar energy in the Czech Republic is developing at a high pace, and although The Czech Republic is not a large country in Europe (total area is 78 866 km ^{2}) it has a varied terrain such mountains, plains, and huge agricultural zones etc. Unfortunately, (from the photovoltaic energetics point of view) the Czech Republic doesn't have a good amount of solar radiation, and climatic conditions if compared to Spain or Italy Huld (2012). We could see the amount of solar radiation (insolation) figure № 1 and figure № 2.

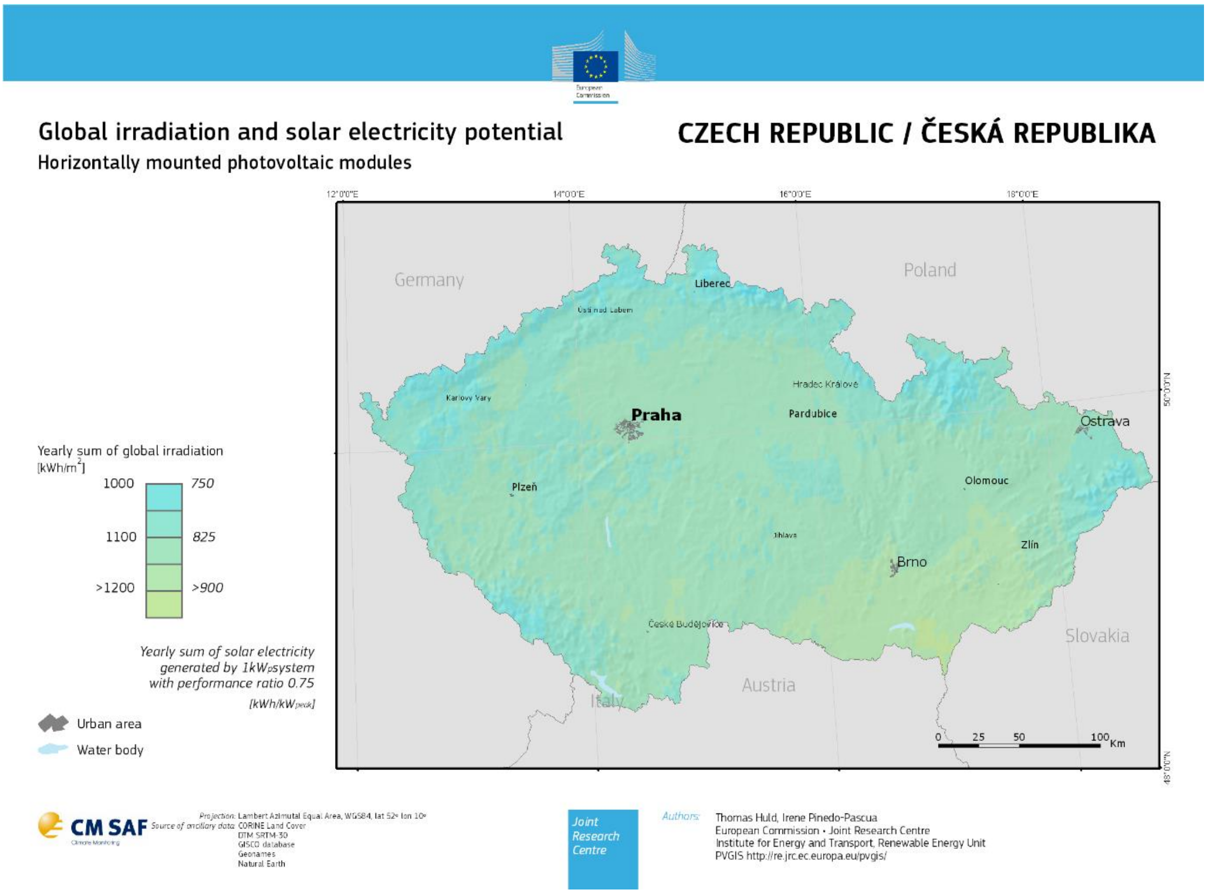

Figure 1. Global irradiation and solar electricity potential (horizontally mounted) (source: http://re.jrc.ec.europa.eu/pvg_download/map_index.html)

For more efficient use of the solar panel, it is better to use the optimal inclination. But even this is not enough to get the maximum performance, in this case it is worth using the system of tracking the sun. The system of tracking the sun will help to achieve worthy values even for northern countries.

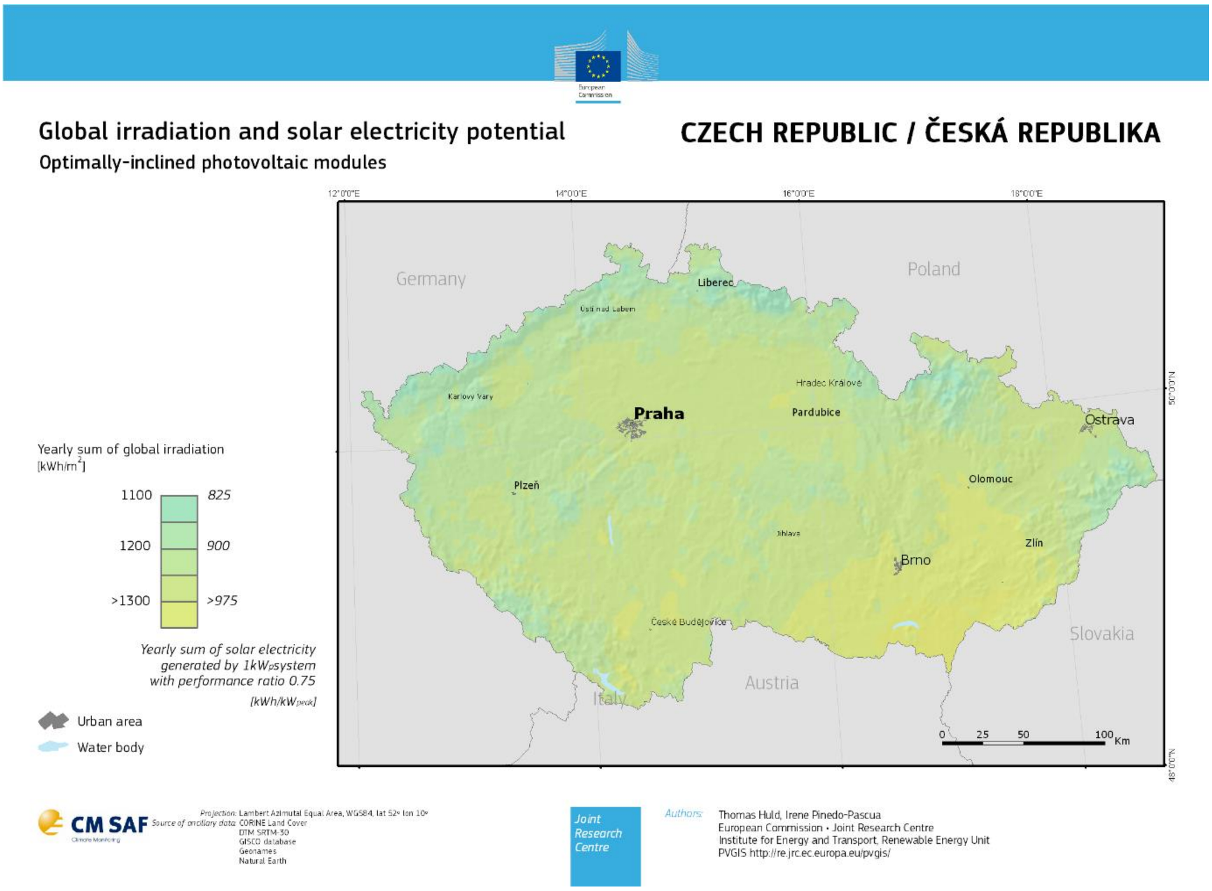

Figure 2. Global irradiation and solar electricity potential (optimally-inclined) (source: http://re.jrc.ec.europa.eu/pvg_download/map_index.html)

If we compare the figure №1 and the picture №2, it is possible to estimate how much the simple variation of the angle of the inclination to obtaining solar radiation. The difference is quite significant.

Furthermore, the energy of the Sun is enormous. Even that insignificant part of it, which radiates on the ground, is simply incredible Williams (2013). The Earth as a whole receives from the Sun a colossal amount of energy, tens of thousands of times more energy produced by all sources of energy in the world (under condition of operating at full capacity). To this we can add that almost all energy sources, such as coal, oil, natural gas - is "conserved" solar energy. The energy of rivers also owes its origin to the Sun, which supports the water cycle in nature Trenberth et al. (2009).

3.3 Pollutants

In the previous paragraph and in the introduction, the enormous energy of the sun was noted, but the amount of this energy that gets to the surface of our planet depends on a lot of factors, most of which we could not change. The amount of energy "radiating" on the surface of the earth is in the strongest dependence on weather phenomena such as: dust, fog, the presence of clouds, precipitation, etc. Daniele Pepe (2017).

Clouds - the main atmospheric phenomenon, determining the amount of solar radiation reaching the surface of the Earth. At any point of the earth, the solar radiation reaching the surface of the Earth decreases with increasing cloud thickness. Consequently, countries with prevailing cloudy weather receive less solar radiation than deserts, where the weather is mostly cloudless. The formation of clouds is influenced by the presence of such features of the local region such as mountains, seas and oceans, as well as large lakes. Therefore, the amount of solar radiation received in these regions and the regions adjacent to them may differ. For example, mountains can receive less solar radiation than adjacent foothills and plains. Winds blowing towards the mountains force part of the air to rise and while cooling the moisture in the air, form clouds. The amount of solar radiation in coastal areas may also differ from those recorded in areas located within the continent Kómar and Kocifaj (2016).

Anthropogenic and natural phenomena can also limit the amount of solar radiation reaching the surface of the Earth. City smog, smoke from forest fires and airborne ash formed as a result of volcanic activity, reduce the possibility of using solar energy, increasing the dispersion and absorption of solar radiation. That is, these factors have a greater impact on direct solar radiation than on the total Khodakarami_ and Ghobadi (2016).

All these factors could be avoided if the solar power station were in space but to date, this is impossible due to technological features such as: the collection of a power plant in space, the transfer of energy to Earth, and many other variables. There are not only technical difficulties, there are also economic problems; this energy will be too expensive, which makes the entire project unprofitable. That is why we must think of how to improve solar stations on the surface of the planet and minimize dependence on atmospheric and geographical shortcomings Zheng Ai Cheng (2016).

3.4 P-N Junction

Modern life would be incredibly hard to imagine without P-N junctions. Since the p-n junction has penetrated almost all spheres of human activity and they are found nearly everywhere. P-n junction is the thinnest layer of semiconductor zones in the contact zone, these regions are usually called the acceptor and the donor. The acceptor and donor zones are electrically neutral. Neutrality is associated with the features of the structure of the semiconductor, in one area there are so-called "holes", in the other zone there are free electrons. In the p-zone of the junction there are holes, the n-zone contains free electrons Sproul (2013).

3.4.1. P-N Junctions in Solar Panels

A thin plate consists of two layers of silicon with different properties. The outer layer is "contaminated" silicon, usually with an admixture of phosphorus (n type). The inner layer is crystalline silicon (p type). On the back of the plate is a solid metallic contact. At the boundary of the p and n layers, as a result of charge transfer, depleted regions with an uncompensated positive charge in the n zone and a negative charge in the p-zone appear. These regions form a p-n junction Smyrnakis (2017).

The potential barrier (potential difference) that appeared at the junction obstructs the passage of the main current carriers, i.e. electrons from the side of the p-layer, but freely pass the minority carriers in opposite directions. This property of p-n junctions determines the possibility of obtaining a photo-emf. When the transducers are illuminated, the absorbed photons create a nonequilibrium electron-hole pair. The electrons formed in the p-region near the boundary of the regions approach the pn junction and the electric field existing in it is transferred to the n zone Stepanov (2001). By the same principle, excess holes created in the n-region go over into the p-zone (Figure 3 (a)). As a result, n layer has an excess negative charge, p layer - positive. The initial contact voltage between the layers in the semiconductor junction decreases, and a voltage appears in the external circuit (Figure 3 (b)).

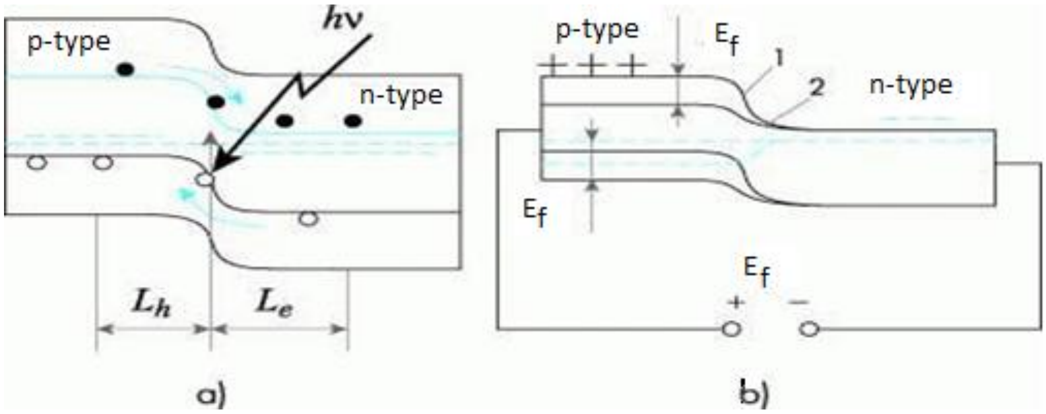

Figure 3. Voltage generation in p-n junction (in Russian (http://www.solarhome.ru/basics/pv/techpveffect.htm))

The principle of operation and the device of the photoelectric converter remained virtually unchanged despite the impressive lifetime of the technology of creating solar modules. Only structural solutions and the materials used in the photocell were upgraded. The use of new materials, made progress occurred in such an important indicator as the photoelectric conversion coefficient or the efficiency of the device. It should be noted that the magnitude of the output current and voltage directly depends on the level of external illumination, affecting the solar panel. Even though the materials have undergone significant changes since the creation and have become more sophisticated and complex in creation. This concerns not only the composition of the photo-converting element itself, but also the composition of the seal, and much more. All these changes had the single goal of making photovoltaic converters more advanced and increasing their profitability Ramos-Ruiz and Wilkening (2017). For 50 years, a lot of work has been done and today we can observe that photocells have become cheaper, have good efficiency, and extended service life Guenounou (2016)).

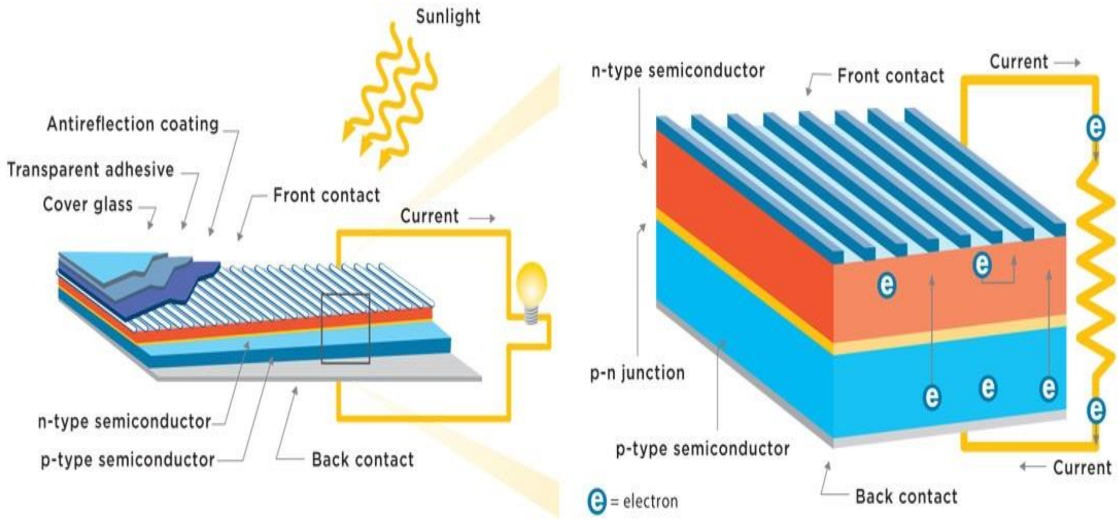

Figure 4. The principle of work in solar panel (https://www.ucsusa.org/clean-energy/renewable-energy/how-solar-panels-work)

Most solar photoconverters of developments of the new generation have one p-n junction. In such modules, the free carriers are generated only by photons whose energy is greater than or equal to the width of the forbidden band Moutinho (2018). And because of this, the photoelectric response of such a panel is strongly limited by the part of the spectrum. Overcoming this limitation is possible with the help of multilayer structures from two or more p n junctions with different bandgap widths. Such systems are called “multipass, cascade”. Since they work with a much larger part of the solar spectrum, the efficiency of photoelectric conversion is higher for them than for conventional elements. In a typical multi-transient solar transducer, single photocells are arranged one behind the other in such a way that sunlight first hits the element with the largest bandgap, and photons with the greatest energy are absorbed. The photons transmitted by the upper layer will be used in the following elements with a smaller value of the forbidden band Jung (2017). The use of gallium arsenide is actively developing in the field of cascade photocells Moutinho (2018).

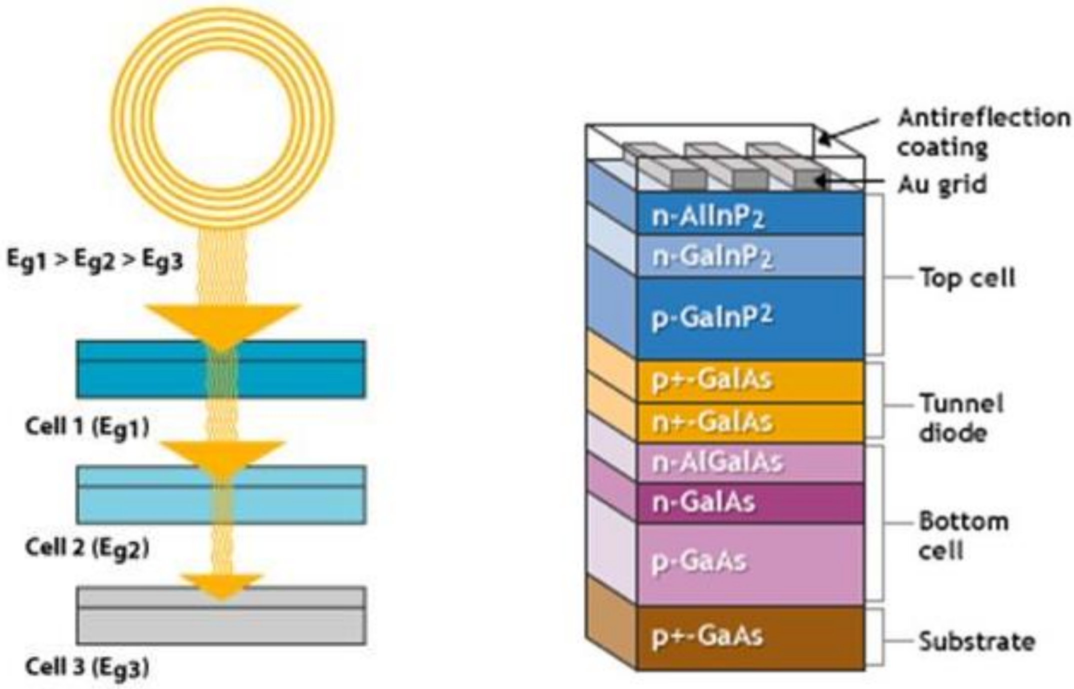

Figure 5. Absorption of solar energy and the structure of the cascaded solar cell Bagher (2015)

3.5 Types of Solar Cell

The structure and composition of the solar module, often speak of its efficiency and maximum values of electricity generation. To date, there are many different in composition of solar cells.

3.5.1 Monocrystalline Cell

A Monocrystalline cell uses high-quality silicon created in a special way. The method of growing crystals is similar to obtaining silicon blanks for processors, microcircuits. The monocrystalline type has a high efficiency, about 19-23% Khanna and Sundaram (2017).

Figure 6. Monocrystalline solar panel (https://www.sharp.co.uk/cps/rde/xchg/gb/hs.xsl/-/html/product-details-solar-modules-2189.htm?product=NURJ280)

3.5.2 Polycrystalline Cell

The polycrystalline type of cell uses cheaper silicon produced by the directional crystallization method. This method was specially developed for the production of solar panels. The resulting silicon plates consists of multidirectional crystals, small sizes of 1-10 mm, separated by grain boundaries. All these defects affect the efficiency. The efficiency of polycrystalline modules is 14-19%. Low efficiency is offset by the cost, so the price per watt of the electricity produced is approximately the same for monocrystalline silicon and polycrystalline silicon panels Liu (2015).

Figure 7. Polycrystalline solar panel (https://renogensolar.com/product/280w-60cells-poly-solar-panel/)

3.5.3 Thin-Film Solar Cells

Figure 8. Thin-film solar panel (https://www.northerntool.com/shop/tools/product_200660269_200660269)

The question arises why create other types of modules, if solar cells from crystalline and polycrystalline silicon already exist and show good performance? The answer is quite simple - to create modules with better performance and lower cost, compared to silicon analogues.

Along with the benefits, silicon elements have significant disadvantages, such as a low absorption coefficient (especially in the field of infrared waves), the problem lies in the physical properties of silicon. To effectively use solar radiation, the thickness of the plates should be between 100 and 300 μm. Increasing the thickness of the plate is not cost-effective, as a lot of material is spent, which increases the cost of the panel Wang (2016).

To date, there are semiconductors such as, GaAs, CdTe, Cu (inGa) Se2 and even modified silicon. They are able to use the required amount of solar energy and a small thickness (several microns). An interesting prospect of saving material and energy spent on creating solar modules opens up. Also, the above semiconductors have an interesting feature, they do not reduce their effectiveness even under diffuse radiation (shadow or cloudy weather) Moutinho (2018).

3.5.4. Concentrator Photovoltaics

Figure 9. Concentrator photovoltaic module Katherine Bourzac (2010)

The best, but at the same time the most expensive, are solar cells. These modules have an impressive efficiency of up to 40%. They consist of multilayer structures, different semiconductors, successively grown layer by layer. It is a very successful structure consisting of 3 layers. Ge, GaAs, and GalnP (the structure is based on the width of the forbidden band) Essig (2015). In this structure, each layer effectively uses its specific range of light. Due to this, the most complete and rational utilization of solar energy is achieved. As a result, we can observe an impressive efficiency. However, the process of creating solar batteries is very expensive, because of the high-tech production process Theristis (2017).

If solar panels are extremely expensive, focusing sunlight on a smaller area can reduce costs. Collecting solar radiation from 10 m2 and concentrating it on 1 m2 we will receive the same amount of electricity as with 10 m2, but saving a colossal area. But the set of solar panel and lens should be connected to the solar tracking system, which in turn will affect the cost of installation. This system is advantageous only in large solar power plants and in countries where direct solar radiation is available for a whole year Renno (2017).

3.5.5 Organic Solar Modules

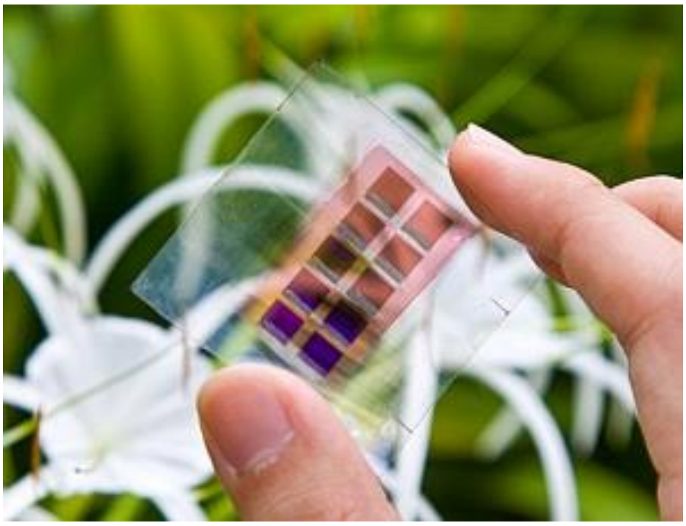

Figure 10. Organic photovoltaic module (https://www.research.a-star.edu.sg/feature-and-innovation/6323/new-ways-to-harvest-light)

There is also a new type of thin-film solar modules, organic and photosensitized dyes. Also known as polymer solar cells. The materials used in this type of photovoltaic panels are, in theory, fast in production and fairly cheap, which leads to low production costs for manufacturing a large volume Nelson (2011). The principle of operation of these modules differs radically from the principles on which other photoelectric converters operate. But, unfortunately, today they are not in commercial sale. Perhaps in the foreseeable future, with due support of this technology, we will see the sale of organic solar cells N. Yeh and P. Yeh (2013).

4. Materials and Methods

4.1 Methods

4.1.1 Experiments

The experiments are carried out to understand and evaluate the influence of pollution on the efficiency of photovoltaic solar panels. During the experiment, several kinds of pollutants (dust, sand, dirt, environmental conditions) were studied and compared with clean solar panels, for testing the impact of air pollutants in which compared values were collected in the deferent places. All the measurements were taken at 12 o'clock and were made by using the equipment below. Place of the experiments: Czech Republic, Prague.

4.1.2 Measuring of the Area

The method of measuring the area of a complex figure in photoshop, which can be used in almost any situation. To apply this calculation method to any multi-coloured area of the image, it is necessary to select the required object, that is, to create its mask, then fill the selection with black, invert it, Select, then Invert and fill it with white. After this transformation, image becomes two-colour, and the necessary black portion of the pixels can be seen on the histogram on the left side in the form of a very thin black vertical strip. If hover over it, then in the field described earlier, the number of pixels from which the object is made will be indicated.

4.2 Equipment

4.2.1 Solar Panel

The panel used was a polycrystalline silicon solar panel. This PV panel was chosen, because it is the most common and popular type of panel today.

Benefits of SMP mini-panels:

· High power stability. Small dimensions and weight.

· Portability.

· A neutral silicone sealant is used for hermetic encapsulation.

· The mechanical resistance of the panel is plastic or duraluminous anodized frame.

· Wide range of operating temperatures from -30 ° C to + 70 ° C.

· Built-in isolation diode on all panels prevents discharging connected battery packs on low-intensity days solar radiation.

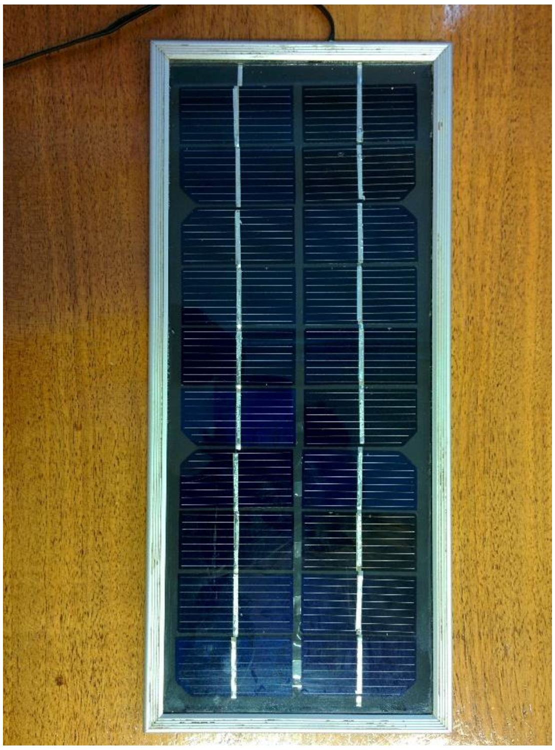

Figure 11. Solar panel (Solartec SMP 8-350)

Table 1. Characteristics of the solar panel

Brand and name	Solartec SMP 8-350
Pmax	3.3 W
Umpp	9.7 V
Impp	0.34 A
Uoc	12 V
Isc	0.37 A
Dimensions	291x126x8 mm
Weight	0,48 kg

(Source: Operator’s Manual)

4.2.2 Multi-meter

This multi-meter includes many functions and is a high-quality measuring tool. Since the dimensions of the panel are small enough, the values obtained are small and the values obtained, which is why it is necessary to use a multi-meter with good measurement accuracy.

Figure 12. Wavetek model 235 digital multimeter (figure was taken from specifications)

Table 2. Characteristics of the multi-meter

DC voltage	
Ranges	400 mV, 4 V, 40 V, 400 V, 1000 V
Accuracy	(0.25 % rdg + 2 dgts)
Resolution	100 µV in 400 mV range
Input Impedance	400 mV: >100 MΩ 4 V: 10 MΩ 40-1000 V: > 9.1 MΩ
DC current	
Ranges	400 µA, 4 mA, 40 mA, 400 mA, 10 A
Accuracy	400 µA- 400 mA: ± (0.8 % rdg + 2 dgts) 10 A: ± (2 % rdg + 3 dgts)
Resolution	100 nA in 400 µA range
Voltage Burden	400 µA range: 0.5 mV/µA 4 ma-400 ma range: 7 mV/mA 10 A range: 3 mV/A

(Source: Operator's Manual)

4.3 Location.

Data for experiments from the first to third were collected close to the Czech University of Life Sciences stadium, because there are no large buildings and trees nearby that could interfere with the proper collection of information. GPS coordination 50.130136, 14.379580.

Figure 13. Location №1 (google.com/maps)

For the fourth experiment, data was collected close to Observatoř Libuš bus station. That place was chosen, because earlier data was used from EEA and it could help determine the effect of pollution on efficiency. GPS coordinate is 50.006571, 14.446786.

Figure 14. Location №2 (google.com/maps)

4.4 Pollutants

4.4.1 Dust

Dust are fine particles of matter. It generally consists of particles in the atmosphere that come from various sources such as soil, particles lifted by weather, volcanic eruptions, and pollution. Dust in homes, offices, and other place contains small amounts of flowers pollen, human and animal hairs, textile and paper fibres, minerals from outdoor, soil, skin cells, metal particles, and many other materials which may be found in the local environment Hess-Kosa, (2002).

4.4.2 Mud

Mud is a semi-liquid mixture of soil and the water. It usually appears close to water sources or after rain.

4.4.3 Sand

Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. It is defined by size, being finer than gravel and coarser than silt. Sand can also refer to a textural class of soil or soil type; i.e., a soil containing more than 85 percent sand-sized particles by mass Canada Department of Agriculture (1976).

4.4.4 Air Pollution

Air pollution is defined as the contamination of outdoor and indoor environments by any agent that could modify the natural characteristics of the atmosphere. Outdoor air pollution is produced by fossil fuel combustion (ie, automobiles, power generation, and industry), construction and demolition activities, forest fires, and volcanic emissions and encompasses a mixture of particulate matters (PMs), with various gaseous compounds and molecules in a vapor phase and an aerodynamic diameter ranging from 2.5 to 10 μm (PM10), below to 2.5 μm (PM2.5; fine PM), and below to 0.1 μm (PM0.1; ultrafine PM). The gaseous part of polluted air includes nitrogen oxides, carbon monoxide, sulphur dioxide, and ozone Elias (2017).

4.4.4.1 Nitrogen Oxides

Nitrogen oxides (NO, and to a lesser extent NO_2) are released during any high-temperature combustion which breaks the strongly bonded atmospheric N_2 and combines atomic N with oxygen: power plants are their largest stationary sources, vehicles and airplanes the most ubiquitous mobile emitters. Anthropogenic hydrocarbon emissions result from incomplete combustion of fuels, as well as from evaporation of fuels and solvents, incineration of wastes, and wear on car tires Smil (2001).

4.4.4.2 Sulfur Dioxide

Sulphur dioxide commonly meets in the big cites, because it is produced by fossil fuel combustion. This toxic gas is encountered in the various industrial processes like power plants, chemical manufacture, paper manufacture, food preservation, metal and ore refining, and refrigeration Newman (2012).

4.4.4.3 Ozone

Ozone (O_3) is a gas without colour or in some cases blue which one has a pungent odour. Marhaba (2009) Ozone is formed in polluted urban areas by photochemical reactions involving two classes of precursors: hydrocarbons (or, more generally, volatile organic compounds or VOCs) and oxides of nitrogen (NO and NO_2) Sillman (2003). Ozone is one of the most important absorber of infrared and ultraviolet (UV) radiations Smit (2015).

4.4.4.4 Particulate Matter

PM can be formed by a wide variety of natural and man-made processes, one of the largest sources of PM pollution is through combustion of biomass and fossil fuels. PM is composed of organic and inorganic compounds that vary greatly in size. Fine PM (<2.5 µm) has the most well-recognized health effects, and the ultrafine PM fraction (<0.1 µm) may be especially important Rinne and Kaufman (2012).

4.5 Statistics methods

4.5.1 T-test

The t test (Student's T Test) compares two means and with the help of this comparison can be determined and whether this difference is random. Statistics How To (2018).

4.5.2 F-test

The f test is a statistical test where an f-distribution is conducted under the null hypothesis. It is usually used for comparing statistical models that have been fitted to a data set, in order to find whether a group of results is statistically significant, meaning that they did not happen by chance but rather have relevance to the characteristics of those values. Statistics How To (2018).

4.5.3 Standard Deviation and Mean Value

The standard deviation is used to quantify the value of variation or variance of a set of data values. A low standard deviation indicates that the data points are close to the average (expected value) of the set, and a high standard deviation indicates that the data points are spread over a wider range of values. Bland and Altman (1996).

Mean value is one of the simplest mathematical functions which describe the average value of a data set. The average value is the addition of all values and the division by their number.

4.6 Software Used

Microsoft Word, Microsoft Excel, Adobe Photoshop cs6.

5. Results

5.1. Dust

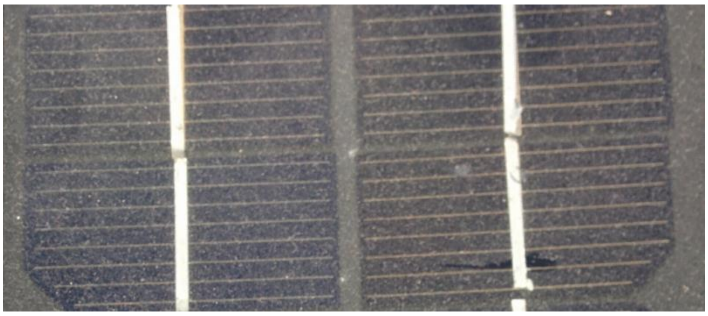

Figure 15. Contaminated PV panel (dust)

In the first experiment, the effect of dust on the efficiency of the solar panel was produced.

Table 3. Values of the first experiment (dust)

	Clean panel			Dust			
Date	Voltage [V]	Amperage [mA]	Power [W]	Voltage [V]	Amperage [mA]	Power [W]	Impact of pollutant [%]
07/10/2017	11.3	75.3	0.85	11.3	69.7	0.79	7.44
08/10/2017	11.2	56.8	0.64	11.2	51.2	0.57	9.86
09/10/2017	11.4	113.2	1.29	11.4	102.5	1.17	9.45
10/10/2017	11.3	85.3	0.96	11.3	77.3	0.87	9.38
11/10/2017	11.4	105	1.20	11.3	93.5	1.06	11.73
12/10/2017	11.1	36.8	0.41	11.1	34.2	0.38	7.07
13/10/2017	11.1	38.2	0.42	11.1	34.8	0.39	8.90
14/10/2017	11.4	149.3	1.70	11.4	131.1	1.49	12.19
15/10/2017	11.7	197.1	2.31	11.6	168.2	1.95	15.39
16/10/2017	11.5	175.9	2.02	11.4	152.6	1.74	14.00
17/10/2017	11.4	156.8	1.79	11.3	136.2	1.54	13.90
18/10/2017	11.1	39.4	0.44	11.1	35.2	0.39	10.66
19/10/2017	11.1	37.6	0.42	11.1	33.8	0.38	10.11
20/10/2017	11.4	111.3	1.27	11.3	100.7	1.14	10.32
21/10/2017	11.6	180.3	2.09	11.5	159.1	1.83	12.52

22/10/2017	11.4	109.6	1.25	11.4	99.9	1.14	8.85
23/10/2017	11.2	40.2	0.45	11.1	36.7	0.41	9.52
24/10/2017	11.1	38.5	0.43	11.1	35.1	0.39	8.83
25/10/2017	11.4	127	1.45	11.4	114.1	1.30	10.16
26/10/2017	11.1	37.9	0.42	11.1	34.6	0.38	8.71
27/10/2017	11.5	179.6	2.07	11.4	158.3	1.80	12.63
28/10/2017	11.3	72.4	0.82	11.3	67.2	0.76	7.18
29/10/2017	11.3	58.1	0.66	11.3	53.8	0.61	7.40
30/10/2017	11.4	119.9	1.37	11.5	110.7	1.27	6.86
31/10/2017	11.2	44.8	0.50	11.2	38.3	0.43	14.51
01/11/2017	11.2	42.3	0.47	11.2	35.6	0.40	15.84
02/11/2017	11.2	43.6	0.49	11.2	37.1	0.42	14.91
03/11/2017	11.4	126.5	1.44	11.4	114.3	1.30	9.64
04/11/2017	11.5	178.3	2.05	11.4	157.1	1.79	12.66
05/11/2017	11.5	166.6	1.92	11.4	144.9	1.65	13.78
06/11/2017	11.4	144.1	1.64	11.4	130.8	1.49	9.23
07/11/2017	11.2	63.2	0.71	11.2	58.2	0.65	7.91
08/11/2017	11.1	31.3	0.35	11.1	30	0.33	4.15
09/11/2017	11.1	39.7	0.44	11.1	36.5	0.41	8.06
10/11/2017	11.3	81.1	0.92	11.3	75.4	0.85	7.03
11/11/2017	11.5	177.4	2.04	11.5	154.1	1.77	13.13
12/11/2017	11.4	156.9	1.79	11.4	136.3	1.55	13.13
13/11/2017	11.3	101.2	1.14	11.3	92.1	1.04	8.99
14/11/2017	11.5	178.3	2.05	11.5	156.9	1.80	12.00
15/11/2017	11.4	98.3	1.12	11.4	91.5	1.04	6.92
16/11/2017	11.3	83.3	0.94	11.3	77.2	0.87	7.32
17/11/2017	11.1	37.2	0.41	11.05	35.1	0.39	6.07
18/11/2017	11.2	54.1	0.61	11.1	49.8	0.55	8.77
19/11/2017	11.2	55.6	0.62	11.2	51.2	0.57	7.91
20/11/2017	11.1	34.8	0.39	11.1	32.4	0.36	6.90
21/11/2017	11.2	52.2	0.58	11.2	48.5	0.54	7.09
22/11/2017	11.3	87.6	0.99	11.3	77.9	0.88	11.07

23/11/2017	11.6	181.2	2.10	11.5	158.4	1.82	13.34
24/11/2017	11.5	176.3	2.03	11.5	152.9	1.76	13.27
25/11/2017	11.4	144.6	1.65	11.4	131.1	1.49	9.34
26/11/2017	11.4	137.4	1.57	11.3	124.2	1.40	10.40
27/11/2017	11.3	93.5	1.06	11.3	82.7	0.93	11.55
28/11/2017	11.2	47.3	0.53	11.2	41	0.46	13.32
29/11/2017	11.1	35.2	0.39	11.1	32.7	0.36	7.10
30/11/2017	11.2	48.7	0.55	11.2	42.3	0.47	13.14
01/12/2017	11.3	77.5	0.88	11.2	72.2	0.81	7.66
02/12/2017	11.5	173.8	2.00	11.4	150.6	1.72	14.10
03/12/2017	11.3	82.3	0.93	11.3	76.1	0.86	7.53
04/12/2017	11.5	176.1	2.03	11.5	155.2	1.78	11.87
05/12/2017	11.4	129.5	1.48	11.3	117.3	1.33	10.22
06/12/2017	11.3	88.7	1.00	11.3	79.1	0.89	10.82
07/12/2017	11.6	184.2	2.14	11.5	160	1.84	13.89
08/12/2017	11.4	122.4	1.40	11.4	112.7	1.28	7.92
09/12/2017	11.5	166.8	1.92	11.4	145.2	1.66	13.71
10/12/2017	11.5	174.3	2.00	11.5	151.4	1.74	13.14
11/12/2017	11.2	65.3	0.73	11.2	60.2	0.67	7.81
12/12/2017	11.2	64.1	0.72	11.2	59.1	0.66	7.80
13/12/2017	11.5	169.4	1.95	11.5	148.4	1.71	12.40
14/12/2017	11.5	166.2	1.91	11.5	144.7	1.66	12.94
15/12/2017	11.4	132.7	1.51	11.4	120.3	1.37	9.34
16/12/2017	11.2	59.9	0.67	11.2	55.5	0.62	7.35
17/12/2017	11.3	94.3	1.07	11.3	87.1	0.98	7.64
18/12/2017	11.5	173.6	2.00	11.4	150.4	1.71	14.12
19/12/2017	11.4	143.8	1.64	11.4	130.1	1.48	9.53
20/12/2017	11.1	40.2	0.45	11.1	37.1	0.41	7.71
21/12/2017	11.05	32.1	0.35	11	30.8	0.34	4.48
22/12/2017	11.1	39.4	0.44	11.1	36.6	0.41	7.11
23/12/2017	11.2	63	0.71	11.2	57.8	0.65	8.25
24/12/2017	11.2	62.2	0.70	11.2	57.1	0.64	8.20

25/12/2017	11.3	91.1	1.03	11.3	85.1	0.96	6.59
26/12/2017	11.5	167.6	1.93	11.5	146.1	1.68	12.83
27/12/2017	11.5	172.1	1.98	11.5	150	1.73	12.84
28/12/2017	11.1	42.2	0.47	11.1	39.2	0.44	7.11
29/12/2017	11.4	141.6	1.61	11.3	128.8	1.46	9.84
30/12/2017	11.5	170.5	1.96	11.5	147.3	1.69	13.61
31/12/2017	11.4	134.3	1.53	11.4	122.4	1.40	8.86
01/01/2018	11.2	83.6	0.94	11.2	76.7	0.86	8.25
02/01/2018	11.1	43.2	0.48	11.1	40.1	0.45	7.18
03/01/2018	11.5	172.8	1.99	11.5	149.6	1.72	13.43
04/01/2018	11.5	179	2.06	11.4	156.3	1.78	13.44
05/01/2018	11.2	67.3	0.75	11.2	62.1	0.70	7.73
06/01/2018	11.5	178.2	2.05	11.4	155.6	1.77	13.44
07/01/2018	11.1	47.2	0.52	11.1	42.5	0.47	9.96
08/01/2018	11.1	44.8	0.50	11.1	40.5	0.45	9.60
09/01/2018	11.4	139.1	1.59	11.4	127.3	1.45	8.48
10/01/2018	11.2	70.1	0.79	11.2	65	0.73	7.28
11/01/2018	11.1	45.3	0.50	11.1	41.2	0.46	9.05
12/01/2018	11.1	35.2	0.39	11.1	32.3	0.36	8.24
13/01/2018	11.1	38.2	0.42	11.1	36.1	0.40	5.50
14/01/2018	11.1	43.7	0.49	11.1	40.3	0.45	7.78
15/01/2018	11.1	40.6	0.45	11.1	37.6	0.42	7.39
16/01/2018	11.1	37.2	0.41	11.1	35.1	0.39	5.65
17/01/2018	11.1	36.6	0.41	11.1	33.6	0.37	8.20
18/01/2018	11.1	45.8	0.51	11.1	42.6	0.47	6.99
19/01/2018	11	30.1	0.33	11	28.3	0.31	5.98
20/01/2018	11.4	132.4	1.51	11.4	120.3	1.37	9.14
21/01/2018	11.5	172.4	1.98	11.5	149.4	1.72	13.34
22/01/2018	11.5	168.2	1.93	11.4	146.2	1.67	13.84
23/01/2018	11.4	142.8	1.63	11.4	130.5	1.49	8.61
24/01/2018	11.1	46.1	0.51	11.1	42.1	0.47	8.68
25/01/2018	11.6	181.1	2.10	11.5	158.3	1.82	13.34

26/01/2018	11.2	66.7	0.75	11.2	61.4	0.69	7.95
27/01/2018	11.2	58.9	0.66	11.2	54.5	0.61	7.47
28/01/2018	11.1	40.2	0.45	11.1	37.1	0.41	7.71
29/01/2018	11.1	39.3	0.44	11.1	36.3	0.40	7.63
30/01/2018	11.4	136.7	1.56	11.4	124.6	1.42	8.85
31/01/2018	11.5	164	1.89	11.5	143.2	1.65	12.68
01/02/2018	11.5	158.9	1.83	11.5	138.5	1.59	12.84
02/02/2018	11.4	140.1	1.60	11.4	128.3	1.46	8.42
03/02/2018	11.2	72.1	0.81	11.2	66.9	0.75	7.21
04/02/2018	11.4	138.2	1.58	11.4	126.4	1.44	8.54
05/02/2018	11.1	42.8	0.48	11.1	39.6	0.44	7.48
06/02/2018	11.5	174.4	2.01	11.4	151.2	1.72	14.06
07/02/2018	11.2	64.2	0.72	11.1	59.1	0.66	8.77
08/02/2018	11.1	44.6	0.50	11.1	41.2	0.46	7.62
09/02/2018	11.2	71	0.80	11.1	64.2	0.71	10.38
10/02/2018	11.2	149.5	1.67	11.4	130.3	1.49	11.29
11/02/2018	11.2	169.2	1.90	11.4	148.4	1.69	10.73
12/02/2018	11.4	155.3	1.77	11.4	136.2	1.55	12.30
13/02/2018	11.4	166.2	1.89	11.4	145.3	1.66	12.58
14/02/2018	11.5	177.2	2.04	11.5	153	1.76	13.66
15/02/2018	11.2	90.3	1.01	11.2	82.5	0.92	8.64
16/02/2018	11.6	178.1	2.07	11.6	154.6	1.79	13.19
17/02/2018	11.1	34.5	0.38	11.1	32.2	0.36	6.67
18/02/2018	11.1	41.5	0.46	11.1	38.1	0.42	8.19
19/02/2018	11.2	100.2	1.12	11.2	91.2	1.02	8.98
20/02/2018	11.1	65	0.72	11.1	59.5	0.66	8.46
21/02/2018	11.4	150.1	1.71	11.4	132.2	1.51	11.93
22/02/2018	11.4	152	1.73	11.4	135.1	1.54	11.12
23/02/2018	11.5	150.2	1.73	11.4	133.2	1.52	12.09
24/02/2018	11.4	146.6	1.67	11.4	127.2	1.45	13.23
25/02/2018	11.7	196.7	2.30	11.6	167.3	1.94	15.67
mean	11.31	103.11	1.17	11.29	91.97	1.04	9.97

standard deviation	0.17	54.60	0.63	0.15	47.00	0.54	2.69

T-test: for the voltages, t stat = 4.266, P(T<=t) one-tail = 1.81E-05, t critical one-tail = 1.656, pearson correlation = 0.956. For the amperages t stat = 16.79, P(T<=t) one-tail = 9.61E-35, t critical one-tail = 1.656, pearson correlation = 0.991. For the powers t stat = 16.334, P(T<=t) one-tail = 1.26E-34, t critical one-tail = 1.656, pearson correlation = 0.998.

F-test: for the voltages, F = 1.169, P(F<=f) one-tail = 0.178, F critical one-tail = 1.32. For the amperages F = 1.35, P(F<=f) one-tail = 0.038, F critical one-tail = 1.32. For the powers F = 1.361, P(F<=f) one-tail = 0.034, F critical one-tail = 1.32.

Thanks to the conducted experiment, it is possible to estimate the influence of dust on the efficiency of the polycrystalline solar panel. The pollution area was 96%, which is very high. The greatest effect of pollution was provided in sunny weather and clear skies, the reverse effect could be observed in cloudy weather.

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5.2 Mud

Figure 16. Contaminated PV panel (mud)

Pollution in the form of dirt is quite specific, usually they can occur after the rain, provided that the solar panel is close to the ground

Table 4. Values of the second experiment (mud)

	Clean panel			Mud			
Date	Voltage [V]	Amperage [mA]	Power [W]	Voltage [V]	Amperage [mA]	Power [W]	Impact of pollutant [%]

07/10/2017	11.3	75.3	0.85	11.3	63.4	0.72	15.80
08/10/2017	11.2	56.8	0.64	11.1	47.6	0.53	16.95
09/10/2017	11.4	113.2	1.29	11.4	98.4	1.12	13.07
10/10/2017	11.3	85.3	0.96	11.3	71.3	0.81	16.41
11/10/2017	11.4	105	1.20	11.3	87.3	0.99	17.59
12/10/2017	11.1	36.8	0.41	11.1	29.6	0.33	19.57
13/10/2017	11.1	38.2	0.42	11.1	31	0.34	18.85
14/10/2017	11.4	149.3	1.70	11.4	125.2	1.43	16.14
15/10/2017	11.7	197.1	2.31	11.6	153.2	1.78	22.94
16/10/2017	11.5	175.9	2.02	11.4	146.5	1.67	17.44
17/10/2017	11.4	156.8	1.79	11.3	130.1	1.47	17.76
18/10/2017	11.1	39.4	0.44	11.1	32.5	0.36	17.51
19/10/2017	11.1	37.6	0.42	11.1	30.9	0.34	17.82
20/10/2017	11.4	111.3	1.27	11.3	95.6	1.08	14.86
21/10/2017	11.6	180.3	2.09	11.5	147.8	1.70	18.73
22/10/2017	11.4	109.6	1.25	11.4	93.4	1.06	14.78
23/10/2017	11.2	40.2	0.45	11.1	32.3	0.36	20.37
24/10/2017	11.1	38.5	0.43	11.1	31.3	0.35	18.70
25/10/2017	11.4	127	1.45	11.4	109.6	1.25	13.70
26/10/2017	11.1	37.9	0.42	11.1	30.7	0.34	19.00
27/10/2017	11.5	179.6	2.07	11.4	147.4	1.68	18.64
28/10/2017	11.3	72.4	0.82	11.3	61.5	0.69	15.06
29/10/2017	11.3	58.1	0.66	11.3	49.7	0.56	14.46
30/10/2017	11.4	119.9	1.37	11.5	103.2	1.19	13.17
31/10/2017	11.2	44.8	0.50	11.2	36.6	0.41	18.30
01/11/2017	11.2	42.3	0.47	11.2	33.1	0.37	21.75
02/11/2017	11.2	43.6	0.49	11.2	35.2	0.39	19.27
03/11/2017	11.4	126.5	1.44	11.4	109.4	1.25	13.52
04/11/2017	11.5	178.3	2.05	11.4	146.1	1.67	18.77
05/11/2017	11.5	166.6	1.92	11.4	135.4	1.54	19.43
06/11/2017	11.4	144.1	1.64	11.4	129.4	1.48	10.20
07/11/2017	11.2	63.2	0.71	11.2	54.6	0.61	13.61

08/11/2017	11.1	31.3	0.35	11.1	28.7	0.32	8.31
09/11/2017	11.1	39.7	0.44	11.1	32.1	0.36	19.14
10/11/2017	11.3	81.1	0.92	11.3	71.2	0.80	12.21
11/11/2017	11.5	177.4	2.04	11.5	145.3	1.67	18.09
12/11/2017	11.4	156.9	1.79	11.4	129.8	1.48	17.27
13/11/2017	11.3	101.2	1.14	11.2	86.3	0.97	15.48
14/11/2017	11.5	178.3	2.05	11.5	146.3	1.68	17.95
15/11/2017	11.4	98.3	1.12	11.4	88.2	1.01	10.27
16/11/2017	11.3	83.3	0.94	11.3	73.4	0.83	11.88
17/11/2017	11.1	37.2	0.41	11.05	31.2	0.34	16.51
18/11/2017	11.2	54.1	0.61	11.1	45.3	0.50	17.01
19/11/2017	11.2	55.6	0.62	11.2	47	0.53	15.47
20/11/2017	11.1	34.8	0.39	11.1	29.2	0.32	16.09
21/11/2017	11.2	52.2	0.58	11.2	44.3	0.50	15.13
22/11/2017	11.3	87.6	0.99	11.3	73.1	0.83	16.55
23/11/2017	11.6	181.2	2.10	11.5	145.1	1.67	20.61
24/11/2017	11.5	176.3	2.03	11.5	144.2	1.66	18.21
25/11/2017	11.4	144.6	1.65	11.4	129.9	1.48	10.17
26/11/2017	11.4	137.4	1.57	11.3	119.1	1.35	14.08
27/11/2017	11.3	93.5	1.06	11.3	79.1	0.89	15.40
28/11/2017	11.2	47.3	0.53	11.2	38.8	0.43	17.97
29/11/2017	11.1	35.2	0.39	11.1	29.8	0.33	15.34
30/11/2017	11.2	48.7	0.55	11.2	39.5	0.44	18.89
01/12/2017	11.3	77.5	0.88	11.2	66.8	0.75	14.57
02/12/2017	11.5	173.8	2.00	11.4	142	1.62	19.01
03/12/2017	11.3	82.3	0.93	11.3	72.1	0.81	12.39
04/12/2017	11.5	176.1	2.03	11.5	144.6	1.66	17.89
05/12/2017	11.4	129.5	1.48	11.3	112.5	1.27	13.89
06/12/2017	11.3	88.7	1.00	11.3	75.4	0.85	14.99
07/12/2017	11.6	184.2	2.14	11.5	148.3	1.71	20.18
08/12/2017	11.4	122.4	1.40	11.4	106.3	1.21	13.15
09/12/2017	11.5	166.8	1.92	11.4	135.9	1.55	19.23

10/12/2017	11.5	174.3	2.00	11.5	142.7	1.64	18.13
11/12/2017	11.2	65.3	0.73	11.2	56.3	0.63	13.78
12/12/2017	11.2	64.1	0.72	11.2	55.4	0.62	13.57
13/12/2017	11.5	169.4	1.95	11.5	138.8	1.60	18.06
14/12/2017	11.5	166.2	1.91	11.5	135.2	1.55	18.65
15/12/2017	11.4	132.7	1.51	11.4	115.1	1.31	13.26
16/12/2017	11.2	59.9	0.67	11.2	51.2	0.57	14.52
17/12/2017	11.3	94.3	1.07	11.3	82.6	0.93	12.41
18/12/2017	11.5	173.6	2.00	11.4	141.6	1.61	19.14
19/12/2017	11.4	143.8	1.64	11.4	124.1	1.41	13.70
20/12/2017	11.1	40.2	0.45	11.1	34.7	0.39	13.68
21/12/2017	11.05	32.1	0.35	11	29.6	0.33	8.21
22/12/2017	11.1	39.4	0.44	11.1	34.2	0.38	13.20
23/12/2017	11.2	63	0.71	11.2	55.1	0.62	12.54
24/12/2017	11.2	62.2	0.70	11.2	54.3	0.61	12.70
25/12/2017	11.3	91.1	1.03	11.3	81.7	0.92	10.32
26/12/2017	11.5	167.6	1.93	11.5	136.8	1.57	18.38
27/12/2017	11.5	172.1	1.98	11.5	141.3	1.62	17.90
28/12/2017	11.1	42.2	0.47	11.1	36.3	0.40	13.98
29/12/2017	11.4	141.6	1.61	11.3	124	1.40	13.20
30/12/2017	11.5	170.5	1.96	11.5	137.8	1.58	19.18
31/12/2017	11.4	134.3	1.53	11.4	118.6	1.35	11.69
01/01/2018	11.2	83.6	0.94	11.2	73.6	0.82	11.96
02/01/2018	11.1	43.2	0.48	11.1	36.9	0.41	14.58
03/01/2018	11.5	172.8	1.99	11.5	140	1.61	18.98
04/01/2018	11.5	179	2.06	11.5	143.2	1.65	20.00
05/01/2018	11.2	67.3	0.75	11.2	59.2	0.66	12.04
06/01/2018	11.5	178.2	2.05	11.5	142.3	1.64	20.15
07/01/2018	11.1	47.2	0.52	11.1	39.3	0.44	16.74
08/01/2018	11.1	44.8	0.50	11.1	37.2	0.41	16.96
09/01/2018	11.4	139.1	1.59	11.4	123.6	1.41	11.14
10/01/2018	11.2	70.1	0.79	11.2	62.3	0.70	11.13

11/01/2018	11.1	45.3	0.50	11.1	37.9	0.42	16.34
12/01/2018	11.1	35.2	0.39	11.1	29.7	0.33	15.63
13/01/2018	11.1	38.2	0.42	11.1	32.1	0.36	15.97
14/01/2018	11.1	43.7	0.49	11.1	37.5	0.42	14.19
15/01/2018	11.1	40.6	0.45	11.1	34.3	0.38	15.52
16/01/2018	11.1	37.2	0.41	11.1	31	0.34	16.67
17/01/2018	11.1	36.6	0.41	11.1	30.7	0.34	16.12
18/01/2018	11.1	45.8	0.51	11.1	39.8	0.44	13.10
19/01/2018	11	30.1	0.33	11	27.1	0.30	9.97
20/01/2018	11.4	132.4	1.51	11.4	116.5	1.33	12.01
21/01/2018	11.5	172.4	1.98	11.5	139.8	1.61	18.91
22/01/2018	11.5	168.2	1.93	11.4	137.2	1.56	19.14
23/01/2018	11.4	142.8	1.63	11.4	126.3	1.44	11.55
24/01/2018	11.1	46.1	0.51	11.1	38.3	0.43	16.92
25/01/2018	11.6	181.1	2.10	11.5	145.3	1.67	20.46
26/01/2018	11.2	66.7	0.75	11.2	57.6	0.65	13.64
27/01/2018	11.2	58.9	0.66	11.2	50.3	0.56	14.60
28/01/2018	11.1	40.2	0.45	11.1	34.6	0.38	13.93
29/01/2018	11.1	39.3	0.44	11.1	33.7	0.37	14.25
30/01/2018	11.4	136.7	1.56	11.4	120.6	1.37	11.78
31/01/2018	11.5	164	1.89	11.5	136.3	1.57	16.89
01/02/2018	11.5	158.9	1.83	11.5	132.2	1.52	16.80
02/02/2018	11.4	140.1	1.60	11.4	124.4	1.42	11.21
03/02/2018	11.2	72.1	0.81	11.2	64.4	0.72	10.68
04/02/2018	11.4	138.2	1.58	11.4	122.3	1.39	11.51
05/02/2018	11.1	42.8	0.48	11.1	36.8	0.41	14.02
06/02/2018	11.5	174.4	2.01	11.5	146.5	1.68	16.00
07/02/2018	11.2	64.2	0.72	11.1	55.9	0.62	13.71
08/02/2018	11.1	44.6	0.50	11.1	38.7	0.43	13.23
09/02/2018	11.2	71	0.80	11.2	61.5	0.69	13.38
10/02/2018	11.2	149.5	1.67	11.4	123.1	1.40	16.19
11/02/2018	11.2	169.2	1.90	11.4	141.2	1.61	15.06

12/02/2018	11.4	155.3	1.77	11.4	130.4	1.49	16.03
13/02/2018	11.4	166.2	1.89	11.4	138.3	1.58	16.79
14/02/2018	11.5	177.2	2.04	11.4	141.9	1.62	20.62
15/02/2018	11.2	90.3	1.01	11.2	76.8	0.86	14.95
16/02/2018	11.6	178.1	2.07	11.6	143.5	1.66	19.43
17/02/2018	11.1	34.5	0.38	11.05	29.2	0.32	15.74
18/02/2018	11.1	41.5	0.46	11.1	35.7	0.40	13.98
19/02/2018	11.2	100.2	1.12	11.2	85	0.95	15.17
20/02/2018	11.1	65	0.72	11.1	55.4	0.61	14.77
21/02/2018	11.4	150.1	1.71	11.4	124.2	1.42	17.26
22/02/2018	11.4	152	1.73	11.4	127.4	1.45	16.18
23/02/2018	11.5	150.2	1.73	11.4	125.3	1.43	17.30
24/02/2018	11.4	146.6	1.67	11.4	120.1	1.37	18.08
25/02/2018	11.7	196.7	2.30	11.5	152.2	1.75	23.95
mean	11.31	103.11	1.17	11.29	86.51	0.98	15.71
standard deviation	0.17	54.60	0.63	0.15	44.54	0.52	3.02

T-test: for the voltages, t stat = 4.225, P(T<=t) one-tail = 2.13E-05, t critical one-tail = 1.656, pearson correlation = 0.953. For the amperages t stat = 18.508, P(T<=t) one-tail = 7.35E-40, t critical one-tail = 1.656, pearson correlation = 0.997. For the powers t stat = 17.963, P(T<=t) one-tail = 1.43E-38, t critical one-tail = 1.656, pearson correlation = 0.998.

F-test: for the voltages, F = 1.154, P(F<=f) one-tail = 0.197, F critical one-tail = 1.32. For the amperages F = 1.5, P(F<=f) one-tail = 0.008, F critical one-tail = 1.32. For the powers F = 1.516, P(F<=f) one-tail = 0.07, F critical one-tail = 1.32.

This type of pollution is not as common as dust. As in the previous experiment, measurements were carried out for five months and during this time a tendency was found like the previous experience, on sunny days the effect on efficiency reached its maximum values, and on cloudy days the effect was minimal. The contaminated area was about 90% of the total area, which is slightly less than in the previous experiment. But the effect was more significant.

5.3 Sand

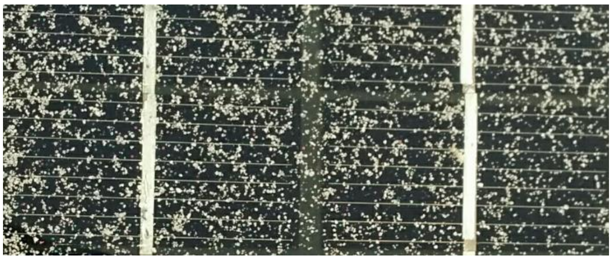

Figure 17. Contaminated PV panel (sand)

Sand is the most uncommon type of pollution in the Czech Republic in comparison with other types of pollution considered in this work. However, it is also possible to meet sea sand in the Czech Republic near sand mining areas, when using small, mobile solar panels.

Table 5. Values of the third experiment (sand)

	Clean panel			Sand			
Date	Voltage [V]	Amperage [mA]	Power [W]	Voltage [V]	Amperage [mA]	Power [W]	Impact of pollutant [%]
07/10/2017	11.3	75.3	0.85	11.3	66.2	0.75	12.08
08/10/2017	11.2	56.8	0.64	11.1	49.6	0.55	13.46
09/10/2017	11.4	113.2	1.29	11.4	99.8	1.14	11.84
10/10/2017	11.3	85.3	0.96	11.3	74.4	0.84	12.78
11/10/2017	11.4	105	1.20	11.3	89.8	1.01	15.23
12/10/2017	11.1	36.8	0.41	11.1	31.2	0.35	15.22
13/10/2017	11.1	38.2	0.42	11.1	32.7	0.36	14.40
14/10/2017	11.4	149.3	1.70	11.4	128.7	1.47	13.80
15/10/2017	11.7	197.1	2.31	11.4	156.8	1.79	22.49
16/10/2017	11.5	175.9	2.02	11.4	148.6	1.69	16.25
17/10/2017	11.4	156.8	1.79	11.3	133.3	1.51	15.73
18/10/2017	11.1	39.4	0.44	11.1	33.7	0.37	14.47
19/10/2017	11.1	37.6	0.42	11.1	32.5	0.36	13.56
20/10/2017	11.4	111.3	1.27	11.3	97.8	1.11	12.90

21/10/2017	11.6	180.3	2.09	11.5	152.4	1.75	16.20
22/10/2017	11.4	109.6	1.25	11.4	95.7	1.09	12.68
23/10/2017	11.2	40.2	0.45	11.1	33.5	0.37	17.41
24/10/2017	11.1	38.5	0.43	11.1	32.6	0.36	15.32
25/10/2017	11.4	127	1.45	11.4	113.3	1.29	10.79
26/10/2017	11.1	37.9	0.42	11.1	31.9	0.35	15.83
27/10/2017	11.5	179.6	2.07	11.4	151.6	1.73	16.32
28/10/2017	11.3	72.4	0.82	11.3	64.3	0.73	11.19
29/10/2017	11.3	58.1	0.66	11.3	51.6	0.58	11.19
30/10/2017	11.4	119.9	1.37	11.5	105.6	1.21	11.15
31/10/2017	11.2	44.8	0.50	11.2	37.8	0.42	15.63
01/11/2017	11.2	42.3	0.47	11.2	34.6	0.39	18.20
02/11/2017	11.2	43.6	0.49	11.2	36.2	0.41	16.97
03/11/2017	11.4	126.5	1.44	11.4	112.1	1.28	11.38
04/11/2017	11.5	178.3	2.05	11.4	149.9	1.71	16.66
05/11/2017	11.5	166.6	1.92	11.4	138.9	1.58	17.35
06/11/2017	11.4	144.1	1.64	11.4	130.1	1.48	9.72
07/11/2017	11.2	63.2	0.71	11.2	55.8	0.62	11.71
08/11/2017	11.1	31.3	0.35	11.1	29.4	0.33	6.07
09/11/2017	11.1	39.7	0.44	11.1	33	0.37	16.88
10/11/2017	11.3	81.1	0.92	11.3	72.3	0.82	10.85
11/11/2017	11.5	177.4	2.04	11.5	151.1	1.74	14.83
12/11/2017	11.4	156.9	1.79	11.4	133.3	1.52	15.04
13/11/2017	11.3	101.2	1.14	11.2	89.6	1.00	12.25
14/11/2017	11.5	178.3	2.05	11.5	150.2	1.73	15.76
15/11/2017	11.4	98.3	1.12	11.4	90.1	1.03	8.34
16/11/2017	11.3	83.3	0.94	11.3	74.7	0.84	10.32
17/11/2017	11.1	37.2	0.41	11.05	32.3	0.36	13.56
18/11/2017	11.2	54.1	0.61	11.1	47.6	0.53	12.80
19/11/2017	11.2	55.6	0.62	11.2	49.3	0.55	11.33
20/11/2017	11.1	34.8	0.39	11.1	30.3	0.34	12.93
21/11/2017	11.2	52.2	0.58	11.2	46.6	0.52	10.73

22/11/2017	11.3	87.6	0.99	11.3	75.6	0.85	13.70
23/11/2017	11.6	181.2	2.10	11.5	149.2	1.72	18.37
24/11/2017	11.5	176.3	2.03	11.5	149.8	1.72	15.03
25/11/2017	11.4	144.6	1.65	11.4	130.2	1.48	9.96
26/11/2017	11.4	137.4	1.57	11.3	121.4	1.37	12.42
27/11/2017	11.3	93.5	1.06	11.3	81.1	0.92	13.26
28/11/2017	11.2	47.3	0.53	11.2	39.9	0.45	15.64
29/11/2017	11.1	35.2	0.39	11.1	30.9	0.34	12.22
30/11/2017	11.2	48.7	0.55	11.2	40.6	0.45	16.63
01/12/2017	11.3	77.5	0.88	11.2	68.1	0.76	12.91
02/12/2017	11.5	173.8	2.00	11.4	147.4	1.68	15.93
03/12/2017	11.3	82.3	0.93	11.3	73.5	0.83	10.69
04/12/2017	11.5	176.1	2.03	11.5	149.2	1.72	15.28
05/12/2017	11.4	129.5	1.48	11.3	115.1	1.30	11.90
06/12/2017	11.3	88.7	1.00	11.3	77.5	0.88	12.63
07/12/2017	11.6	184.2	2.14	11.5	152.1	1.75	18.14
08/12/2017	11.4	122.4	1.40	11.4	108.7	1.24	11.19
09/12/2017	11.5	166.8	1.92	11.4	139.2	1.59	17.27
10/12/2017	11.5	174.3	2.00	11.5	148.3	1.71	14.92
11/12/2017	11.2	65.3	0.73	11.2	57.9	0.65	11.33
12/12/2017	11.2	64.1	0.72	11.2	56.7	0.64	11.54
13/12/2017	11.5	169.4	1.95	11.5	141.4	1.63	16.53
14/12/2017	11.5	166.2	1.91	11.5	138.3	1.59	16.79
15/12/2017	11.4	132.7	1.51	11.4	117.7	1.34	11.30
16/12/2017	11.2	59.9	0.67	11.2	52.9	0.59	11.69
17/12/2017	11.3	94.3	1.07	11.3	85.1	0.96	9.76
18/12/2017	11.5	173.6	2.00	11.4	146.9	1.67	16.12
19/12/2017	11.4	143.8	1.64	11.4	127.6	1.45	11.27
20/12/2017	11.1	40.2	0.45	11.1	35.2	0.39	12.44
21/12/2017	11.05	32.1	0.35	11	30.4	0.33	5.72
22/12/2017	11.1	39.4	0.44	11.1	34.9	0.39	11.42
23/12/2017	11.2	63	0.71	11.2	56.2	0.63	10.79

24/12/2017	11.2	62.2	0.70	11.2	55.4	0.62	10.93
25/12/2017	11.3	91.1	1.03	11.3	84.1	0.95	7.68
26/12/2017	11.5	167.6	1.93	11.5	139.9	1.61	16.53
27/12/2017	11.5	172.1	1.98	11.5	144.4	1.66	16.10
28/12/2017	11.1	42.2	0.47	11.1	37.4	0.42	11.37
29/12/2017	11.4	141.6	1.61	11.3	126.1	1.42	11.73
30/12/2017	11.5	170.5	1.96	11.5	141.4	1.63	17.07
31/12/2017	11.4	134.3	1.53	11.4	120.6	1.37	10.20
01/01/2018	11.2	83.6	0.94	11.2	74.8	0.84	10.53
02/01/2018	11.1	43.2	0.48	11.1	38.1	0.42	11.81
03/01/2018	11.5	172.8	1.99	11.5	144.3	1.66	16.49
04/01/2018	11.5	179	2.06	11.5	146.8	1.69	17.99
05/01/2018	11.2	67.3	0.75	11.2	61	0.68	9.36
06/01/2018	11.5	178.2	2.05	11.5	145.7	1.68	18.24
07/01/2018	11.1	47.2	0.52	11.1	40.4	0.45	14.41
08/01/2018	11.1	44.8	0.50	11.1	38.3	0.43	14.51
09/01/2018	11.4	139.1	1.59	11.4	125.6	1.43	9.71
10/01/2018	11.2	70.1	0.79	11.2	64.4	0.72	8.13
11/01/2018	11.1	45.3	0.50	11.1	39	0.43	13.91
12/01/2018	11.1	35.2	0.39	11.1	30.8	0.34	12.50
13/01/2018	11.1	38.2	0.42	11.1	33.3	0.37	12.83
14/01/2018	11.1	43.7	0.49	11.1	38.6	0.43	11.67
15/01/2018	11.1	40.6	0.45	11.1	35.6	0.40	12.32
16/01/2018	11.1	37.2	0.41	11.1	32.2	0.36	13.44
17/01/2018	11.1	36.6	0.41	11.1	31.5	0.35	13.93
18/01/2018	11.1	45.8	0.51	11.1	40.6	0.45	11.35
19/01/2018	11	30.1	0.33	11	27.8	0.31	7.64
20/01/2018	11.4	132.4	1.51	11.4	118.6	1.35	10.42
21/01/2018	11.5	172.4	1.98	11.5	143.4	1.65	16.82
22/01/2018	11.5	168.2	1.93	11.4	140.1	1.60	17.43
23/01/2018	11.4	142.8	1.63	11.4	128.2	1.46	10.22
24/01/2018	11.1	46.1	0.51	11.1	40	0.44	13.23

25/01/2018	11.6	181.1	2.10	11.5	148.7	1.71	18.60
26/01/2018	11.2	66.7	0.75	11.2	59.9	0.67	10.19
27/01/2018	11.2	58.9	0.66	11.2	52.6	0.59	10.70
28/01/2018	11.1	40.2	0.45	11.1	35	0.39	12.94
29/01/2018	11.1	39.3	0.44	11.1	34.2	0.38	12.98
30/01/2018	11.4	136.7	1.56	11.4	122.5	1.40	10.39
31/01/2018	11.5	164	1.89	11.5	139.8	1.61	14.76
01/02/2018	11.5	158.9	1.83	11.5	135.8	1.56	14.54
02/02/2018	11.4	140.1	1.60	11.4	126.6	1.44	9.64
03/02/2018	11.2	72.1	0.81	11.2	65.7	0.74	8.88
04/02/2018	11.4	138.2	1.58	11.4	124.5	1.42	9.91
05/02/2018	11.1	42.8	0.48	11.1	37.4	0.42	12.62
06/02/2018	11.5	174.4	2.01	11.5	149.1	1.71	14.51
07/02/2018	11.2	64.2	0.72	11.1	58	0.64	10.46
08/02/2018	11.1	44.6	0.50	11.1	38.5	0.43	13.68
09/02/2018	11.2	71	0.80	11.2	62.9	0.70	11.41
10/02/2018	11.2	149.5	1.67	11.4	127.6	1.45	13.12
11/02/2018	11.2	169.2	1.90	11.4	145.4	1.66	12.53
12/02/2018	11.4	155.3	1.77	11.4	134.1	1.53	13.65
13/02/2018	11.4	166.2	1.89	11.4	141.4	1.61	14.92
14/02/2018	11.5	177.2	2.04	11.4	144.9	1.65	18.94
15/02/2018	11.2	90.3	1.01	11.2	80.1	0.90	11.30
16/02/2018	11.6	178.1	2.07	11.6	146.2	1.70	17.91
17/02/2018	11.1	34.5	0.38	11.06	30.3	0.34	12.49
18/02/2018	11.1	41.5	0.46	11.1	36.1	0.40	13.01
19/02/2018	11.2	100.2	1.12	11.2	89.8	1.01	10.38
20/02/2018	11.1	65	0.72	11.1	57.2	0.63	12.00
21/02/2018	11.4	150.1	1.71	11.4	129.4	1.48	13.79
22/02/2018	11.4	152	1.73	11.4	132.1	1.51	13.09
23/02/2018	11.5	150.2	1.73	11.4	130.2	1.48	14.07
24/02/2018	11.4	146.6	1.67	11.4	125.6	1.43	14.32
25/02/2018	11.7	196.7	2.30	11.5	156.3	1.80	21.90

mean	11.31	103.11	1.17	11.29	88.86	1.01	13.31
standard deviation	0.17	54.60	0.63	0.15	45.59	0.53	2.93

T-test: for the voltages, t stat = 4.146, P(T<=t) one-tail = 2.91E-05, t critical one-tail = 1.656, pearson correlation = 0.943. For the amperages t stat = 17.647, P(T<=t) one-tail = 8.13E-38, t critical one-tail = 1.656, pearson correlation = 0.9977. For the powers t stat = 17.034, P(T<=t) one-tail = 2.44E-36, t critical one-tail = 1.656, pearson correlation = 0.997.

F-test: for the voltages, F = 1.186, P(F<=f) one-tail = 0.156, F critical one-tail = 1.32. For the amperages F = 1.434, P(F<=f) one-tail = 0.016, F critical one-tail = 1.32. For the powers F = 1.448, P(F<=f) one-tail = 0.014, F critical one-tail = 1.32.

In this experiment the impact of this pollution was greater than the effect of dust, but less than the effect of dirt. Pollution occupied about 85% of the surface of the solar panel.

5.4 Environmental conditions

In this experiment, the values were collected in different places with different degrees of air pollution.

Table 6. Values of the forth experiment (environmental conditions)

	Clean panel location 1			Clean panel location 2			
Date	Voltage [V]	Amperage [mA]	Power [W]	Voltage [V]	Amperage [mA]	Power [W]	impact of pollution [%]
14/10/2017	11.4	149.3	1.7	11.4	147.5	1.68	1.09
15/10/2017	11.7	197.1	2.31	11.7	195.3	2.29	1.08
16/10/2017	11.5	175.9	2.02	11.5	174.7	2.01	0.54
21/10/2017	11.6	180.3	2.09	11.55	181.7	2.10	-0.41
27/10/2017	11.5	179.6	2.07	11.5	180.2	2.07	-0.11
04/11/2017	11.5	178.3	2.05	11.5	177.2	2.04	0.60
05/11/2017	11.5	166.6	1.92	11.5	169.1	1.94	-1.28

06/11/2017	11.4	144.1	1.64	11.4	142.3	1.62	1.08
11/11/2017	11.5	177.4	2.04	11.5	176.3	2.03	0.62
12/11/2017	11.4	156.9	1.79	11.4	154.8	1.76	1.41
14/11/2017	11.5	178.3	2.05	11.5	179.2	2.06	-0.53
23/11/2017	11.6	181.2	2.1	11.6	178.7	2.07	1.29
24/11/2017	11.5	176.3	2.03	11.5	178.4	2.05	-1.06
02/12/2017	11.5	173.8	2	11.5	172.4	1.98	0.87
04/12/2017	11.5	176.1	2.03	11.5	175.6	2.02	0.52
07/12/2017	11.6	184.2	2.14	11.6	185.2	2.15	-0.39
09/12/2017	11.5	166.8	1.92	11.5	164.3	1.89	1.59
10/12/2017	11.5	174.3	2	11.5	175.1	2.01	-0.68
13/12/2017	11.5	169.4	1.95	11.5	167.8	1.93	1.04
14/12/2017	11.5	166.2	1.91	11.5	165.2	1.90	0.53
18/12/2017	11.5	173.6	2	11.5	177.1	2.04	-1.83
26/12/2017	11.5	167.6	1.93	11.5	166.6	1.92	0.73
27/12/2017	11.5	172.1	1.98	11.5	176.5	2.03	-2.51
30/12/2017	11.5	170.5	1.96	11.4	169.4	1.93	1.47
03/01/2018	11.5	172.8	1.99	11.5	176.7	2.03	-2.11
04/01/2018	11.5	179	2.06	11.5	176.4	2.03	1.52
06/01/2018	11.5	178.2	2.05	11.5	174.3	2.00	2.22
21/01/2018	11.5	172.4	1.98	11.5	171.1	1.97	0.62
22/01/2018	11.5	168.2	1.93	11.5	167.9	1.93	-0.04
23/01/2018	11.4	142.8	1.63	11.4	141.2	1.61	1.25
25/01/2018	11.6	181.1	2.1	11.6	185.6	2.15	-2.52
31/01/2018	11.5	164	1.89	11.4	162.8	1.86	1.80
01/02/2018	11.5	158.9	1.83	11.5	157.1	1.81	1.28
06/02/2018	11.5	174.4	2.01	11.5	172.8	1.99	1.13
10/02/2018	11.2	149.5	1.67	11.2	147.5	1.65	1.08
11/02/2018	11.2	169.2	1.9	11.3	173.6	1.96	-3.25
12/02/2018	11.4	155.3	1.77	11.4	157.7	1.80	-1.57
13/02/2018	11.4	166.2	1.89	11.4	164.2	1.87	0.96
14/02/2018	11.5	177.2	2.04	11.5	178.3	2.05	-0.51

16/02/2018	11.6	178.1	2.07	11.6	176.3	2.05	1.20
21/02/2018	11.4	150.1	1.71	11.4	148.9	1.70	0.73
22/02/2018	11.4	152	1.73	11.4	149.7	1.71	1.35
23/02/2018	11.5	150.2	1.73	11.5	150.1	1.73	0.22
24/02/2018	11.4	146.6	1.67	11.4	144.3	1.65	1.50
25/02/2018	11.7	196.7	2.3	11.7	197.2	2.31	-0.31
mean	11.49	169.31	1.95	11.48	168.98	1.94	0.27
standard deviation	0.09	12.84	0.16	0.09	13.50	0.17	1.30

T-test: for the voltages, t stat = 0.829, P(T<=t) two-tail = 0.411, t critical two-tail = 2, pearson correlation = 0.958. For the amperages t stat = 1, P(T<=t) two-tail = 0.316, t critical two-tail = 2, pearson correlation = 0.88. For the powers t stat = 1.28, P(T<=t) two-tail = 0.206, t critical one-tail = 2, pearson correlation = 0.988.

F-test: for the voltages, F = 1.12, P(F<=f) two-tail = 0.708, F critical two-tail = 3.302. For the amperages F = 0.9, P(F<=f) two-tail = 0.74, F critical two-tail = 1.22. For the powers F = 0.925, P(F<=f) two-tail = 0.8, F critical two-tail = 1.22.

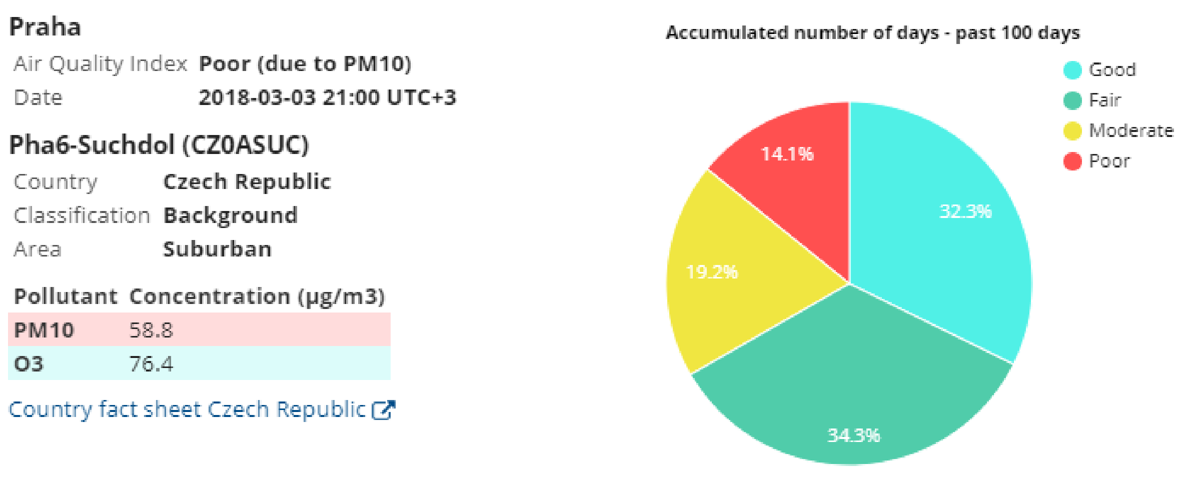

Figure 18. Air pollution location №1 (http://www.eea.europa.eu/themes/air/air-quality-index)

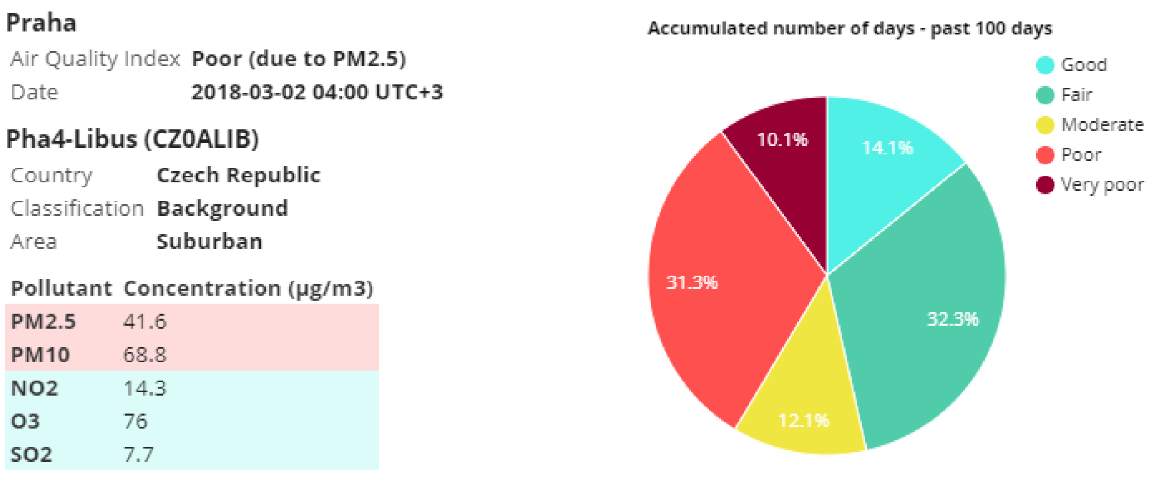

Figure 19. Air pollution location №2 (http://www.eea.europa.eu/themes/air/air-quality-index)

Table 7. Air quality

Pollutant	Index level (based on pollutant concentrations in µg/m3)				
	Good	Fair	Moderate	Poor	Very poor
Particles less than 2.5 µm ($PM_{2.5}$)	0-10	10-20	20-25	25-50	50-800
Particles less than 10 µm (PM_{10})	0-20	20-35	35-50	50-100	100-1200
Nitrogen dioxide (NO_2)	0-40	40-100	100-200	200-400	400-1000
Ozone (O_3)	0-80	80-120	120-180	180-240	240-600
Sulphur dioxide (SO_2)	0-100	100-200	200-350	350-500	500-1250

(Source: http://www.eea.europa.eu/themes/air/air-quality-index)

This experiment revealed that the effect of air pollution is within the error limits. When calculating the energy received, these values can be disregarded since there is no apparent correlation of the data. Although the fact that the data was collected only with a clear sky, other factors had a greater effect on efficiency than air pollution.

6. Discussion

6.1 Measurements

The measurements found in the analysis gave important information about the effects of pollution, but because of the characteristics of the measurements, one cannot predict the effect with 100 percent certainty the accuracy of the results. Date collection took about 10-15 minutes for each type of contamination. In ideal conditions it would be good to take measurements throughout the daylight hours, but not only at noon for 15 minutes.

For the evaluation, a very compact solar panel with a rather small maximum power was used, in addition, the error of the multi-meter when measuring the voltage is 0.25%, and when measuring the current, the accuracy is 0.8%. Since in this multi-meter model there is no watt meter function, the formula (W=I*U) was used in consequence of which the measurement accuracy decreased. With panel dimensions of 291x126x8 mm and 3.3-watt power, the error plays an important role in measuring the effect of impurities on efficiency. Suppose that because of the size of the panel it is extremely difficult to obtain accurate data, it has many important advantages. Due to the compactness, it became possible to investigate the effects of air pollution.

When measuring the effect of air pollution, the conditions for conducting the experiment differed not significantly. Because of this it cannot with absolute certainty assess the influence of this type of pollution, since all other factors are stronger than the effect of air pollution, but this fact also indicates that the effect on efficiency is extremely small and is within the margin of error. When calculating and designing a solar station, this meter can be neglected, unless, of course, we are talking about huge industrial stations where even a loss of one-tenth of a percent will have a colossal impact and entail large economic losses.

6.2 Pollutants

Some of the tested types of pollution are not common for the Czech Republic. It is possible to estimate the sand contamination, but it is not so important for determining the impact on efficiency, but without mentioning it is quite difficult to provide a complete picture. Pollution in the form of dirt is extremely rare but they can occur during or after heavy rain and if the solar panel is located close enough to the ground or in other specific cases.

One of the most important drawbacks of the diploma project is the inability to check the thickness of the contaminating layer. This was considered extremely important along with the percentage of contaminated surface of the solar panel

6.3 Layer Thickness

Although there is the opportunity to determine the percentage of the contaminated surface, unfortunately, it is impossible to determine one of the most important parameters for determining the influence of pollution on the efficiency of the solar panel, the thickness of the contamination layer. In the case of sand, we can set the thickness of the layer equal to the thickness of one grain of sand. In the case of dirt and dust, unfortunately, we cannot apply this scheme.

Because of the inability to measure the layer and its quality, the effect of precipitation on pollutants was not influenced. According to the research, rain drops absorb small dust particles and can transfer them to the solar panel Sánchez, Cohim and Kalid (2015), which also can be considered as an effect affecting the efficiency of the photovoltaic panel, but at the same time rainfalls clean the solar panel from the pollutions and the highest values were recorded after heavy rain Elminir and Ghitas (2006). It would be good to estimate the influence of different dust layers on the efficiency according to Zaihidee, Mekhilef and Horan et. al. (2016) there are three important dust layers. Layer C: is a top layer, loose surface of soil, which could easily be removed by rain. Layer B: is a middle layer of soil, has a resistant to removal by rain, but remove readily by washing and adhesive tape. Layer C: is the primary surface layer of soil, like the layer b has a resistant to removal by rain, but also has a resistant to washing and adhesive tape.

6.4 Types of Photovoltaic Panels

The effect that turns out to be on different types of solar panels has not been tested. If the data obtained during the work can easily be projected onto monocrystalline panels since these types of cuttings are based on silicon, it is completely unclear how the panels using other technologies will behave. We can only assume that the impact will be different. The effect is exerted on concentrator and cascade solar modules as the technology used in them differs from the usual silicon modules. It is also extremely difficult to assess the effect on organic solar modules.

Although this type has not yet entered widespread use, perhaps in the near future it will become the most popular.

7. Conclusion

In this study, attention was paid to the effect of impurities on the effectiveness of monocrystalline siliceous solar panels. The effects of four different pollutants (dust, mud, air pollution) have been investigated, each type has a different effect, it has also been found that they have the greatest effect in sunny weather, when, in the presence of clouds, their influence decreases significantly. The data were collected for about five months under different weather conditions, which significantly reduces the possibility of statistical errors. However, in the experiment, the effect of air pollution on the apparent correlation of the data was not detected by the inspectors, since the influence of this factor is extremely small, plus the difference in the weather conditions is the place to be, even though the data in this experiment is collected only in clear skies.

Unfortunately, the exact effect of air pollution on the efficiency of solar panels could not be detected and therefore the data appeared to be in error precursors and there were no general correlations of the data. Perhaps the experiment did not because of the complexity of the experiment and the presence of an extremely large number of extraneous factors from which it was extremely difficult to get rid of. It is also possible that the difference between the locations was not large and the effect would be better observed in more polluted air.

The influence of dust (relative power decrease) was about 10%, which is quite large, as the efficiency of modern polycrystalline silicon panels is up to 18%. With such low-level efficiency, every watt is extremely important. If in cloudy weather it is possible to neglect the decrease in efficiency, since under these conditions the panel produces very little electricity and, moreover, the effect of pollution is reduced to about 6-7%. Much more important is the effect on sunny days, when the panel gives out its peak values. The reduction of these values is highly undesirable, the pollution effect reaches rather high values in 14-15%

Sand pollution is not common in the Czech Republic. Sand pollution is more common in Africa, in Australia or Asia, but if you do not take into consideration the industrial photovoltaic solar power plants, and focus on small panels installed near sand quarries. The average effect of sand on the efficiency of the solar panel is 12-13%, which is quite large. With cloudy weather, the effect is 6-10%, but the maximum effect can reach 17-19%.

The effect of dirt was more significant compared with other pollutants in the average effect of 15-16%, as in other cases, the maximum effect is noticeable in sunny weather, these values can reach quite large values of 22-24%. Even the cheapest solar panels (flint polycrystalline) are quite expensive, and without proper maintenance could lose up to 24% of the maximum, the efficiency is extremely unprofitable.

Perhaps it would be necessary to conduct research for a thesis under laboratory conditions, excluding the influence of other conditions, but the main purpose of this work was to check the influence of pollution in real conditions, as the use of photovoltaic panels is not in the laboratory.

It could be believed that soon new dust and dirt-repellent materials will be applied or there will be a sharp reduction in the cost of production of cascade photovoltaic panels that are not so influenced by these factors.

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