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NEW DEVELOPMENTS OF SOLAR ENERGY UTILIZATION IN THE ASPECT OF EU DIRECTIVES

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ABSTRACT

Photovoltaic systems are very efficient concerning proper utilization of solar radiation. However, the nanotechnology solution can replace the photovoltaic by the use of new production technology to lower the price of solar cells to one tenth. Sun provides nearly unlimited energy resource, but existing solar energy harvesting technologies are quite expensive and cannot compete with fossil fuels. The central part of Poland, which represents about 50 percent of the area, gives solar radiation at the level of 1000 kWh·m^{-2}/year. Other new developments, which can help improve existing efficiency of solar systems are: diatoms utilization, artificial photosynthesis, nanoleaves and rotation solar towers.

Introduction

According to estimates, more than 100,000 Poles use various kinds of solar installations, such as solar collectors. With regard to the EU requirements set forth in Directive 2009/28/EC, every Member State of EU is obliged to increase the share of renewable energy in total energy consumption by 2020. For Poland, the target was set at the level of 15%. Nevertheless, the place of changes is not sufficient so far and in the coming years the sector will require further improvement. Photovoltaic systems are becoming the most efficient ones concerning proper utilization of solar radiation. Solar collectors are popular for individual use, but still there are not many commercial investments. Poland is one of Europe's leaders in the production and sale of solar collectors. According to data presented by Poland's National Fund for Environmental Protection and Water Management, Poland is ranked third in Europe, a surprising growth from the ninth place in 2009 (Wardal, 2015).

Artificial photosynthesis

Artificial photosynthesis will not add up to the greenhouse gases and thus to global warming. This will be a renewable resource for transportation energy. The idea is to create an artificial leaf that can duplicate a few steps of photosynthesis. That leaf can capture the solar photons and have a catalytic system in place that can oxidize water. It concentrates on developing of fuels from sunlight. Research is now in the process of a major breakthrough

towards artificial photosynthesis in the Lawrence Berkeley National Laboratory. It brings some hope with regard to the properties of nano-sized crystals of cobalt oxide. Cobalt oxide can effectively carry out the crucial photosynthetic reaction of splitting water molecules. Water molecules changing into oxygen, electrons and protons (hydrogen ions) is one of the two essential half reactions of an artificial photosynthesis system – it provides the electrons needed to reduce carbon dioxide to a fuel. Effective photo oxidation requires a catalyst that is both efficient in its use of solar photons and fast enough to keep up with solar flux in order to avoid wasting those photons. Clusters of cobalt oxide nanocrystals are sufficiently efficient and fast, and are also robust and abundant. The usage of iridium oxide for artificial photosynthesis is not very popular. Although iridium oxide is efficient and fast enough for light absorption and is a good catalyst, this metal is the least abundant metal on earth. Therefore, it is not very practical to use it on the commercial scale. We need a metal that is equally effective but far more abundant. It was verified to take the manganese-based organometallic complexes for artificial photosynthesis. However, manganese - containing compounds are water insoluble and not very robust. Moreover, attention was paid to cobalt oxide which is a highly abundant material and fit for commercial use. Cobalt oxide also dissolves in water. The next big step, however, will be to integrate the water oxidation half reaction with the carbon dioxide reduction step in the artificial leaf type system. Not everything that is artificial is bad for earth; a London based company called Solar Botanic intends to use energy harvesting trees to generate solar as well as wind energy. The solution is unique in a sense that the same installation can use two alternative energy sources to produce clean electricity. The concept is going to be used to implement some of the nature's processes in order to produce clean, environmentally – friendly energy (Borek, 2015). The tree, once installed, will replicate the functions of a solar-wind harvester. This energy capturing powerhouse is going to be "nanoleaf". According to the nanoleaf idea it is thin like a natural leaf, when outside forces, like the wind pushes the nanoleaf back and forth, mechanical stresses appear in the petiole, twig and branches. When thousands of nanoleaves flap back and forth due to wind, millions and millions of Pico watts are generated. The stronger the wind, the more energy is generated. Nanoleaves reflect back only a small portion of the sunlight and the remaining light is used to produce energy. Due to the unique combination of photovoltaic and thermo-voltaic in our nanoleaves it converts this thermal radiation into electricity, even hours after the sun has set. They can even convert the infrared radiations into energy. The constant development in nanotechnology, the photovoltaic and thermo-voltaic materials will be easier and less costly to produce, bringing down the production and installation costs significantly. Of course the biggest benefit of such trees will consist in availability of extremely non-polluting electricity. However, along with this, they will also eliminate the need to create eyesores in the form of gigantic wind turbines and solar panels. These energy harvesting trees will look as natural as normal trees. This is like growing gardens and mini forests that are actually silent electricity generators (Berkeley lab., 2013).

Solar systems development

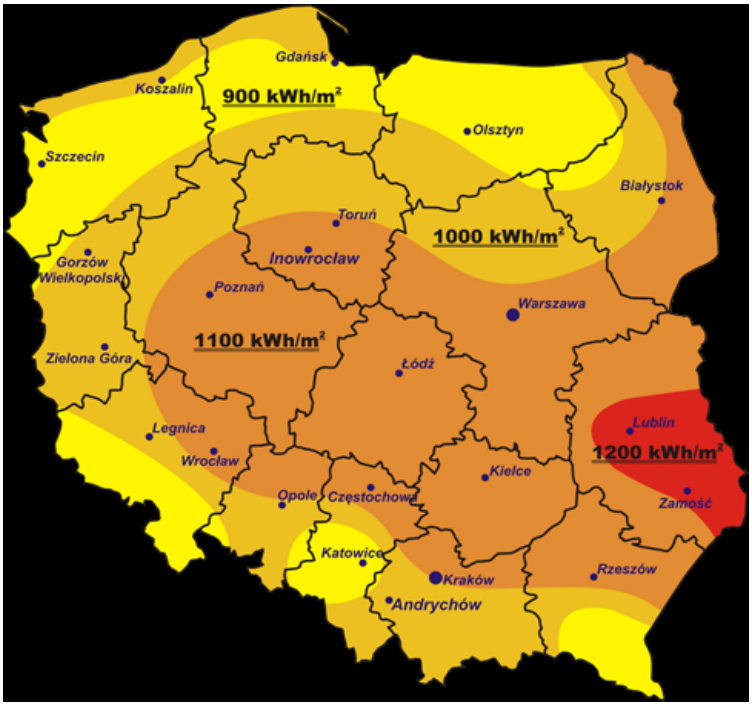
The numbers reflect the popularity of solar panels in rural Poland, where they are often installed on rooftops. Home and agriculture builders can make use of special loans that are partially financed by the National Fund for Environmental Protection and Water Manage-

ment and it can be utilized for financing projects related to solar collectors. In 2011, production and sales of solar collectors in Poland increased by some 70 percent compared to the previous year. The solar-collector market is the only renewable energy segment that shows such strong growth. The Institute for Renewable Energy estimates that Poland's solar-collector market is worth 170 million € and that there are about 70 companies in Poland producing and selling those devices. Solar collectors with the total area of 12 million sqm have been installed in Poland so far. That is an area three times as big as Vatican City. It is expected that solar collectors with the total area of some 420 000 m^2 will be installed with the help of these loans. Estimation shows that they can reduce carbon emissions by 65 100 metric tons by 2015. Actually, there is one solar farm working with the total capacity of 1 MW and four others of that size each are planned to complete a construction in a coming year. Solar energy could be a good solution for the growing need for renewable energy in Poland. Actually when we are looking at the total renewable energy capacity installed in Poland equal to 4400 MW as of the end of 2012, only 1.3 MW is coming from solar farms. Currently, only 10.5 percent of energy consumed in Poland comes from renewable energy sources, but that number is expected to grow, since it is designed to obtain 15 percent of its energy from renewable sources by 2020. Living conditions have a great impact on the attitude towards installing solar collectors. The research showed that 30% of respondents plan to install such devices on the roofs of their houses or agricultural buildings in the future, while in cities – only 14%. Such a situation is justified by the fact that 56% of them has no such possibility or do not know if there are solar collectors already installed on the building they are living in. Results of the research prove that using solar thermal energy is not very popular in Poland, as only 8% of the respondents confirmed that they are using such devices for improving energy efficiency in their households. Increasing consciousness concerning alternative energy sources in the society, gives a chance for distributors to boost sales as 30% of respondents declare willingness to buy solar collectors. However, solar activation in Poland is not so effective as it is in southern countries, but solar collectors can also be utilized with a quite great success. As we are looking at Germany, where solar radiation is very similar to the Polish conditions, solar systems are very popular there. About 40 percent of solar collectors in Europe are installed in Germany. A well-planned solar system for one household can cover about 60 percent of annual requirement for hot water, and thus we can save a lot of energy in the country's scale (Wardal, 2015).

The central part of Poland, which represents about 50 percent of the area, gives solar radiation at the level of 1000 $kWh \cdot m^{-2}$/year. A lower solar radiation is presented along the Baltic coastal line and gives the value of 900 $kWh \cdot m^{-2}$/year. A big difference in capacity of solar radiation during the year was confirmed. Furthermore, only during the summer time 43 percent of the total yearly solar radiation is obtained. Figure 1 presents solar radiation in different regions of Poland.

Between 2000 and 2010 the surface of installed solar collectors increased from 21 000 m^2 to 655 800 m^2, that is over 3000 percent. Most of the solar collectors are of flat plate model and they account for about 70 percent of total sales on domestic market (PGE, 2013). This type is also the most commonly produced one, as contrasted to the tube model. According to the data published by the Renewable Energy Institute, in 2010 145 900 m^2 of solar collectors have been installed in Poland, which is a level parallel to the one of the

previous year. The recent financial crisis in the European Union resulted in slowdown in the industry which negatively influenced exports of Polish producers (Central Statistical Office, Poland, 2010). According to the European Union's requirements expressed in Directive 2009/28/EC, every member state is obliged to increase the share of renewable energy in total energy consumption by 2020. For Poland, the target was set at the level of 15%. Nevertheless, the place of changes is not sufficient so far and in the oncoming years the sector will require further profound review. There are over 40 companies operating in the solar thermal collector market in Poland. The market is strongly concentrated. In 2009, 60% of the market was controlled by four companies, in 2011 – by six. This fact indicates that the market creates possibilities for development and gaining significant market shares (PGE, 2013). The offer of Polish solar collectors producers is aimed at both internal and external markets. In fact, a large portion – approximately 50% (i.e. 80 000 m^2) – of the devices produced in Poland is exported to other countries, mainly to Germany, Spain, Portugal, Austria, Italy, Great Britain, Sweden, Finland, Czech Republic and Slovakia. Between 2009 and 2010 sales of solar collectors decreased in many western countries, such as Germany, France or Spain. The solar thermal market in Poland increased in that period by 3.2 percent. As mentioned before, the poor result is explained by disadvantages of economic situation caused by the global crisis. In spite of that, since 2000 the market has been developing on average at 40 percent per year (PGE, 2013).



Source: PGE, 2013

Figure 1. Solar capacity in different regions of Poland

Currently, Poland needs to face a problem of depreciation of assets in traditional power industry. In fact, almost a half of them are 30-40 years old. As a result, new investments are required which is also caused by the requirements of The EU Climate and Energy Package. In 2010, the Polish government has approved "National action plan for energy from renewable resources" implementing solutions required by the European Union Directive 28/2009/WE (Borek, 2015). The target of 15% share of renewable energy in the energy structure in Poland will be achieved mainly thanks to wind plants. Nevertheless, according to the forecasts of the Ministry of Economy, as far as heat is concerned, solar energy will be one of the main resources and the demand will be increasing dynamically until 2020.

According to the data published by the European Solar Thermal Industry Federation, the Polish market may grow by 30% per year and reach 20 million square meters of installed collectors by 2020, which is 0.5 square meters per capita. Nevertheless, the provisions of the Polish government are less optimistic, as it is estimated that the solar thermal installations may reach 14.7 million square meters in the same period. Surface of solar collectors used in countries similar to Poland with regard to isolation proves that the conditions are sufficient at this latitude. For example, in Germany in 2010 the total surface of solar collectors installed amounted to 9 676 800 square meters, compared to 459 200 square meters in Poland (Polish Energy Policy, 2009).

Results of the research prove that using solar thermal energy is not very popular in Poland, as only 8% of the respondents confirmed that they are using such devices for improving energy efficiency in their households. Increasing consciousness concerning alternative energy sources in the society, gives a chance for distributors to boost sales as 30% of respondents declare willingness to buying solar collectors (PGE, 2013).

European Union regulations and a strong need for a change of structure in the power industry require introducing incentives to stimulate usage of renewable energy on different levels. The Polish government, also thanks to European Union funds, prepared financial help, for households and small and medium enterprises. The European Bank for Reconstruction and Development prepared a 75 million € loan scheme for small and medium enterprises operating in the Polish market. The main aim of the Poland Sustainable Energy Financing Facility is to boost energy efficiency in the sector. Among many different devices that may be financed thanks to the program also solar collectors are present.

In the beginning of 2012, an application round for funds, from the so-called Norwegian Funds, began 75 million € were assigned for supporting the development of usage of renewable resources in Poland and increasing energy efficiency.

The program resulting from cooperation of Financial Mechanism of the European Economic Area and the Norwegian Financial Mechanism is prepared for the years 2009-2014. The current round is the second stage of the cooperation, the previous one was executed between 2004 and 2009 and it was used in 100% (the funds available were 50 millions € smaller than currently).

In 2011, the Polish parliament passed a bill concerning energy efficiency, which introduced numerous solutions aimed at increasing rational energy use. On this basis, the so - called "white certificates" are introduced. They might be obtained for energy use optimization by diminishing the use and losses in transmission and distribution of energy. The initiative's objective is to encourage companies selling electric energy, heat and gas to improve energy efficiency in their operation (PGE, 2013).

Nanotechnology

Scientific work at the University of Texas on a low-cost, nanomaterial solution that can replace the current photovoltaics is provided. It is quite hopeful that the new technique coupled with different manufacturing processes will lower the price of solar cells to one tenth. The University of Texas outlines the needs of cheaper solar cells in the market, The sun provides a nearly unlimited energy resource, but existing solar energy harvesting technologies are inadmissibly expensive and cannot compete with fossil fuels. This system is utilizing the light-absorbing nanomaterials. Their specialty is that they are 10 000 times thinner than a strand of hair. Their microscopic size makes it possible to attain higher efficiency devices. The inks could be printed on a roll-to-roll printing process. They can use a plastic substrate or stainless steel for printing. It seems that this type of ink could be used to paint a rooftop or building and it does not look like a tall claim. These links are semi transparent and apart from roofs they could be pasted on the windows too. It have to be painted with the light absorbing material and a few other layers as well. This is one step towards paintable solar cells (EU, 2011).

Copper indium gallium selenide called CIGS are used for development of the solar cells. These materials are cheaper in comparison to current materials utilized in the solar cells and mild for environment, too. It's a direct band gap semiconductor, which means that you need much less material to make a solar cell, and that's one of the biggest potential advantages (Berkeley lab., 2013). Sunlight is a non-exhaustible source of energy which does no emit greenhouse gases to the atmosphere. But still, it is far away from replacing the fossil fuels. There are many reasons for that. One of its biggest disadvantages is that it is still out of reach for the common man and it has a long break-even period. Unless a product or service is embraced by masses it cannot be treated as an alternative source to fossil fuels. However, scientists work hard on solar cells. It is believed that solar cells could soon be produced more cheaply using nanoparticle. These nanoparticles can help in printing solar cells like a newspaper or paint them onto the sides of buildings or rooftops to absorb electricity-producing sunlight (Borek, 2015).

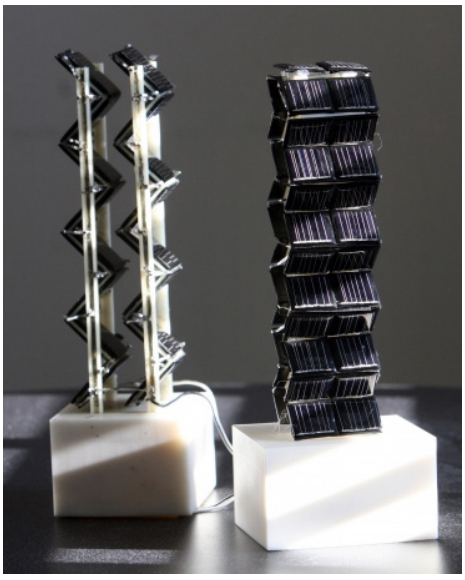
Diatoms utilization

Diatoms are considered the basis for much of the life in the oceans. Their unique property is they have rigid shells that can be used to create order in a natural way at the extraordinarily small level of nanotechnology. Most existing solar cell technology is based on silicon and is nearing the limits of what we may be able to accomplish with that. There is an enormous opportunity to develop different types of solar energy technologies, and it is likely that several forms will ultimately all find uses, depending on the situation. Here the research is using biology instead of usual traditional semiconductor devices for the betterment in solar technology (MIT, 2013). Photons bounce around like they were in a pinball machine, striking these dyes and producing electricity. Research work using the diatoms for furthering new technology in solar energy was developed in the Oregon State University. Diatoms are small, unicellular marine life forms. They have inhabited the oceans for at least 100 million years. This technology also performs well under lower light conditions and makes a manufacturing process simple and effective. The greatest advantage of the diatoms is that they already have shells with nanostructures required for solar technology. They are permitted to settle down on a conductive glass surface. After the completion of this step, the

living material is removed and what is left are tiny skeletons of the diatoms forming templates. The team has then utilized a biological agent to precipitate soluble titanium into very tiny “nanoparticles” of titanium dioxide. This titanium dioxide develops a thin film operating as the semiconductor for the dye-sensitized solar cell device. Thus, these biological materials make the manufacturing process simple. Conventional thin film photosynthesizing dyes also take photons from the sunlight and transfer it to titanium dioxide, creating electricity. However, in this system the photons bounce around more inside the pores of the diatom shell, making it more efficient (Berkeley lab., 2013).

Tower rotation modules

Recent activity of research work has focused on improving the performance of solar photovoltaic cells and trying to bring down their cost. However, very little attention has been paid to the best ways of arranging those cells, which are typically placed flat on a rooftop or other surface, or sometimes attached to motorized structures that keep the cells pointed toward the sun as it crosses the sky what is presented in figure 2.



Source: MIT, 2013

Figure 2. Solar energy: arranging of photovoltaic cells for improving solar overall output

MIT researchers have come up with a very different approach: building cubes or towers that extend the solar cells upward in three-dimensional configurations. The results from the structures they have tested show power output ranging from double to more than 20 times that of fixed flat panels with the same base area. The biggest boosts in power were seen in the situations where improvements are most needed: in locations far from the equator, in winter months and on cloudier days. The new findings were based on both computer mod-

elling and outdoor testing of real modules. It looks that this concept could become an important part of the future of photovoltaic. The MIT team initially used a computer algorithm to explore an enormous variety of possible configurations, and developed analytic software that can test any given configuration under a whole range of latitudes, seasons and weather. Then, to confirm their model's predictions, they built and tested three different arrangements of solar cells on the roof of an MIT laboratory building for several weeks. While the cost of a given amount of energy generated by such 3-D modules exceeds that of ordinary flat panels, the expense is partially balanced by a much higher energy output for a given footprint, as well as much more uniform power output over the course of a day, over the seasons of the year, and in the face of blockage from clouds or shadows (MIT, 2013). These improvements make power output more predictable and uniform, which could make integration with the power grid easier than with conventional systems. The basic physical reason for the improvement in power output – and for the more uniform output over time – is that the 3-D structures' vertical surfaces can collect much more sunlight during mornings, evenings and winters, when the sun is closer to the horizon (EU, 2011).

Solar energy algorithms have a key role in optimization and simplification of a solar system.

Although computer modelling showed that the biggest advantage would come from complex shapes – such as a cube where each face is dimpled inward – these would be difficult to manufacture. The algorithms can also be used to optimize and simplify shapes with little loss of energy. It turns out the difference in power output between such optimized shapes and a simpler cube is only about 10 to 15 percent – a difference that is dwarfed by the greatly improved performance of 3-D shapes in general. That was analysed both simpler cubic and more complex accordion like shapes in their rooftop experimental tests. At first, the researchers were distressed when almost two weeks went by without a clear, sunny day for their tests. But then, looking at the data, they realized they had learned important lessons from the cloudy days, which showed a huge improvement in power output over conventional flat panels. For an accordion-like tower – the tallest structure the team tested – the idea was to simulate a tower that "you could ship flat, and then could unfold at the site". Such a tower could be installed in a parking lot to provide a charging station for electric vehicles (MIT,2013).

Individual 3-D modules have been modelled so far. A next step is to study a collection of such towers, accounting for the shadows that one tower would cast on others at different times of a day. In general, 3-D shapes could have a big advantage in any location where space is limited, such as flat-rooftop installations or in urban environments. Such shapes could also be used in larger-scale applications, such as solar farms, once shading effects between towers are carefully minimized.

Conclusions

The "National action plan for energy from renewable resources" implementing solutions required by the European Union Directive 28/2009/WE was approved. The target of 15% share of renewable energy in the energy structure in Poland will be achieved mainly thanks to wind plants. Nevertheless, according to the forecasts of the Ministry of Economy, as far

as heat is concerned, solar energy will be one of the main resources and the demand will be increasing dynamically until 2020.

Energy estimates that Poland's solar-collector market is worth 170 million € and that there are about 70 companies in Poland producing and selling those devices. Solar collectors with the total area of 12 million sqm have been installed so far. According to the data presented by Poland's National Fund for Environmental Protection and Water Management, Poland is ranked third in Europe concerning amount of solar systems already installed.

Photovoltaic systems are becoming the most efficient ones concerning proper utilization of solar radiation (MIT, 2013).

It is believed that solar cells could soon be produced more cheaply using nanoparticles. They can help in printing solar cells like a newspaper or paint them onto the sides of buildings or rooftops to absorb electricity-producing sunlight.

It is quite hopeful that the new technique coupled with different manufacturing processes will lower the price of solar cells to one tenth.

For furthering new technology in solar energy, biology was utilized. Water molecules changing into oxygen, electrons and protons are one of the two essential half reactions of the artificial photosynthesis system – it provides the electrons needed to reduce carbon dioxide to a fuel.

The new "nanoleaf" concept is going to be used to implement some of the nature's processes in order to produce clean, environmental friendly energy. The tree, once installed, will replicate the functions of a solar-wind harvester.

Building rotation cubes or towers that extend the solar cells upward in three-dimensional configurations gives new development of solar systems. The results from such structures, which were tested, show power output ranging from double to more than 20 times that of fixed flat panels with the same base area.

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NOWE TECHNOLOGIE ROZWOJU ENERGETYKI SOLARNEJ W ASPEKCIE DYREKTYW UE

Streszczenie. Układy fotowoltaiczne są bardzo wydajne pod względem właściwego wykorzystania promieniowania słonecznego. Jednakże rozwiązania nanotechnologiczne mogą zastąpić fotowoltaikę dzięki wykorzystaniu nowej technologii produkcji, w celu obniżenia ceny ogniw słonecznych do jednej dziesiątej. Słońce dostarcza prawie nieograniczone zasoby energii, ale istniejące technologie jej pozyskiwania są dość kosztowne i nie mogą konkurować z paliwami kopalnymi. W centralnej części Polski, która stanowi około 50 procent powierzchni, promieniowanie słoneczne osiąga poziom 1000 kWh·m^{-2}/rok. Innymi nowymi rozwiązaniami, które mogą przyczynić się do poprawy istniejącej efektywności systemów słonecznych są: wykorzystanie sztucznej fotosyntezy, nanotechnologii, czy też wprowadzenie obrotowych wież słonecznych.

Słowa kluczowe: energia słoneczna, kolektory słoneczne, nanotechnologia, sztuczna fotosynteza, wieże słoneczne