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THE USE OF PHOTOVOLTAIC INSTALLATIONS IN ORDER TO IMPROVE THE ENERGY INDEPENDENCY OF A DAIRY EQUIPPED WITH A BIOGAS REACTOR

Abstract
This article attempts to demonstrate the importance of photovoltaic installations in improving the energy independence of a dairy equipped with a biogas reactor. It focuses on the development of photovoltaic technologies towards the wider use of solar cells in industrial power engineering installations, the potential of photovoltaic installations in Poland, and the storage and processing of energy from photovoltaic sources. An attempt has also been made to analyze the potential of a milk processing plant to meet its energy needs using photovoltaic sources.

Key words
photovoltaic installations, photovoltaic technologies, photovoltaic storage and processing, milk processing plants

Introduction: Expanding the use of solar cells in industrial power engineering installations

The constant and dynamically growing consumption of energy, especially electricity, urges the search for new technological solutions in most countries in the world [1, 2]. At the same time, the pursuit of environmental protection and the desire to diversify the sources of power, thus ensuring energy security, result in an increase of the interest in renewable energy [3]. One such option is photovoltaics, and the electricity generated by photovoltaic conversion, during which no waste or pollution is generated. It belongs to the group of renewable energy sources that are environmentally friendly [4]. Solar panels do not cause any noise, nor are they otherwise inconvenient to the environment, so they can be built in the immediate vicinity of human settlements. Long-term, fault-free operation of solar cells allows them to be operated for up to thirty years [5], while the high degree of freedom of assembly allows them to be located almost anywhere, extending power supply to mobile receivers or in difficult terrain conditions away from the grid [6, 7]. The modular design of the battery cells also makes it easy to adjust the size of the system to the energy needs of the receiver.

Over the last few years, photovoltaics has shifted from an area of interest for researchers and preliminary implementation work to real use in the energy sector of most developed countries. The recent increase in the production of photovoltaic modules, as well as the installed electrical power from these modules, is unprecedented and incomparable to any other type of generator. Only in the years 2008-2011, despite the economic crisis, was there a global increase in installed capacity from photovoltaic sources was recorded above 1300% and an increase in module production of 6000% [8]. According to the report of the European Photovoltaic Industry Association, in 2011 the installed capacity of photovoltaic equipment in the world amounted to over 64 GW, which is almost twice the value of 2010. Similarly, the number of companies operating in the photovoltaic industry is increasing, which is accompanied by an increase in employment. According to estimates, by 2030, photovoltaics should meet 14% of the world's electricity demand [9].

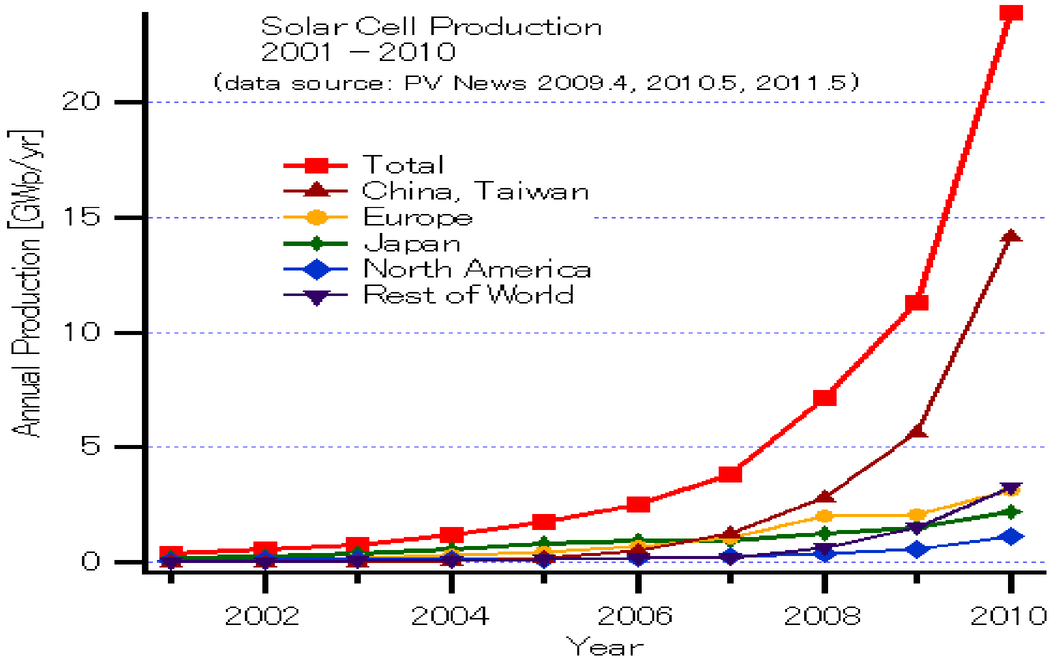


Fig. 1. Growth of world production of photovoltaic modules in 2000-2010

Source: [10]

The facts clearly indicate the importance of photovoltaic installations for modern energy systems. This is also reflected in many programs supporting the development of such energy sources, especially in European countries. Due to the EU's renewable energy development plan and the reduction of pollution, commonly called 3×20%, Poland is also committed to the intensive development of environmentally friendly energy [11]. Also, the new Energy Law, as expected, should facilitate the widespread introduction of photovoltaic installations to the National Energy Network.

The power potential of photovoltaic installations in Poland

The primary source of energy in our solar system is the electromagnetic radiation of the Sun. Solar radiation reaching the surface of the Earth is the source of electricity generated in the photovoltaic cell. The density of the power emitted from the surface of the Sun is enormous at 62.5 MW/m^2, 1350 W/m^2 of which reaches the Earth's surface. This radiation comes predominantly from the so-called photosphere, that is, the outer surface of the Sun's gas layer. The photosphere's temperature is about 5,780 K, and its emission is mainly electromagnetic radiation with a continuous spectrum. The spectrum's maximum energy distribution is around 460 nm visible light, which corresponds to the blue-green color. This fact encourages the modeling of the distribution of solar radiation based on the model of a perfectly black body, according to Stefan Boltzman's law. Unfortunately, in fact, the solar emission is different from the ideal black body distribution, as depicted below.

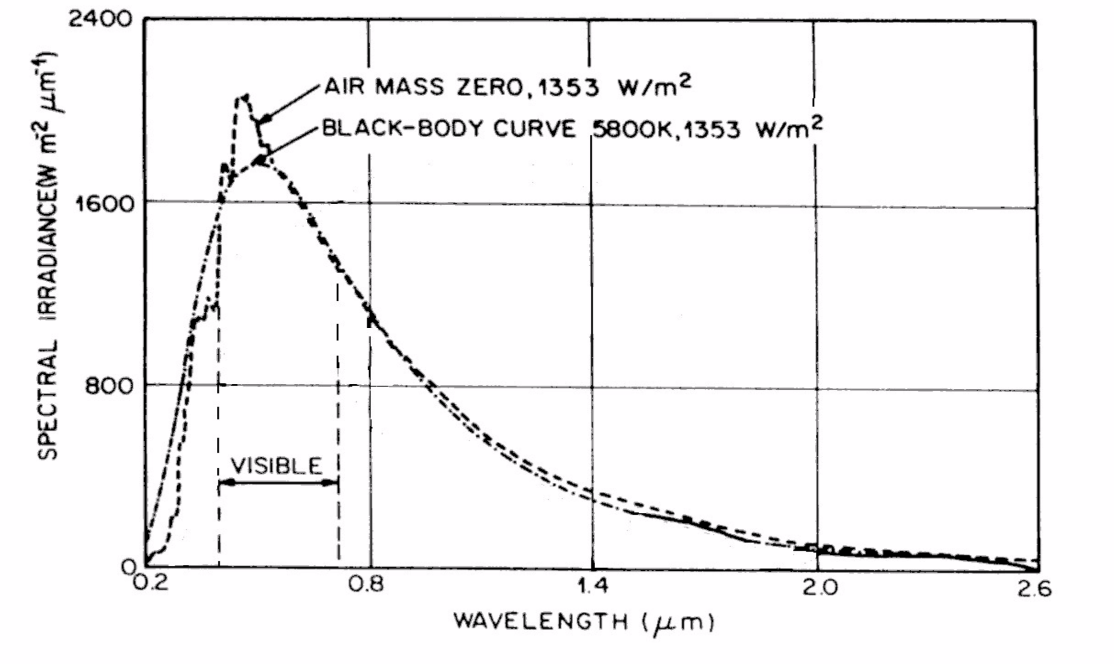


Fig. 2. Ideal black body emission distribution with a temperature of at 5780K and the actual solar photosphere emission
Source: [12]

The greatest differences between the two courses occur in the short wavelength range and result from the heterogeneous composition of the Sun, however these differences are not significant to the changes that affect the Earth's atmosphere. This effect not only reduces the radiation power, but also significantly modifies its spectral distribution. The basic phenomena that occur in the atmosphere, important from the point of view of light travel, are:

- Reduction of radiation power through absorption, dispersion and reflection in the atmosphere;
- The change in the radiation spectrum is due to higher absorption and dissipation in some wavelength ranges;
- Introducing additional lighting from radiation diffused in the atmosphere;
- Local changes in the transparency of the atmosphere, such as clouds, fog, and dust;

The sun's radiation reaching the surface of the atmosphere is partially reflected, which is the first reason for the reduction of its energy. Then, the portion of the beam that enters the atmosphere is partially diffused and absorbed by the various layers of the atmosphere. Due to the inhomogeneous composition of the atmosphere, and the presence of some light-absorbing gases in the selected wavelength ranges, the distribution of radiation permeating the atmosphere is altered and to a large extent inhomogeneous. The dispersed part of the visible radiation, however, to a large extent reaches the surface of the Earth, introducing an additional modification of the light characteristics. In addition, the Earth's atmosphere is largely heterogeneous and, because of local cloudiness, dustiness or haze, the lighting can be subject to high fluctuations. For this reason, the actual lighting and the amount of solar energy reaching an area per unit of time may be quite different due to local atmospheric conditions.

All described phenomena have a direct impact on the size and distribution of energy reaching the surface of our planet. It is obvious that these changes are greater the longer the route of the light beam in the atmosphere. That is why, for the sake of comparison, standard STC lighting conditions have been introduced, used to determine the spectrum of sunlight seen at different latitudes. The unit determining the position of the receiver on the surface of the Earth and the length of the light's route through the atmosphere, depending on the latitude, is the AM (air mass) coefficient. To calculate its value in a place, use the relationship 1, explained in the figure below.

$$AM = 1/\cos\theta \qquad (1)$$

Where: θ - minimum angle between the direction of incidence of light and the normal angle

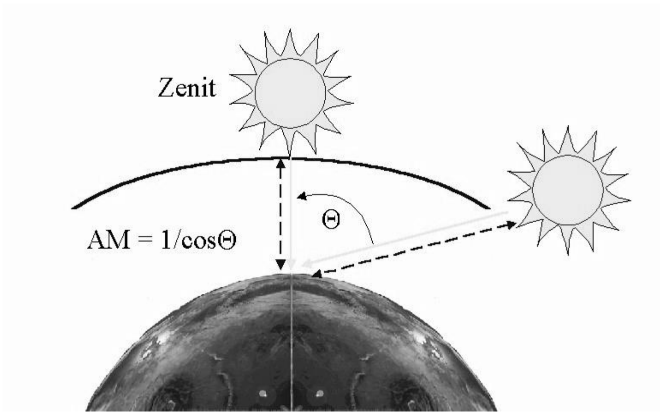


Fig. 3. The method of determining the AM coefficient depending on latitude
Source: The author's own study.

One should point out that angle θ is the minimum angle obtainable in the northern hemisphere at noon on the longest day of the year. It is easy to see that the AM coefficient defined this way can reach values from one at the equator to infinity at the poles. In addition to these values, a special case of AM = 0 has been introduced, describing the conditions of insolation in space. The AM coefficient is widely used for comparison for different devices which convert solar energy, whereas AM = 1.5 has been adopted as the universal value, corresponding to the latitude of 48^{o}, which is also typical for Poland. The changes introduced by the Earth's atmosphere in the solar radiation characteristics for high AM coefficients are very high, as shown below.

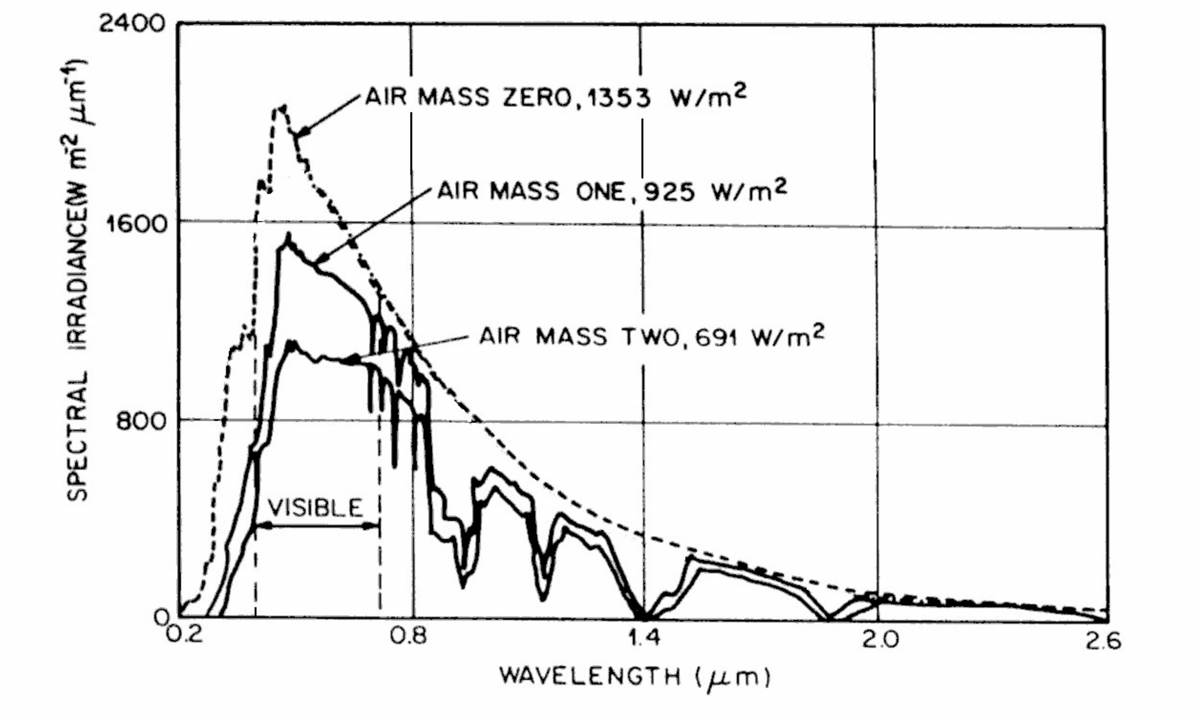


Fig. 4. The characteristics of solar radiation for different values of the AM coefficient
Source: [13]

In addition to the significant reduction in maximum power, there are numerous discontinuities, the main sources of which are atmospheric components such as ozone (ultraviolet), water vapor and water (visible and infrared range), and oxygen and carbon dioxide (near and far infrared).

In conclusion, the actual insolation conditions in Poland, as determined by the value of the Air Mass coefficient, are AM = 1.65 on average. To determine the real value of insolation in a region, the local conditions that contribute to reducing the transparency of the atmosphere should be considered. The measured values of solar radiation power, based on research by the Institute of Meteorology and Water Management, are presented in the following map.

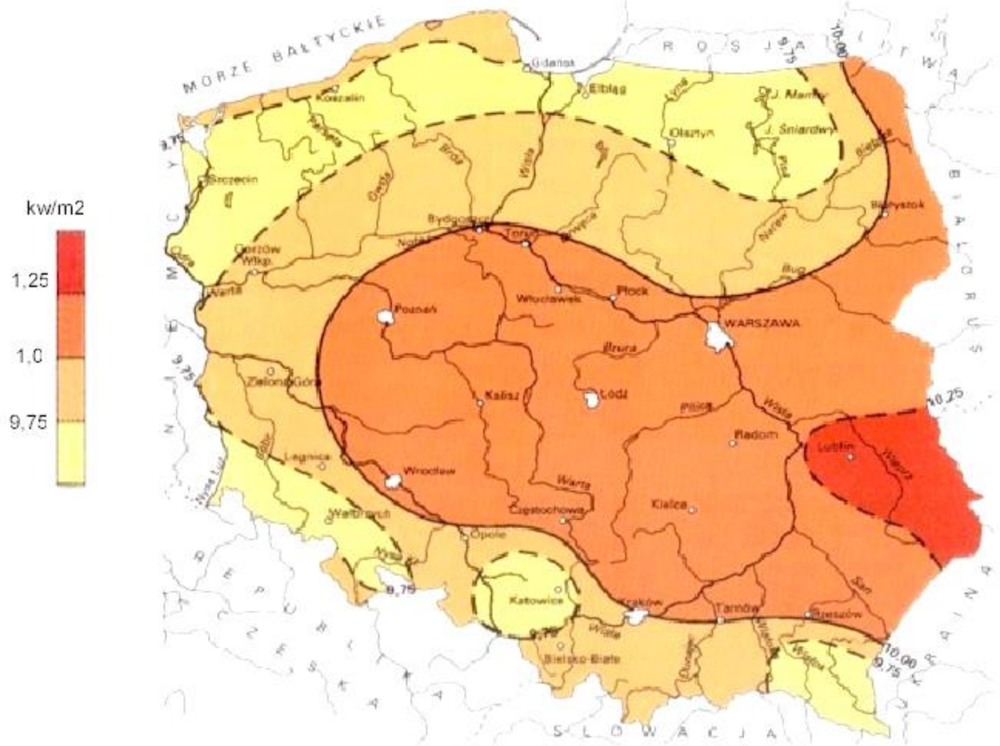


Fig. 5. Map of insolation conditions in Poland
Source: [15]

Based on the results presented, one can estimate the amount of available solar energy for the installation located in the Łódź region. Analysis of local conditions leads to the following conclusions:

- The AM conditions for Łódź based on location (latitude: 51.7, 19.4) amount to 1.61;
- Taking the above data into account, the total power density of solar radiation equal to 1.01kW/m^2 is obtained (with the use of direct and diffused radiation);
- The measurements show that the local atmospheric conditions did not significantly change the value calculated based on geographic data;
- Assuming a solar module efficiency of 18% (polycrystalline silicon) and a total system efficiency of 15%, a total usable power density of 181.8W/m^2 and an actual density of 151.5W/m^2 is obtained.

To select the appropriate geographic orientation and the angle of inclination of the photovoltaic installation, an analysis of the effect of the orientation on the efficiency of the modules, depending on the path of the apparent solar shade in different seasons of the year, should be conducted. The results of such an analysis for the summer and winter seasons are shown in the chart below.

Czerwiec – June; Grudzień – December; Kąt nachylenia – Angle of inclination; wschód – east; orientacja – orientation; zachód - west

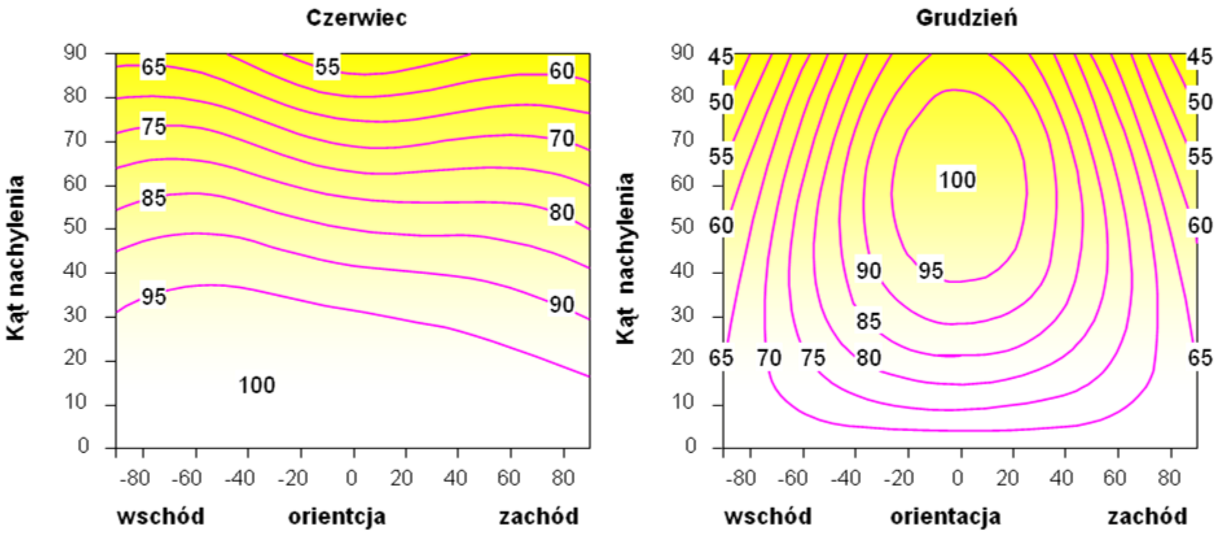
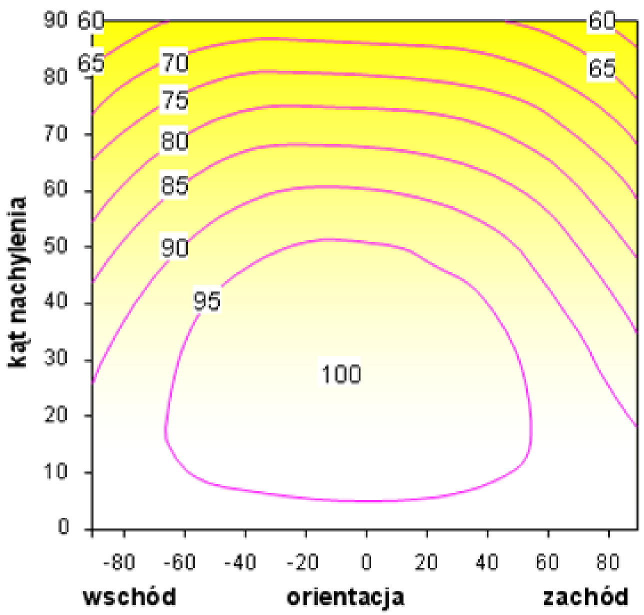


Fig. 6. The influence of the orientation of the solar modules against cardinal directions and their angle of inclination on the relative energy efficiency of photoconversion for Łódź in the summer and winter period
Source: The author's own study.

The calculations show that to achieve the highest efficiency of solar cells in summer time, the modules should have a south or south-eastern orientation, and the angle of inclination should be from 0° to 30°. In winter, the most favorable optimum angle of inclination is 60° and the most favorable orientation is the southern direction.

Assuming a constant system orientation, based on the presented data, one should calculate the average annual, the most favorable optimal orientation of the modules. For that purpose, both cases presented above should be considered in relation to the amount of energy supplied during the summer and winter season. The results of the average annual calculation for Łódź is presented in Graph 5.



Graph 5. The average annual influence of the orientation of the solar modules against cardinal directions and their angle of inclination on the relative energy efficiency of photoconversion for Łódź
Source: The author's own study.

The calculations show that the most favorable annual average orientation of the solar cells in Łódź can be obtained by orienting the installation in the southern direction at 30° angle. Such module mounting also satisfies the self-cleaning condition that pollutants would be washed away by atmospheric precipitation. This significantly increases maintenance-free performance and improves the efficiency and lifespan of the installation. At the same time, it should be borne in mind that the most important factor stimulating the increase in the use of renewable energy sources is the ability to reduce costs and reap the benefits of energy generated by these devices. To find out whether photovoltaic power plants are cost-effective, it is important to analyze the theoretical profit balance in detail, and as a result analyze the time of return on this type of investment in an area.

The first step is to indicate the price of building a solar power plant in Poland. For this purpose, the data collected from the websites of selected photovoltaic device distributors [15] were collected and analyzed, as shown in Table 1. As can be seen, device prices per Watt oscillate between PLN 5 and 12, and the average from the data presented is about PLN 8. In comparison, with the current price list for photovoltaic modules in the world, in April 2012 these figures were € 0.99 in Germany, € 0.71 in China and PLN 4.05 € 0.98 in Japan per watt (on average PLN 3.68 - € 0.89), which based on the exchange rate from 24.10.2012, respectively amounted to: PLN 4.09, 2.93 and 4.05.

Table 1. Price comparison of photovoltaic modules in Poland in 2012.

Nazwa firmy	Działalność	Typ modułu	Model	Cena za 1W w PLN
Renvolt	Dystrybutor	Polikrystaliczny	-	5,24
Eco Technologies	Dystrybutor	Polikrystaliczny	Moduł fotowoltaiczny Yingli YL240PT-29b 240W	9,02
Eco Solar	Dystrybutor	Polikrystaliczny	IBC PolySol 240MS, 240W	8,66
Solar Shop	Dystrybutor	Polikrystaliczny	Suntech Power, 120 W	11,98
Solar Systems	Dystrybutor	Polikrystaliczny	Bateria Słoneczna 230Wp German Solar Poly	6,08
			Średnia cena	**8,19**

Source: [16].

The next stage of the analysis is the calculation of the revenue generated by the actual photovoltaic installation located in a company within the country. To obtain this value, one should calculate the actual amount of energy produced by a photovoltaic power station at local conditions. With the weather data and the average efficiency of crystalline silicon modules, it can be calculated that a 1kWp PV installation in Poland can produce an average of 925kWh [17] per year. Currently, the price that can be obtained from the sale of 1kWh consists of two components. The first is the average price of energy in the market from the previous year (in 2011 - PLN 195.32). One should add the value from the sale of the green certificates (PLN 286.74) to this amount. Summing up both, the price of purchase of energy from renewable sources in 2012 amounts to PLN 482.06/1MWh (in euros: € 111.59) [18].

Based on this data and on the return periods of photovoltaic installations in other European countries, an analysis has been developed showing the changes in the actual time of return on the photovoltaic investment in Poland, Spain, and Germany and is pictured below.

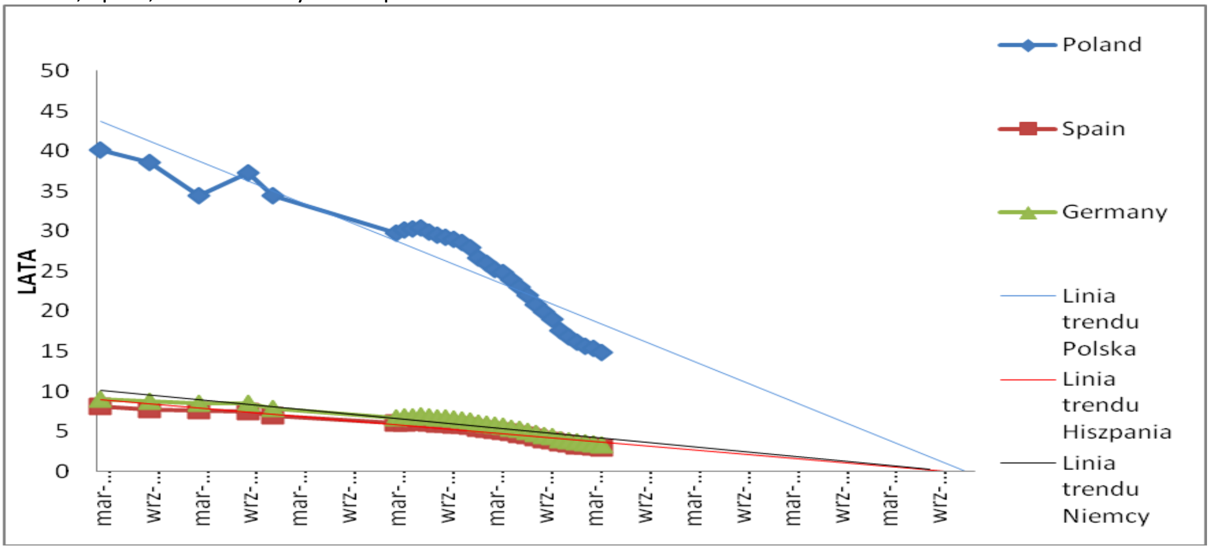


Fig. 7. Change of the return on investment period regarding photovoltaic installations in Germany, Spain and Poland in the years 2005-2014
Source: [15]

Based on this analysis, it can be observed that although there are still significant differences in the return on the investment in photovoltaic installations between Western European and Polish countries, these conditions are becoming more even each year. Due to the decline and leveling of prices, widespread availability and increased ease of implementation, the photovoltaic installations in Poland should bring returns like the installations in Western countries within a couple of years. At present, the time of the return on photovoltaic investment is already almost twice as short as its average life expectancy, which in the long run guarantees profits for companies and individual investors. The above installation does not consider the possible and soon-to-be-changed legal regulations, additionally working to the benefits of photovoltaics.

The analysis of the potential of a milk processing plant to meet its energy needs using photovoltaic sources

Considering the above, it is necessary to emphasize the unique profile of the production of a typical photovoltaic installation, which is especially predisposed for industrial applications, including in the processing and dairy industries. Due to the typical daily lighting in moderate climates, photovoltaic systems are particularly advantageous in compensating the shortages of electricity in the daily cycle, with the highest production in the so-called "energy peak". The research carried out at the Department of Semiconductor and Optoelectronic Devices of the Polish Academy of Science and Technology in the years 2005-2013 for various types of solar cells confirms the favorable distribution of electricity production from photovoltaic sources. Based on the measurements of four types of photovoltaic modules composed of polycrystalline silicon, ribbon silicon, amorphous silicon, and indium-copper diselenide, the highest PV energy production from photovoltaic sources was observed between the hours of 8:00 and 18:00 in the summer. This is the so-called energy peaks period, including increased demand during the operation of most food processing plants. Exemplary graphs for the distribution of electricity production from a photovoltaic installation located in the Łódź region in the summer are shown in Figure 8a. In winter, an almost normal distribution is observed, with an average value in the early afternoon and much lower variance, as depicted in Figure 8b.

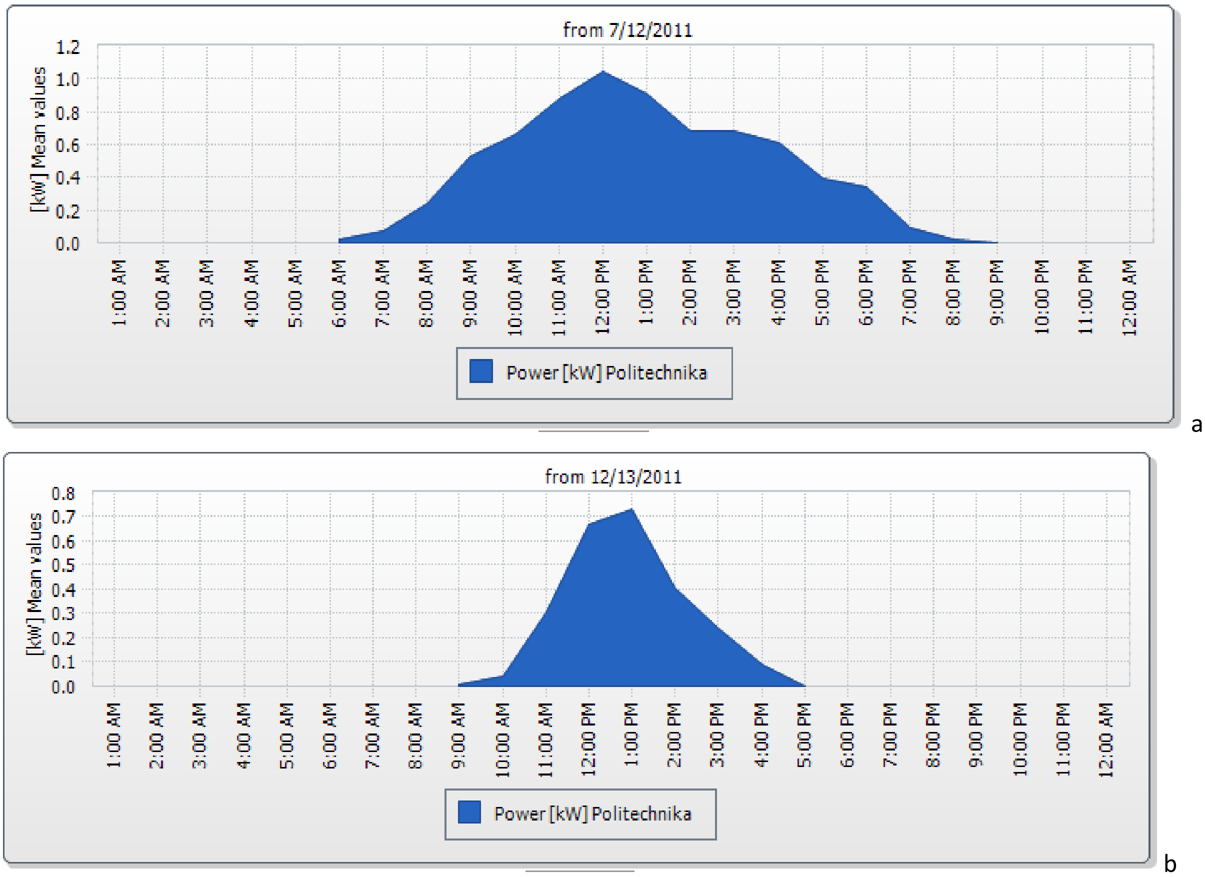
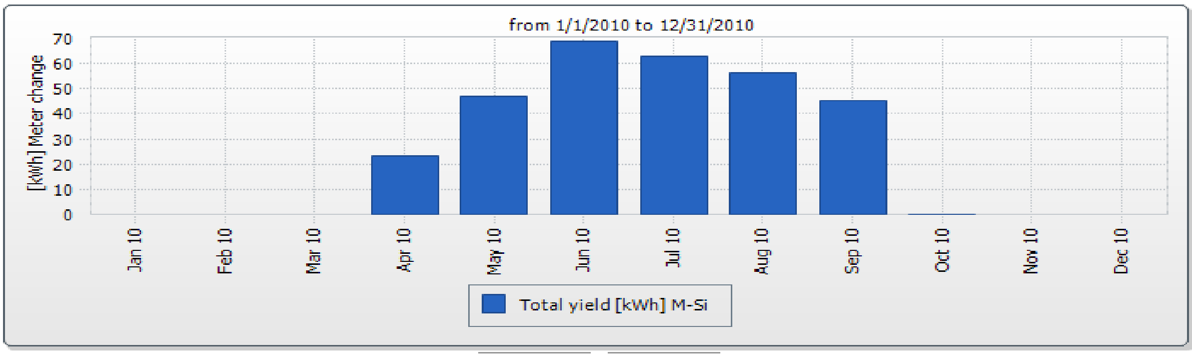


Fig. 8. Typical daily photovoltaic energy generation cycles in the summer (July) (a) [7] and in the winter (December) (b)[2]

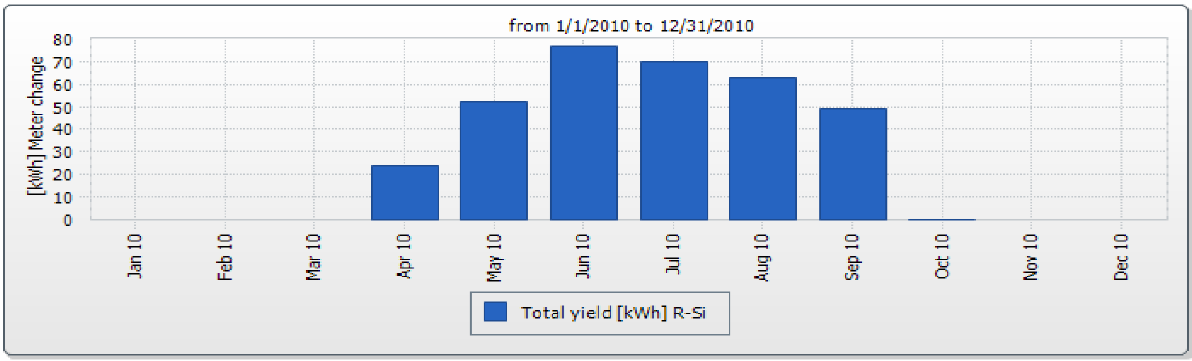
Source: [7] and own research

Also, the annual production of photovoltaic energy is tailored to the needs of food processing companies due to the increased consumption of electricity in the summer when chillers are in use. Examples of averaged distributions of photovoltaic power generation for selected types of photovoltaic installations are shown below.

[2]The results are averaged over four types of photovoltaic cells: a-Si, c-Si, ribbon Si, CIS.



a



b

Fig. 9. Exemplary results of generation of energy from photovoltaic sources based on polycrystalline silicon (a) and ribbon silicon (b)

Source: [7] and own research

Observing these dependencies, as well as considering an out-of-town location far from power lines, practical use of photovoltaics to power the dairy processing plants should be considered. For this purpose, it is reasonable to examine the actual energy needs of dairy facilities.

Because of the internship research conducted, the data on actual electricity consumption in individual seasons of the year were obtained along with the exact distribution of daily electricity consumption. Data of this kind, although usually difficult to obtain, are a very valuable source for energy consumption analysis, and thanks to their accuracy enhance the potential matching of the actual photovoltaic installation project being prepared. At the same time, thanks to the cross-cutting nature of the measurements, information on the average demand of enterprises in a sector can be obtained, which gives the opportunity to develop universal technological solutions that are tailored to the actual energy needs of the customers.

The first step in the measurements was to check the average annual distribution of electricity consumption in medium-sized dairy facilities. The data thus obtained is depicted below.

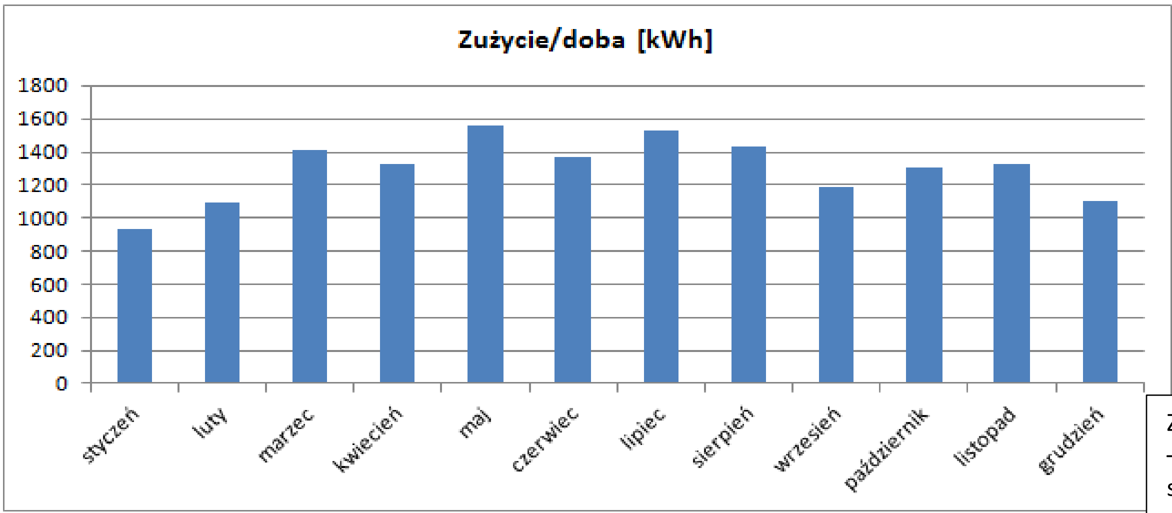


Fig. 10. Distribution of the electricity consumption of a medium-sized dairy facility on an annual basis
Source: The author's own study.

Zużycie/doba – Use/day; styczeń…grudzień – January…December

The obtained data provided a preliminary confirmation of the nature of the distribution of electricity consumption with the peak in the spring-summer period, with an annual variation of about 40%. To obtain precise demand values in the period under investigation, a statistical analysis of the instantaneous data from the electric energy loggers was required. On this basis, the output data for the preparation of a photovoltaic power plant project was obtained. The preparation of the right components of the photovoltaic system, matching them to the needs of a given consumer, the manner of connection to the supply network, the conditions of supply and consumption, and finally the integration with the building or other supporting structure essentially affect the technical and economic parameters of the investment. For this reason, the first, necessary stage of an investment involving photovoltaic installation is a proper multi-stage design process.

The initial assumption was to prepare the design of an energy distribution installation covering 100% of the annual electricity demand in the dairy facility, without considering the potential consumption of the designed biogas reactor. The following output data was used at the preliminary stage of the design:

- Cumulative annual consumption for 2012 (December 2012 - approximation): 481 MWh;
- Maximum monthly usage: 48.329 MWh (May);
- Minimum monthly usage: 28.892 MWh (January);
- Maximum spread: 39%;
- Schedule: pursuant to the logs;
- Assumptions: Location - Łódź region;
- Conditions of insolation: AM1.5;
- Assumed average solar power of 1000W/m^2;
- Suggested system power: 450 kWp;
- Technology: Polycrystalline silicon;
- Mounting method: on grounds optimized with respect to the volume of energy produced.

Based on such assumptions, the photovoltaic installation was initially dimensioned. Dimensioning is one of the most important steps in designing and should be done using professional CAD tools. The basic criteria for dimensioning a photovoltaic installation are, in addition to the geographical location and available space, the conditions of its shadowing, or partial shadowing, and the financial conditions. The assumed peak power and the available area of the modules is usually used as a criterion for selecting specific modules. In some cases, the preferred execution technology may also impose the choice of specific products. By using larger modules, one will usually get lower installation costs; however, such a solution can result in reduced installation possibilities. In general, the total number of modules is determined by the ratio of the total power required and the module's peak power, considering the total system losses.

The PVGIS (Photovoltaic Geographical Information System Geographical Assessment of Solar Resource and Performance of Photovoltaic Technology) was used for the initial dimensioning and estimation of the parameters of the photovoltaic system. It is also a scientific, demonstrative program, and a tool for supporting the development of RES and the idea of distributed generation of energy based on real data, obtained from measurement units in Europe and North Africa. Using this tool, data of great compliance with the design assumptions (Table 2) were obtained through appropriate dimensioning and preparation of the installation design, while the full energy distribution of the project is presented in Table 3.

Table 2. Basic PV installation data - the PV GIS project

Nominal power	**450kWp**
Type of modules	Crystalline silicon
Temperature losses	7.5%
Reflective losses	3%
Energy processing losses	14%
Total losses	22.8%
Azimuth	0º
Inclination	35º

Source: The author's own study.

Table 3. Summary of basic power engineering data of the PV GIS project

Fixed system: inclination=35°, orientation=0°				
Month	E_d	E_m	H_d	H_m
Jan	427.00	13200	1.11	34.3
Feb	761.00	21300	2.02	56.6
Mar	1130.00	35000	3.08	95.6
Apr	1450.00	43400	4.13	124
May	1760.00	54400	5.22	162
Jun	1620.00	48700	4.89	147
Jul	1710.00	53000	5.18	161
Aug	1600.00	49700	4.81	149
Sep	1190.00	35800	3.45	104
Oct	951.00	29500	2.66	82.3
Nov	485.00	14500	1.30	38.9
Dec	307.00	9520	0.80	24.8
Yearly average	**1120**	**34000**	**3.23**	**98.2**
Total for year		**408000**		**1180**

Source: The author's own study.

The installation designed this way fully covers the entire annual energy needs of the facility, but because of the periodicity of production it does not match actual production-related consumption. For this reason, an attempt was made to match the size and structure of the installation to the identified consumption for its maximum reduction. The second version of the project was based on exclusive production of energy for the needs of the facility, with the best possible match to the current needs resulting from the current business profile. For this purpose, many of simulations were carried out based on the logger data and the meteorological data, and the legal regulations in force. These included:

- Calculating energy demand of receivers considering their specificity, daily distribution, maximum momentary consumption;
- Checking local conditions of insolation, including energy availability at different times of the year and in the daily cycle. At this stage, the geographical orientation of the building and its bearing surfaces should be considered, as well as any possible terrain obstructions that overshadow the planned installation;
- Checking the technical possibilities and the cost-effectiveness of the installation of other renewable energy sources for cogeneration, or the conditions for using the local power grid;
- Checking the storage capacity of electricity;
- Verifying the need for obtaining relevant building permits and terms for a power connection (if planned);
- Calculating of the required size of the photovoltaic installation (so-called dimensioning of the installation) considering the above items.

The issues of cooperation of the installation with the bioreactor-based waste disposal system, as well as the possible storage of energy from the photovoltaic installation, were left as a separate item of the last stage of the research. Because of the simulations conducted, an initial system architecture with a peak power three times lower than the tested initial variant was obtained, assuming 100% coverage of annual energy needs. With its help, a very good adaptation to the energy consumption curves of the facility was achieved in both summer and winter, with almost zero overproduction of electricity. Sample simulation results for the summer period are depicted below.

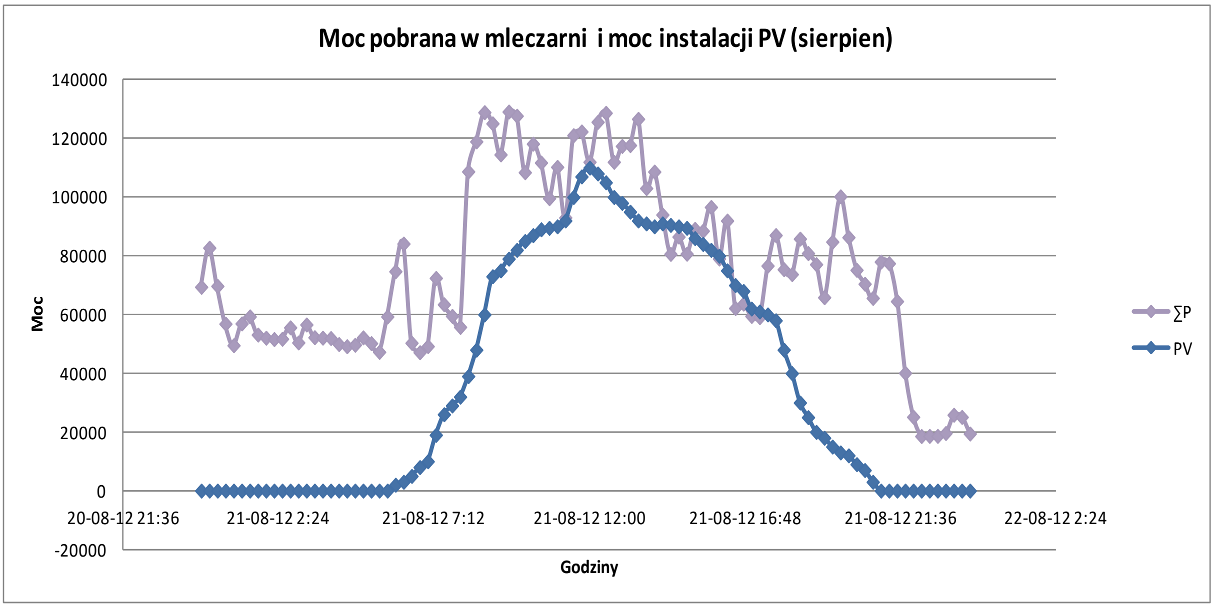


Fig. 11. Power consumed in the dairy and PV installation power (August)
Source: The author's own study.

Moc pobrana w mleczarni I moc instalacji PV (sierpień/grudzień) – Power collected in the diary and power of the PV installation (August/December); Moc – Power; Godziny - Hours

Summer period (data for 21.08.2012). Consumption (instantaneous active power in W) in the dairy based on data from the logger. Simulation of a PV installation with a power of 150kWp - simulation based on measurements from own PV installation (K27 PŁ) and computer calculations.

The obtained results confirm the validity of using photovoltaics to reduce electricity consumption in dairy facilities. The electricity demand coverage at the level of 77% was obtained for the facility during the summer season and at the 30% level during the winter season.

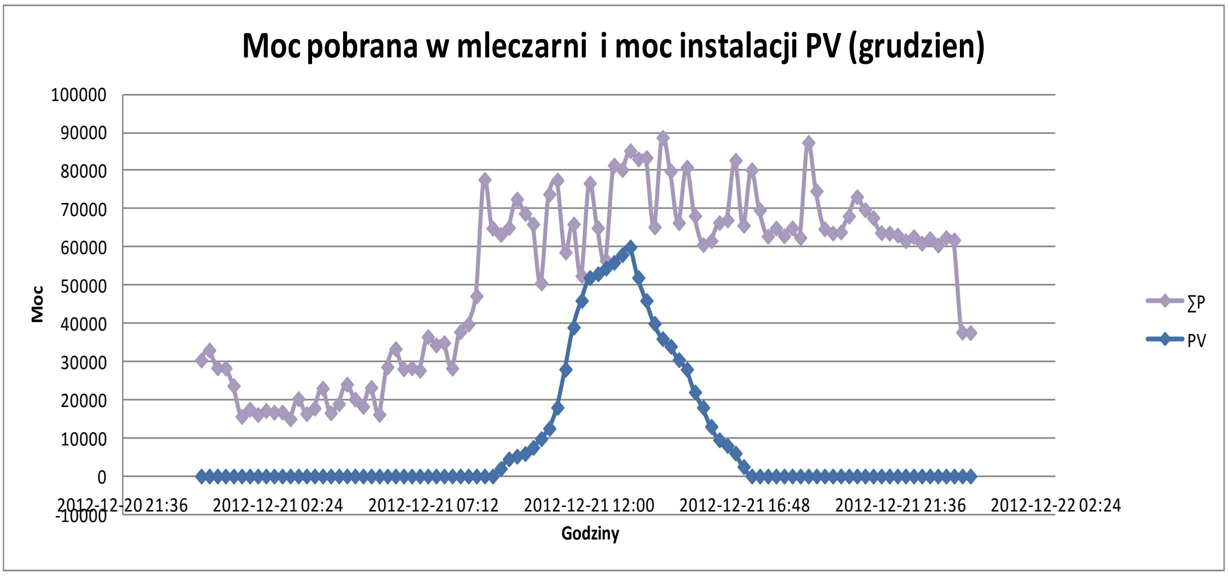


Fig. 12. Power consumed in the dairy and PV installation power (December)
Source: the author's own study.

Winter period (data for 21.12.2012). Consumption (instantaneous active power in W) in the dairy based on data from the logger. Simulation of a PV installation with a power of 150kWp - simulation based on measurements from own PV installation (PŁ) and computer calculations.

It should be emphasized that the solution obtained is fully scalable according to the maximum power used in a facility. With the installation on the ground, one can also to some extent control the position of the average distribution value describing the production of energy in the daily cycle through azimuthal manipulation of the modules. The deviation from the southern direction should, however, not exceed 15^o because of the total amount of energy produced. The obtained results can be used to develop an optimal, scalable photovoltaic installation that meets the operating conditions of a dairy facility, or when using other alternative energy sources.

Storage and processing of energy from photovoltaic sources

A separate issue is the possibility of storing the energy generated in solar cells. In the case of designing photovoltaic installations of greater sizes, energy over-production is unavoidable during certain periods of work. Assuming production for one's own needs, it is not possible to resell surplus energy to a professional network. For this reason, it is advisable to consider the possibility of storing energy and using it during periods of production shortage from photovoltaic sources. Due to the large mass, low energy density, additional safety requirements, and the need to frequently replace acid batteries, their use is not intentional in the solution being prepared. With only slightly better operating parameters, gel batteries with adjustable valves also fail to meet the requirements of the project.

A modern and increasingly popular method of using biomass is the production of liquid biofuels. One of the energy carriers used at present is hydrogen. Hydrogen production can take place via water electrolysis, which is a well-known and easy to use method for practical application due to the easily accessible substrate. This is an energy-consuming method, so it is not very efficient in energy conversion systems. Another technique is the production of hydrogen from organic substances, such as hydrocarbons processed in dairy waste utilization. The use of a reformer is much more energy efficient and additionally contributes to the efficiency of post-production waste utilization. The hydrogen thus obtained can be used to store the energy produced in a photovoltaic installation for periods of reduced solar energy availability. For producing electricity from hydrogen, a fuel cell system is envisaged in the project.

The cell is a device that produces electricity in an efficient and totally environmentally-friendly manner. The principle of its performance as fuel is shown below.

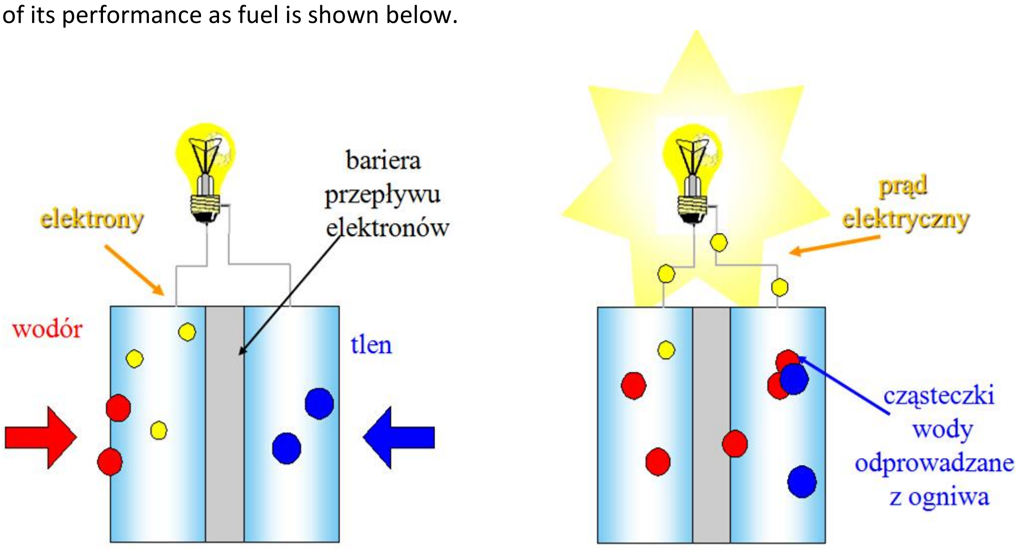


Fig. 13. Fuel cell operation diagram
Source: study based on [4]

Elektrony – electrons; bariera przepływu elektronów – electron flow barrier; wodór – hydrogen; tlen – oxygen; prąd elektryczny – electrical current; cząsteczki wody odprowadzane z ogniwa – water particles discharged from the cell

The production of electricity in a fuel cell is carried out in a multistage manner. In the first step, various hydrocarbons depending on the type of reaction such as CH_2, water and O_2 oxygen are passed through a substance known as a reformer to obtain H_2, hydrogen, carbon dioxide and carbon monoxide. Water is then added to these components. Carbon monoxide is converted to carbon dioxide and water is produced. In this way, hydrogen is prepared as a fuel for the cell, whereas carbon dioxide is disposed of as waste gas. In a catalytic reaction taking place in the fuel cell, the hydrogen breaks down into protons and electrons. The protons penetrate the barrier immersed in the electrolyte inside the fuel cell, while the electrons generate electricity when flowing through the outer conductor. Then in the second part of the cell, the hydrogen electrons and protons recombine with oxygen to form water. Thus, the byproducts of the cell work are only water and heat. It is therefore highly advisable for the designed photovoltaic installation to be supplemented with a hydrogen capture module and a fuel cell to improve its efficiency, increase the plant's energy independence, and streamline the process of dairy waste utilization.

Below is an example of a dairy's power system using a 150kWp photovoltaic system, a reformer, an electrolyser, a hydrogen tank, and an independent electrical load, constructed using the Hybrid Optimization System (HOMER) simulator.

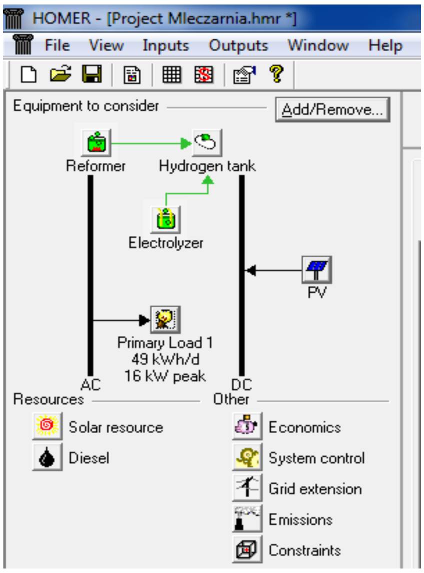


Fig. 14. Diagram of the dairy power system using photovoltaic sources and a photovoltaic installation

Source: The author's own study.

Conclusion

The research presented shows the great potential of using photovoltaic installations in dairy production companies. The paper considered the involvement of photovoltaic installations, both as additional energy sources, improving energy efficiency by reducing the facility's consumption, and an element of a brader power engineering system, including also the utilization of dairy waste. Based on a year-long study of actual electricity consumption profiles in a dairy facility, the demand for electricity was determined according to many factors related to the operation of the production equipment and the mode of operation of the facility. A scalable photovoltaic installation model has been developed, working exclusively for the needs of the dairy facility and meeting up to 77% of its demand during the production period.

In addition, a fuller integration with the dairy waste disposal system was proposed, not only by meeting the potential energy needs of this system, but also by converting chemical to electrical energy using the hydrocarbons derived from the decomposition of organic particles. Using a fuel cell installation, described in a separate chapter of the monographs, the possibility of efficient, long-term storage of electricity was obtained. In this way, both the flexibility of the facility's power engineering system and the improvement of post-production waste management were increased. One also considered the possible integration of the system into the global power grid in the context of new legislation on renewable energy sources.

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USE OF PHOTOVOLTAIC INSTALLATION FOR THE IMPROVEMENT OF ENERGY INDEPENDENVE OF A DAIRY FACTORY EQUIPPED WITH A BIOGAS REACTOR

Abstract
The article presents the role of photovoltaic installations in improvements of energy independency of a dairy factory, which is equipped with a biogas reactor. The main elements of the article are the development of photovoltaic technologies to broader usage of solar cells in Poland, and the storage and conversion of photovoltaic sourced energy. There is also an attempt undertaken to analyze the possibilities of fulfilling the energetic needs of a dairy factory using photovoltaic sources.

Key words
photovoltaic installations, photovoltaic technologies, storage and conversion of energy from photovoltaic sources, dairy factories