Photovoltaics in horticulture as an opportunity to reduce operating costs. A case study in Poland

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Abstract. Fruit farms can become prosumers - producers of electricity for their own needs, without the possibility of selling overproduction. The subject of the study were the costs of electricity in fruit growing. The paper presents a research hypothesis that reads: Agriculture - Polish orcharding can contribute to an increase in the share of energy produced from renewable sources. The aim of the study was to determine the impact of installed photovoltaic panels on the cost of fruit-growing activities. The research methodology was based on a case study. An orchard farm producing apples and peaches on a total area of 33 ha was presented. The costs of fruit growing were developed and the share of electricity consumption costs was indicated in them. Studies have shown that a return on investment in photovoltaic panels is possible after about 8 years. Energy costs account for around 6% of the cost of an orchard. Installing photovoltaic panels on the roofs of cold stores will reduce these costs by half. The main conclusion of the study is that the costs of electricity consumption can be reduced in Poland as a result of the use of photovoltaic installations, provided that you receive financial support from the state or other institutions, e.g. in the form of subsidies or exemption from agricultural tax.

1. Introduction
Storing fruit in cold stores increases the level of operating costs, in particular due to the power consumption to drive refrigeration equipment. Coolers are not the only source of power consumption. Electricity is used to drive devices or sorting lines, to charge batteries in forklifts or ordinary, everyday use, and in some farms to irrigate orchards [1].

The fruit-grower uses electricity for his own needs, which he buys on the basis of a contract with the energy company. Poland has pledged to reach a 15% share of renewable energy in gross final energy consumption by 2020 [2]. The inclusion of fruit growers in the production of electricity may contribute to the fulfillment of obligations. However, the question arises whether the costs of fruit growing can be reduced without harming the environment, e.g. by installing solar panels?

In 2018, when peak power demand was 23,245 MW, power plants were unable to produce enough energy to meet demand. There was no electricity in Poland.

The paper presents a research hypothesis that reads: Agriculture - Polish orcharding can contribute to an increase in the share of energy produced from renewable sources [3].

Interaction studies between the economic, environmental and social dimensions of research on sustainable supply chain management have gained in importance in recent years. However, little
attention was paid to the production of renewable energy produced by fruit growers. Identification of the research gap allowed the purpose of the research to be determined.

The aim of the study was to determine the effect of photovoltaic panels installed on the costs of the orchard.

In spite of apple being an important product, there are few literatures analyzing problem of solar energy in apple farm. Jinwon Bae, Sandy Dall’erba, provides an input-output analysis applied to the characteristics of the Topaz Solar Farm, a 550MW facility built in California between November 2011 and November 2013 and running at full capacity since then [4]. It is an interesting case study because on the one hand in that it is the world’s largest solar farm and its utility scale generation is expected to grow more than commercial and residential solar panels. On the other hand, the installation is so large that it cannot be a comparative installation for Polish micro-installations. According to the report of the Institute for Renewable Energy 'Photovoltaic market in Poland 2018', the total installed capacity in May last year was about 300 MW (and about 30,000 solar systems, including to a large extent micro installations not exceeding 40 kW), which accounted for almost 3.5 percent of the mix renewable energy sources [5].

Solar energy is seen as a major source of carbon emission and water consumption reduction. Lately considered pumping water with using solar energy. The study of Senol, Ramazan (2012) has focused on small and medium-size mobile applications using energy and water conserving forms of drip irrigation to apple orchard on up to 0.5 ha of land in Egirdir District [6].

2. Materials and research methodology
The analysis was based on primary empirical data obtained from the period 2012 - 2018 from an orchard farm located in the Lower Silesian Voivodship. The farm, with a total area of 33 ha, produces apples and peaches. Plantings account for 90% of the area, 10% are land prepared for new plantings. Peaches are grown on the farm - on 6 ha and apple trees on 24 ha (on M9 -18 ha dwarf and M26-dwarf rootstock - 6 ha), the others are meadows. Planting density depends on the type of rootstock used. Apple orchards planted in 1994 at 4.0 m x 2.5 m spacing are 4 ha, the rest are young plantings at 3.5 m and 1.5 m spacing. Peach quarter was established in 2004. The farm in Poland belongs to the least numerous group of entities with the largest orchard area with perennial crops (0.5% of farms have over 20 ha of fruit from trees, which constitute 20% of the area) [7].

The farm has two buildings, serving as fruit storage and sorting, the so-called controlled atmosphere refrigerators. The first was built in 1982 with an area of 372 m², the second in 2002 with an area of 780 m², with a total capacity of 520 tons in KA. The capacity of cold rooms is not sufficient for the harvested harvest. The harvesting season begins in July with the peach harvest, when the cold rooms are empty. Two of the six chambers are used until the middle or end of August for storing peaches. From August, the use of two chambers for storing summer apples begins.

In September and October the process of filling all remaining chambers with harvested apples is underway. Depending on the weather conditions, this process can last until the first days of November [8]. The farm is equipped with four tractors and two sprayers (orchard and field).

In the course of the study, the structure of the cost of fruit-growing activities was calculated in 2018. The farm is not obliged by any law to keep records, it is not a VAT payer. The taxpayers of this tax are also not their owners, therefore the cost analysis includes gross amounts, except for one case, together with the tax on goods and services [9]. As the farm did not keep detailed and separate records of production costs incurred for the production of peaches and apples, fruit cultivation was adopted as the production cost reference unit.

The consumption and prices of electricity were determined and compared in the years 2012 to 2018. It was proposed to install 50 kWh fotovoltaic panels on the roof of the cold store building for electricity production, whose area on the west side is 500 m². The net present value (NPV) was used to calculate the investment effectiveness and payback period [10]. The profitability of the investment was calculated using the average cost of electricity (cost per 1 kWh) method.
3. Results and Discussion
In the examined orchard, which produces dessert fruit, the costs of fruit growing are shaped to the greatest extent by the wages of people entrusted with performing work in the field, and not the consumption of electricity. The works carried out by the recipient consist in protecting the orchard against pests, diseases, frosts and drought, mechanical thinning of buds, summer cutting of trees, harvesting and winter cutting [11]. Wages during the period considered were around 32%, and if other personnel costs related to the provision of protective clothing, medical examinations and drinking water are taken into account, the total personnel costs are 41%. Plant protection products, including fungicides, insecticides, adjuvants, mineral and foliar fertilizers, herbicides and protection against rodents account for 19% of the total cost [12, 13].

In 2018, electricity consumption amounted to PLN 44,232, which represents 6.4% of the cost of the orchard. Over the period considered, electricity consumption was at a very different level. One can point to a slight increase in electricity consumption, and thus also an increase in fees for this consumption.

The highest electricity consumption in the period considered (the highest demand for electricity) was in 2018 and amounted to over 93 374 kWh. The lowest was in 2013 and reached the level of 57 006 kWh. Changes in electricity consumption also resulted in changes in the amount of fees paid.

There were changes in electricity prices per 1 kWh during the period under review. Unit costs of electricity consumption were determined on the basis of prices paid to the seller and distributor and the amount of electricity consumed in two time zones.

Energy consumers pay fees for obtaining it in PLN / kWh. The fees include the price of electricity, reflecting the costs of obtaining it, and fees related to transmission and distribution (variable and fixed). Additional fees, i.e. commercial, permanent, transitional and subscription distribution fees are settled in PLN / month.

Weighted average prices are not average annual electricity sales prices on the competitive market, which are set by the President of the Energy Regulatory Office [14]. The average annual electricity sales price on the competitive market in 2018 was 194.30 [PLN / MWh]. These are the prices paid to the seller for the electricity consumed and to the distributor for the service of supplying it. Electricity sale agreement - an agreement concluded with the Seller, specifying mutual rights and obligations related to the sale of electricity to the Customer. Contract for the provision of distribution services - an agreement concluded with the DSO specifying mutual rights and obligations related to the provision of electricity distribution services to the Customer. The first of these was negotiated with the seller throughout the period considered, while the second was not. The lowest prices occurred in 2017, the highest in 2014. The weighted average price from 2018 approached the level of prices in 2012. Despite the increase in electricity consumption costs in 2018, the weighted average price was low due to high kWh consumption.

The researched farm is a consumer of electricity, belonging to the C12a tariff group.

The marking of the tariff group with the letter "C" indicates the voltage level of the network from which electricity is supplied to the farm and this is the low voltage (nN) level. The digit "1" means a power of not more than 40 kW and the rated current of the pre-meter protection in a current circuit of not more than 63 A. The next digit "2" indicates the number of billing time zones, in this case two zones. The letter "a" in the tariff group "C" means the division of the day into zones: peak and off-peak.

Orchard - farmer - purchasing electricity for his own use is not treated as the final recipient, because in farms electricity collected for production purposes (e.g. greenhouses, cold stores, piggeries, mushroom farms) is accounted for on the basis of separate measurement and settlement systems, at prices appropriate for tariff groups B and C.

Electricity purchased for the purposes of its consumption for the purposes of generation, transmission or distribution from farmers is not included for its own use.

Consumers consuming electricity for the needs of households and utility rooms are included in the group "G". Therefore, group G does not include recipients with agricultural holdings, equipped with three-phase installations, drawing electricity for production purposes, e.g. greenhouses, cold stores,
piggeries, mushroom farms, whose consumption is calculated on the basis of separate measurement and settlement systems.

The time zones used in settlements with recipients of C12a tariff groups are presented in Table 1.

| Months                              | Zone I Peak zone | Zone II Off-peak zone |
|-------------------------------------|------------------|-----------------------|
| from 1 April to 30 September        | 8.00 - 11.00 and 20.00 - 21.00 | 11.00 - 20.00 and 21.00 - 8.00 |
| from 1 October to 31 March          | 8.00 - 11.00 and 17.00 - 21.00 | 11.00 - 17.00 and 21.00 - 8.00 |

A detailed analysis of the current consumption by the orchard showed that the largest consumption takes place in zone II - off peak and is about 80%.

If the consumption of electricity were accounted for in prices assigned to one zone (round the clock), the fruit farm would incur higher costs. For 2018 this would be a 6% increase in costs.

It presents the prices of electricity for 1 kWh for a customer from the C12a tariff group according to the agreement of the seller and distributor. These prices are net prices and do not include fixed, transitional and subscription distribution fees charged by the Distributor.

A detailed analysis of prices allows to draw the conclusion that during the analyzed period the prices of the distributor systematically increased in zones I and II. Seller prices were on a downward trend.

The starting point for the decision to install PV is to determine the climate of the region in which the fruit farm is located. In addition to identifying regions with the highest solar potential, solar energy potential analysis also includes seasonal and annual variability of solar resources. This will determine how seasonal energy production matches demand.

The geographical characteristics of the region or specific location create technical or environmental constraints or even preconditions for the development of a solar plant. The choice of technology is helped by the created maps of generating PV electricity for many options by module type and assembly type. Data is also calculated, such as the optimal angle of inclination for permanently mounted solar systems, such as the exposure of the roof surface relative to the sun, the angle of inclination of the roof slope, the assessment of the roof structure and roofing.

Using the solar calculator Photovoltaic Geographical Information System, developed by the European Union, the region's solar potential and the achievable productivity of the planned investment were checked. The following was determined: location of the town on the world map, installations connected to the network were indicated, the potential of solar energy falling on the farm area and how it would affect production in the sun.

To determine the solar exposure, the most popular Crystalline silicon (PV technology) solar module technology was chosen on the market.

The total potential of solar energy falling on the farm area during the year is shown by the indicator - Yearly in-plane irradiation. In Poland, the insolation is fairly even and ranges from 1050 - 1160 kWh / m² / year. The farm is located in an area where insolation is 1100 kWh / m², and therefore it is one of the best sunny regions of the country (max 1200 kWh / m² south-east of Poland - Lublin Voivodeship).

A small area of land in Poland calculates 3 kWh / m² / day solar radiation, for comparison most areas in the state Arizona record more than 6 kWh / m² / day of solar radiation. The economic impact of a new solar power plant in Arizona: Comparing the input-output results generated by JEDI vs. IMPLAN Jinwon Bae, Sandy Dall’erba.

And how will sunlight affect the operation of a photovoltaic installation, and thus the production of electricity?

Energy potential for location (Yearly in-plane irradiation [kWh / m²]) was set at 1050 kWh / m² and how much 1 kWp installation will produce throughout the year - Yearly PV energy production [kWh]: 802 kWh electricity. Given value is the result of the calculation of the overall energy potential taking into account energy losses, i.e. atmospheric conditions, latitude, roof position and slope (roof position
to the south - roof facing west - Azimuth 90°, roof slope angle - 30°), and specific conditions of PV technology itself.

The figure 6 with breakdown of yields for individual months shows how much energy the installation can produce.

In the spring and summer, the installation can produce the most electricity. The production of electricity at the prosumer solar farm (50 kW) could cover the demand only in three months of the year - March, April and May. In the remaining months of the year, the fruit farm will be forced to buy electricity.

Analysis of electricity consumption in individual months of 2018 (Figure 8) broken down into zones I and II shows that a photovoltaic installation would provide coverage of the energy needs of the first zone from January to the end of September in 100%. In the autumn, from October to December, it would require additional energy to be bought during the summit in zone I.

Due to the lack of data as to how much photovoltaic power plant can produce energy in particular zones, determining how many kWh units the household will have to buy in particular zones is an approximate value. To collect, to be settled, the farm will have 2086 kWh.

The surplus, produced in zone I of electricity and not used, put into the grid is lost, without giving the manufacturer any benefits. This results from the rules of settling the prosumer with the obliged seller.

Settlement of the amount of electricity introduced into the power grid against the amount of electricity drawn from the grid for its own consumption by the prosumer of renewable energy generating electricity in micro-installations with a total installed electrical capacity takes place under the so-called "Discounts" in a quantity ratio of 1 to 0.7.

Electricity introduced into the distribution network in a given time zone and not earlier than 12 months before the date of introduction of energy into the network is subject to billing. The date of introduction of electricity into the network is the last day of a given calendar month in which this energy was introduced into the network, with the proviso that unused electricity in a given accounting period is transferred to subsequent accounting periods, however not longer than for the next 12 months from dates of introduction of this energy into the grid.

If a farm had installed a 50 kW solar plant in 2018, it would have ensured power supply in zone II only between March and May and provided that the fruit farm would give up settling energy consumption in time zones. Having a solar installation in 2018, the farm would have to buy 48772 kWh, which with a weighted average purchase price of 0.488266 PLN / kWh would give electricity consumption costs of PLN 23,814. As a reminder, the actual annual amount of electricity costs in 2018 was PLN 44,232.

In addition, power plants should pay fixed costs, independent of the amount of electricity consumed, which include: 15 PLN commercial fee, 71.04 PLN fixed network, 1.92 PLN transitional, 4.56 PLN subscription fee for each month, which gives a monthly amount gross PLN 113.80 (PLN 92.52 + PLN 92.52 * 0.23) and annual PLN 1366.

Monetary amounts spent on the purchase of a solar installation will pay back after eight years (table 2). The photovoltaic installation is a fixed asset, whose initial value according to the list of depreciation rates can be charged to costs over a period of 5 years, which gives an annual depreciation cost of PLN 45,264. If we accept the warranty period for panels, which is 10 years, then the depreciation amount will be 22632 PLN.

Financial support is provided for farmers, agricultural tax payers investing in solar panels. investment relief. The relief includes the purchase and installation of a solar farm. The amount of the investment relief is 25% of the costs incurred, which means PLN 56580 (PLN 226320 * 0.25). The agricultural tax is reduced by this cost. If the amount of the allowance exceeds the amount of agricultural tax in a given year, then its value will be reduced in subsequent years, but not longer than for a period of 15 years. Thus, if in 2018 the tax amounted to PLN 3166, then the orchard farm could take advantage of the maximum discount of PLN 47490 (PLN 3166 * 15 years).

Summing up the conducted research, it should be stated that after installing 50 kW fotovoltaic panels, the costs of fruit-growing activities will be lower by variable fees for electricity purchase and by
agricultural tax if the farm benefits from the investment relief. The reduction of electricity consumption costs can be approx. 43% (without depreciation of solar panels).

The list of the most important assumptions adopted for the calculations in the article is presented in table 2.

**Table 2. List of assumptions used for calculations**

| No. | Indicator                                                                                                                      | Amount (PLN) | Parameter                           |
|-----|-------------------------------------------------------------------------------------------------------------------------------|--------------|-------------------------------------|
| 1.  | Installation costs (PLN, gross)                                                                                               | 226320       |                                     |
| 2.  | Annual electricity demand for five years (kWh)                                                                               | 75009        |                                     |
| 3.  | Annual production of the 50 KW system - 50,000 kWh * 97%                                                                       | 48500        |                                     |
| 4.  | Energy use for own needs 100% (kWh)                                                                                           | 48500        |                                     |
| 5.  | The cost of electricity 0.4826266 PLN / kWh - an average of 5 years                                                         | 0,488266     |                                     |
| 6.  | Savings resulting from the use of energy for own needs (PLN)                                                                    | 23681        |                                     |
| 7.  | Annual inflation                                                                                                              |              | 2%                                  |
| 8.  | An increase in electricity prices per year                                                                                     |              | 3%                                  |
| 9.  | Payback period for fotovoltaic panels                                                                                        |              | 8 lat                               |
| 10. | Coverage of demand per year compared to 2018                                                                                   |              | 56%                                 |
| 11. | Annual average demand coverage                                                                                                 |              | 63,25%                              |
| 12. | Annual depreciation amount (20%), PLN                                                                                          | 45264        |                                     |

4. Conclusion

Apples may be grown in many parts of the world, but fruit production costs will increase due to the need to insure contractors, watering orchards and high air temperatures. The study was conducted in accordance with the defined research procedure. The obtained results allowed to draw the following conclusions.

During the period considered, costs of electricity consumption did not constitute a significant item in the total amount of costs. This is due to the fact that the farm applied a policy of rational use of electricity in the zones. Expected increases in electricity prices may affect the significance of this item as operating expenses. Changing the production profile, e.g. removing old tree plantings, will affect the lack of demand for electricity in the summer. During this period, however, the demand for electricity used for irrigation of orchards remains. Installing photovoltaic panels is now a high expense. Any increase in electricity prices will shorten the payback period below 8 years. After installing photovoltaic panels, it is required to change the tariff group from two-zone to one-zone in order to collect the produced energy, thanks to which the costs of energy consumption will decrease by about 43%. Conclusion of a comprehensive contract, which customers are forced to, including the provisions of the Electricity Sale Agreement and the Agreement for the provision of electricity distribution services, concluded with the Seller, will deprive him of the possibility of negotiating prices. The selection of a photovoltaic installation set should not exceed the amount of power such that the energy produced during the year does not exceed the annual consumption. The 50 kW solar installation does not guarantee the energy independence of the orchard. After installing solar panels, you cannot opt out of external energy suppliers.

Reduction of electricity costs is supported by investment reliefs. Current methods of determining energy efficiency should be changed/modified and take into account the specific conditions of fruit-growing activities.

The main conclusion of the study is that the costs of electricity consumption can be reduced in Poland as a result of the use of fotovoltaic installations, provided that you receive financial support from the state or other institutions, e.g. in the form of subsidies or exemption from agricultural tax.

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