Perspectives of modern energy storage in miniscule photovoltaic installations

Danuta Olszewska[*,1], *Paulina* Kiełczykowska[1], and *Miłosz* Olszewski[1]

[1]AGH University of Science and Technology, Faculty of Energy and Fuels, Al. A. Mickiewicza 30, 30-059 Kraków

Abstract. In the research work environmental pollution information and idea of solution of this problem through renewable energy sources were presented. The methods of solar energy coversion as well as methods of its storage in lithium batteries were described. The work presents an analysis of energy system: solar panel and energy bank in households. The ecological aspect of this solution was studied. For this purpose, the costs of new single-family house connection to the energy grid and photovoltaic system connection with a modern lithium battery were calculated. Electricity consumption cost estimation within ten years was made and then it was compared to the expenses for connected photovoltaic system with lithium battery. Aim of the study was realized based on the cost of connection to the energy grid and the costs of photovoltaic system connection with Tesla batteries. From the above data one can see that after about 7 years with lower solar exposure level costs of the installation based on renewable energy sources installation will pay off and after that one can only record a profit from storing and producing electricity.

1 Introduction

Environment care has many aspects. This paper attempts to pay attention to the possibility of innovative energy solutions usage in households in Poland, which greatly contribute to the environment degradation. Attention was paid to the most harmed by low emission area in Poland and there were proposed solutions already very popular in the Western Europe.

The usage of photovoltaics/energy bank systems for obtaining and storing energy can be an additional limiting factor for pollution, while investment costs, as in the case of gas-fired furnaces exchange, could be co-financed by local government.

1.1 Environmental pollution in Poland

Air quality at the place of residence is one of the components of the comfort level of human life, therefore air pollution has been a global problem for several years. Poland is the country with the highest air pollution level in the whole European Union. The highest air degradation occurs in Malopolska, especially in Cracow (Tab. 1).

* Corresponding author: dolszew@agh.edu.pl

Table 1 a). PM10 measurements at some areas in EU in 2014. EU daily limit value for particulate matter < 10 µm (PM10): not more than 35 days/year with a daily mean concentration exceeding 50 µg·m^{-3}. Air Pollution Level corresponds to the 36th highest daily mean concentration, based on data [1].Signs: T- Traffic, B-backround, u- urban, s- suburban.

Country (ISO)	City name	Measurement Station		Air Pollution Level (µg·m^{-3})	Country (ISO)	City name	Measurement Station		Air Pollution Level (µg·m^{-3})
		Type	Area				Type	Area	
AT	Wien	T	u	46	FI	Helsinki	T	u	40
AT	Wien	B	u	45	FI	Kuopio	T	u	35
AT	Salzburg	T	u	27	FR	Strasbourg	T	u	48
AT	Innsbruck	T	u	27	FR	Lyon	T	u	46
AT	Salzburg	B	u	26	FR	Grenoble	T	u	43
BE	Antwerpen	T	u	51	FR	Marseille	B	u	41
BE	Brussel	T	u	42	FR	Nice	T	u	41
BE	Mons	B	s	34	GB	London	B	u	34
BG	Sofia	T	u	109	GB	Southampton	B	u	34
BG	Sofia	B	u	102	GB	Leeds	B	u	34
CY	Lefkosia	T	u	68	GB	York	T	u	33
CZ	Kladno	B	u	78	GB	Stockton T.	T	u	30
CZ	Havírov	B	u	75	GB	London	B	u	30
CZ	Ostrava	T	u	69	GB	Eastbourne	B	u	29
CZ	Ostrava	B	s	62	GB	Norwich	B	u	29
CZ	Praha	T	u	61	GB	Newport	B	u	28
CZ	Ústí n. L.	T	u	60	GB	Cardiff	B	u	28
CZ	Praha	B	s	50	GB	Glasgow	B	u	22
CZ	Brno	T	u	48	HU	Miskolc	T	u	61
CZ	Brno	B	u	47	HU	Budapest	B	s	56
DE	Stuttgart	T	u	59	IE	Cork	T	u	34
DE	Berlin	T	u	55	IE	Dublin	B	s	25
DE	Leipzig	T	u	54	IE	Dublin	T	u	23
DE	Cottbus	T	u	51	IT	Avellino	T	u	70
DE	Görlitz	T	u	50	IT	Torino	T	u	67
DE	Berlin	B	u	47	IT	Vicenza	B	u	65
DE	Hamburg	T	u	47	IT	Roma	B	u	54
DE	Rostock	T	u	47	LT	Vilnius	T	u	64
DE	Zwickau	T	u	47	LT	Vilnius	B	u	47
DE	Dresden	T	u	47	LT	Šiauliai	T	u	45
DE	Berlin	B	u	46	LU	Luxembourg	B	u	32
DE	Frankfurt	B	s	46	LV	Riga	T	u	61
DE	Aachen	T	u	46	LV	Riga	B	u	39
DE	Nürnberg	T	u	45	NL	Amsterdam	T	u	40
DE	Dortmund	T	u	45	NL	Rotterdam	B	u	39
DE	Rostock	T	u	45	NL	Eindhoven	T	u	35
ES	Gijón	T	u	51	NO	Oslo	T	u	43
ES	Barcelona	T	u	42	NO	Oslo	T	s	39
ES	Madrid	T	u	38	NO	Trondheim	T	s	38

Table 1 b). PM10 measurements at some areas in Poland in 2014

City name in Poland (in Polish language)	Measurement Station		Air Pollution Level ($\mu g \cdot m^{-3}$)
	Type	Area	
Kraków	T	u	128
Kraków	B	u	96
Górny Śląsk	B	u	102
Górny Śląsk	T	u	85
Nowy Sacz	B	u	96
Łódz	B	u	80
Wroclaw	B	u	66
Poznan	B	u	66
Warszawa	T	u	66
Gdynia	B	u	46
Gdansk	B	u	44
Koszalin	B	u	42
Gdynia	B	u	32

In January and February 2017, elevated concentrations of PM10 particulate matter were noted several times (Fig. 1). It is a mixture of organic and inorganic substances containing toxic polycyclic aromatic hydrocarbons including benzo-(a) pyrene, heavy metals, dioxins and furans. In the Fig. 1 there are compared PM10 values for highly polluted areas of Cracow and Trzebinia suburbs with results for Łomża.

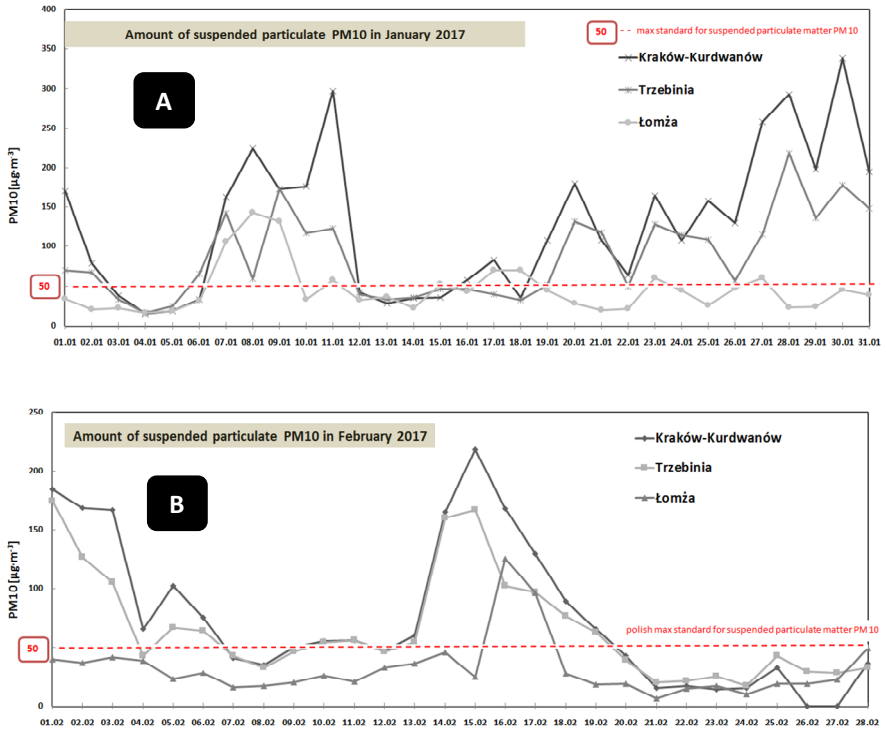

Fig. 1. Amount of PM 10 in January (A) and February (B) in different area of Malopolska region, based on [3].

The last mentioned city is located in the Podlaskie voivodeship and characterizes with low air pollution level. It is commonly called the Poland green lungs [4].

1.2 Eliminating the effects of air pollution from transport

Cracow authorities have taken an action to improve the air quality. One of the elements of smog elimination is 'free communication' introduced by the resolution of the City Council [5] when the average suspended dust PM10 concentration in all measuring stations of the Provincial Inspector for Environmental Protection in Cracow exceeds 150 $\mu g \cdot m^{-3}$. In order to limit car traffic, a person carrying a registration card, not necessarily their car, can travel by public communication with as many people as allowed on the registration card. This causes the car immobilization, however it is not a good solution because it is used the next day after the relevant excess values have been registered.

Due to that it happens that atmospheric conditions on the next day have a significant impact on improving air quality but it is not an effect of limiting private passenger transport. Free public communication has been introduced eighteen times since the beginning of 2017, eleven times in January and seven in February [6].

1.3 Pollution elimination by renewable energy sources application

Air pollution can be reduced by usage of renewable energy sources (short-term RES), which are endless natural resources that can be used to generate energy. Their use is not connected with a long-term deficit since their production processes require short time. Obtaining energy from these sources is more environmentally friendly as it gives an opportunity to reduce CO_2 emission and increase energy efficiency. Furthermore, RES have a significant meaning in terms of climate and energy policy basic goals realization.

The 'National Action Plan on Renewable Energy' from 2010 contained a forecast on Poland achievements by 2020. Renewable energy sources should represent 15% of the final energy consumption [8]. The plan defines the national resources of individual renewable energy sources and the power system state. RES usage will be driven by the use of biomass and wind energy as well as solar energy [7], therefore extensive research on its direct conversion to other energy types, heat energy storage and storage of electrical energy obtained from solar radiation absorption [9]. Poland is located in a temperate climate zone, between 49°00' and 54°30' north latitude. As a consequence, Poland also has an opportunity to generate electricity and heat from solar energy [10].

2 Solar energy conversion usage

Three types of conversion can be distinguished: photochemical, photovoltaic, photothermic. These processes allow the conversion of solar energy into heat or electricity [9]. Photovoltaic conversion allows conversion of solar radiation into electrical energy with the use of semiconductors or so-called solar cells. The photovoltaic cell consists of a silicon semiconducting plate, inside which there is an electrical field in the form of a p-n (positive - negative). The advantages of photovoltaic cell are primarily the direct electricity production without any additional conversion and the possibility to produce power in cloudy days using diffused light. In addition, harmful gases are not produced during electricity generation [7]. Thanks to this, photovoltaics is experiencing intense development. Photovoltaic panels and photovoltaic cells are used in two systems: i) off grid – usually equipped with an electric battery or/and a second energy source in the form of a wind

turbine or thermal engine and ii) grid connected – electricity is delivered directly to the power grid.

The fastest increase in number of installed photovoltaic systems has been observed since March 2015. Such a situation may result from the enactment of the Act on Renewable Energy Sources from RES [11]. The cumulative power of micro-installations in the fourth quarter of 2015 was 31.5 MW. The total power of photovoltaic systems connected to the power grid at the end of the first quarter of 2016 was 119.2 MW. In 2015, 77.2 MW of power was obtained from photovoltaics. Installed 1,585 photovoltaic systems with a total power of 8.8 MW. In Poland by the end of May 2015 installations of off-grid with a capacity of 5.3 MW were instaled [12]. Parts of these installations included energy storage systems. Lithium batteries are already widely used and their operating principles, the materials from which they are made were described in many publications, for example in [13].

Tesla is a global leader in the electric vehicle industry. The same manufacturer has decided to change the power management in the households and change the way it is used. Their offer includes the Powerwall 1 (2015) and Powerwall 2 (2016) batteries, which encourage the storage of the energy produced by solar panels mounted on the roofs and around houses [13]. The Powerwall 1 is a lithium-ion battery, small in size and weight, which is just 100kg, available in both 10kWh and 7kWh. The second one mentioned is more popular, reaching a peak power of 3.3kW and its efficiency is as high as 92.5%. A typical Powerwall 1 system includes solar panels, an inverter for converting direct current (DC) to the alternating current (AC), which powers the home devices. In turn, the Powerwall 2 can be installed inside and outside the building and moreover – on the floor. It is flatter and more rectangular than the previous generation, includes built-in inverter, which lowers the installation costs and requires less space at home to install. It can store 14 kWh of energy and its peak power is estimated at 7kW, which is two times bigger than its predecessor. The manufacturer gives a guarantee for an unlimited number of cycles of up to 10 years. The efficiency of this device in the case of alternating current (AC) delivered from the power plant is 89%, while for direct current (DC) – 91.8% [14]. Powerwall 2 is fully integrated with the inverter. It has installed liquid-cooling system as well as the software that intelligently distributes the accumulated energy. Powerwall 2, like the predecessor can be connected to a photovoltaic system and store the energy produced by the cells, as well as obtaining energy from the power plant.

Tesla Powerwall stores the energy produced by solar panels and energy from the power grid at cheaper tariffs, allows to protect one against power outages due to the fact that it works like an emergency power supply. It is very easy to install and can be installed both inside and outside the building as it characterizes with good working within temperature range from -20°C to 50°C [13]. In Poland, such device would have to be installed inside the building since temperatures below -20°C occur, for example in Cracow 2012 temperature was noted as -23°C and in Bialystok up to -30°C. The another popular currently producers of Lithium-ion Batteries are: Axitec, Pylontech, Mercedes Benz, Kostal, LG Chem, Fronius and Samsung. These companies offer a variety of solutions, including the type of technology used, the usable capacity of the batteries, or the possibility of installing into existing solar systems. There are also various price ranges and battery range from approx. PLN 5 000 to PLN 57 000. Batteries of capacity is in the range of approx. 2 kWh to 10 kWh.

3 Demand for energy in exemplary household in Poland

In order to answer the question of whether to use an innovative solution photovoltaics/energy bank in single-family houses worthwhile in Poland, the costs of connecting a new single-family house to the power grid and photovoltaics system with a modern lithium battery connection, for example Tesla, were calculated. Such a solution could help to reduce the low emission (pollution from the coal burning in households). Holders of such a system could use the solar energy, while the excess could be resale to distributors or use it in months requiring increased power consumption, for example usage of electric heating in winter.

Based on the available data, a comparison of energy savings over a 10 years period has been made for a single-family house connected to a power grid with a home where photovoltaics system and lithium battery Powerwall 1 and Powerwall 2 were installed. The daily electricity consumption by four inhabitants of single-family household (Tab. 2) was assumed. It is higher than an average electricity consumption in Poland, which is about 4500kWh per year (based on data from the statistical yearbook [15]).

Table 2. Assumptions of daily and annual electricity consumption in a single family home with four residents.

Electric device	Average daily consumption [h]	Consumption per year [h]	Established power of the device [W]	Estimated annual consumption [kWh]
Television	4	1460	150	219
DVD player	0.4	140	150	20
Portable radio, 2 pcs.	2	730	15	11
Washing machine	0.7	260	2500	240
Boiler and cylinder package	4	1460	1500	2190
Microwave oven	2	182	1500	273
Electric oven	0.15	52	2000	105
Toaster	0.5	182	1000	182
Blender	4	91	350	32
Espresso	0.5	182	1450	264
Electric Kettle	0.5	182	1850	337
Kitchen hood	0.5	182	250	45.5
Dishwasher	0.6	220	2250	220
Fridg-Freezer	24	8760	70	305
Lighting, 8 sources	8	10500	12	150
Laptop	4	1825	50	91
Chargers	8	2920	15	44
WiFi Router	24	8760	2,26	20
Hair dryer	0.5	182	1800	328
Straightener	0.5	182	40	7
Iron	0.5	182	1000	182
Vacuum cleaner	0.3	104	1800	185
Total annual energy consumption [kWh]				**5450.5**

For electricity consumption in a single-family household one should add the cost of connection to the power grid. The charge depends on the region in which the house is located [16]. Assuming the power connection (200m standard, additional 50m) was made by cable, for 10kW, the base fee would be PLN 1,630, extra payment to the standard length of PLN 2,287.5, the total amount would be PLN 3,917.5 according to rates from

27.12.2016 of distributor Tauron. Average cost of electricity consumption in a single-family household is expected to reach PLN 2,509.18 per year. Table 3 presents the costs according to rates from 27.12.2016 of distributor Tauron.

Table 3. A summary of the annual electricity costs in a single-family home with four inhabitants, at the rate of 27.12.2016, Tauron distributor [16]

	Annual consumption [kWh]	**Multiplies [Amount / month]**	**net price [PLN]**	**The net value [PLN]**
Energy sales	5450.5	1	0.2546	1387.7
Fee	**Energy distribution**			
24 hour fee	5450.5	1	0.1953	1064.48
RES 24 hour fee	5450.5	1	0.00251	13.68
Constant		12	1.81	21.72
Transitional		12	1	12
Subscription		12	0.8	9.6
			Sum	**2509.8**

Assuming that these costs remain at the current level, the cost of electricity usage in single-family house for ten years and costs of connecting this house to the power grid will be in total PLN 28,618.7.

4 The profitability of investment in the solar panel system – Powerwall in Poland

The connection of photovoltaic installation is related to the investment costs that will be discussed below for a single family house with a power consumption of 5,450.5 kWh. In practice, the installation of this power requires the installation of 21 NSP D6P_B3a photovoltaic panels at an angle 30 degrees and its surface of 34.16 m^2, inverter type: Solis 6K. In case of such installation the costs are balanced The calculations *PV calculator* [17] were based on following data: net distribution fee: 0.21 PLN/kWh; net energy fee: 0.24 PLN/kWh; net fixed costs: 9.65 PLN/month; annual energy consumption: 5,450.00 kWh; annual cost of energy: PLN 3,082.38 and gross rate per kWh: PLN 0.54. For such assumptions, the gross cost of photovoltaic installation and assembly is PLN 27,403, annual energy consumption at level of 5,450 kWh, the PV energy yield for the 25 year warranty period is 127.034 MWh, the annual power reduction 0.8%, the electricity price increase of 7%. Taking into account the benefits from the capital invested in the photovoltaic installation, within 9 years and 30 days the installation will be refunded. After deducting the investment costs during the warranty period, the plant generates a profit of PLN 55,085.87. For solar energy storage, converted by solar panels of area of 34.16 m^2 the investment cost of Powerwall 1-10kW (PLN 14,700)/Powerwall 1-7kW (PLN 12,600)/ LG Chem RESU 6.4kWh (PLN 15 258.00) should be taken into account. In this project, a battery type was selected for further testing Powerwall 1. The total cost of photovoltaic and energy storage will amount to PLN 42,103. In subsequent calculations, it was assumed that the battery will also be charged in the night tariff so that the return of investment is faster. At the moment, the difference between the night tariff and the daily tariff in Poland is PLN 0.1 in the G12 tariff offered by PGE (the only available energy distributor in the examined village). There are plans to introduce dynamic energy prices and smart grid installations in Poland. It is a project that allows you to charge the battery when the energy prices between

tariffs are the largest. The given differences and the time of return of the battery accepted for calculations are presented in the **Fig. 2**.

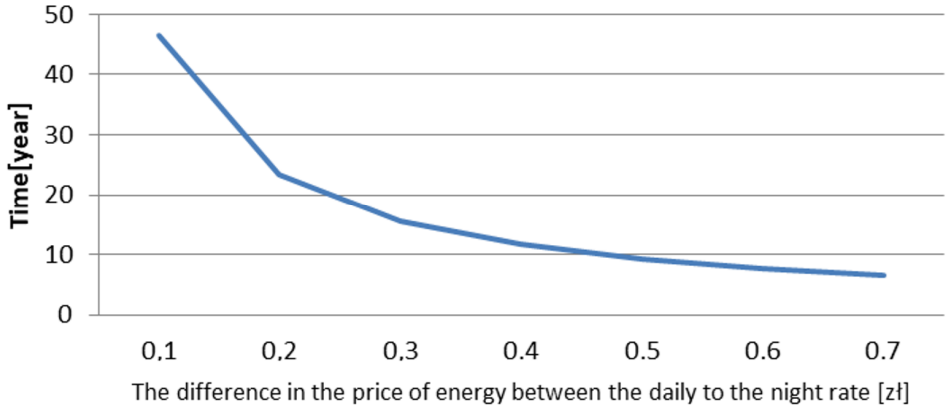

Fig. 2. The return on investment depends on the price of electricity.

The payback time at this point in the battery at the given energy price is over 46 years. The greater the difference, the payback time is shorter. The favorable situation is when the difference reaches PLN 0.6. The payback period is over 7 years with a 10-year battery warranty.

5 Conclusions

The above calculations show that after about 9 years, with a lower level of sunshine, the costs of installing a plant based on renewable energy sources will return and after that time only the profit from storage and electricity generation can be noted. On the other hand, using energy from the power grid, one will still need to pay PLN 2,509.18 a year for energy use in a single family household, which consumes 5,450.5 kWh. This is an investment that requires financial inputs but offers many environmental benefits. it was estimated that it is not profitable to store energy in the night tariff, because there are too small differences in prices between the daily and night tariff, the payback time of this investment to date is 46 years. However, lithium-ion batteries are cheaper from year to year, so the return on investment could be reduced. Lithium-ion batteries for home solar installations are a good solution when energy prices are high. Such a situation occurs in Germany, where the price of energy is PLN 1.2 per kWh. With such energy prices in Germany, the payback time for the 7kWh Lithium-ion battery will be over 3 years.

Acknowledgment :The financial support - the AGH statutory research of Danuta Olszewska

References

1. Air pollutant concentrations at station level (statistics), European Environment Agency, 2016, European Environment Agency, 2016, report has been generated automagically by the EEA Web content management system on 06 Feb 2017 and is available as a website at http://www.eea.europa.eu/data-and-maps/data/air-pollutant-concentrations-at-station
2. Ordinance of the Minister of the Environment of 24th Aug 2012 on the levels of certain substances in the air (pos. 1031, J.Act 2012)

3. Malopolska Provincial Inspector for Environmental Protection in Cracow, measurement data available on the Internet http://monitoring.krakow.pios.gov.pl/dane-pomiarowe (in Polish)
4. *The Gate of Podlasie* – the regional portal prepared and supervised by the Podlaskie Voivodeship Marshal's Office in cooperation with the main public administration organs as well as many institutions, associations and organisations in Podlasie (www.wrotapodlasia.pl/en/)
5. RESOLUTION NO. XXXIV / 578/15 OF THE COUNCIL OF KRAKOW of 16 December 2015 on the establishment of entitlements to free travel by means of Municipal Communications in Cracow on the basis of a car registration certificate in case of exceeding certain levels of harmful substances in the air. (in Polish)
6. Management of Municipal Infrastructure And Transport in Cracow, website: www.zikit.krakow.pl (avilable on 1st Jan-28th Feb 2017)
7. J. Kalotka, *Renewable energy sources* (Scientific Publishing House of the Institute of Exploitation Technology - State Research Institute, 2010)
8. National Fund for Environmental Protection and Water Management, website: www.nfosigw.gov.pl (avilable on 18th Dec 2016)
9. R. Domański, *Storage of heat energy* (PWN, Warszawa, 1990)
10. Imaps Solargis Data, 2016, https://solargis.info/imaps/#tl=GeoModel:dni_yr_avg&c=14.43468,34.321289 (avilable on 15th Mar 2017)
11. Act of 20th Feb 2015 on Renewable Energy Sources (pos. 478, J.Act 2015)
12. The photovoltaic energy market in Poland (Institute for Renewable Energy, Warsow, 2016)
13. B. Scoriati, K.M. Abraham, W. Van Schalkwijk And J. Hassoun (Eds.), *Lithium Batteries Advanced Technologies and Applications* (Willey, 2013)
14. Tesla energy, www.tesla.com (avilable on 28th Dec 2016)
15. *Statistical yearbook of the Republic of Poland - 2015, ISSN 1506-0632 (Statistical Publishing Establishment).* Publication available on the Internet - www.stat.gov.pl
16. TAURON Polska Energia, price list available on the Internet www.tauron24.pl (avilable on 28th Dec 2016) (in Polish)
17. *Hewalex* calculator PV available on the Internet - http://www.hewalex.pl/fotowoltaika/kalkulator/ (in Polish)