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FINANCIAL EFFICIENCY ANALYSIS OF PV PLANTS IN POLAND UNDER THE EVOLVING SUPPORT SCHEME

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ABSTRACT: Financial efficiency analysis of PV plants with a capacity of 1 MWp is presented in the paper, taking into account two RES-E support schemes, which have been implemented in Poland. The aim of the paper is to analyze how the RES-E support mechanisms for Poland impact the actual investor's financial results. The compared RES-E support mechanisms are the following: the auction system (an option of a feed-in-tariff scheme) implemented recently in Poland and the 'green certificates' system, which has been in operation for over a decade now. Financial efficiency analysis method with the sensitivity analysis is implemented to determine the conditions for the most financially effective PV investments. The results show the crucial factors of financial efficiency of the PV farms, which are also discussed in view of the conducted sensitivity analysis, which takes into account changes in the analyzed parameters. The study explores the current policies influencing the conditions of investments in PV plants in Poland providing information for policy makers, investors and researchers interested in the solar energy domain.

KEY WORDS: efficiency analysis, PV farm, auction system, green certificates

Introduction

Our experience of dealing with the potential PV farms investors in Poland shows, that their reluctance to adopt the PV systems is mostly related to the perceived high risk of an investment. This high risk is mostly attributed to the legal ecosystem and financial efficiency of the technology, both adding to the expected profit uncertainty. Therefore, in the paper we examine the profitability factors related to the PV investments under different RES-E support schemes in Poland. This should help the investors to make the better-informed decisions about investments in solar PV systems.

Very important factors for the financial efficiency analysis of PV farms are related to the specific features of the investments size and location, such as solar conditions or grid connection requirements (Dubel, Trela, 2014). Application of multi-criteria decision analyses (Sánchez-Lozano et al., 2016) can help to determine the most favourable locations for the PV investments.

There is a high potential worldwide for the implementation of the RES and especially PV technologies. The Bloomberg New Energy Finance (New Energy Outlook, 2015) is forecasting that declines in the cost of photovoltaic technology (of about 60% by the year 2040 compared to the costs from 2015) will drive a 3,7 trillion USD investments in solar, both large-scale and small-scale, of which 2,2 trillion USD will be attributed to installations on rooftops and other local PV systems, handing consumers and businesses the ability to generate their own electricity. The solar energy will become the cheapest way of producing energy in many countries during the 2020s and 2030s. Its price is expected to decline significantly in this period.

Although Poland is classified among the European developed countries with regard to the PV energy implementation, it still needs to catch up with the countries more advanced in this development. The energy sector in Poland is still dominated by hard coal and lignite industries. (Frost, Sullivan, 2016). The target of energy share from renewable sources in gross final consumption of energy for Poland is at the level of 15%, to be reached by the year 2020 (GUS, 2013).

In order to reach desirable RES targets and incentivise the RES-E production, including PV electricity generation, various schemes have been implemented in the EU Member States to promote this source and to overcome investors' reluctance towards such investments. The main existing policies, diverse among the EU Member States, comprise (Ragwitz et al., 2005a): feed-in tariffs, quota obligations based on tradable green certificates, investment grants, tender procedures and tax measures. The identified (Ragwitz et al., 2005a) key barriers to the mainstreaming of RES-E in the EU countries include: administrative, financial and social issues as well as insufficient elec-

tricity grid capacity. Moreover, the economic efficiency of RES-E support is perceived lower than it would be possible in an advanced policy environment and the level of “risk associated with RES-E investments is still evaluated as comparatively high by the relevant financial institutions in some markets” (Ragwitz et al., 2005a). Building-up on these concerns financial efficiency of PV systems under the evolving support scheme in Poland is analyzed in the paper.

The comprehensive review of support instruments for renewable electricity conducted by Ragwitz et al. in 2005 shows that the best progress towards the RES-E targets was achieved in countries with stable support systems and low overall barriers for the development of RES-E, i.e. Denmark, Finland, Germany and Spain. Rodrigues et al 2016 studied several countries, including Australia, Brazil, China, Germany, India, Iran, Italy, Japan, Portugal, South Africa, Spain, United Kingdom, and the United States of America, to identify the most profitable conditions and places for PV investments and indicated Australia, Germany, and Italy as the best countries.

Case studies dealing with determination of the PV plant economic efficiency as well as the results and profitability of various PV support schemes have been identified (Moreira et al., 2003; Trela, Dubel, 2014; Azofra et al., 2015; Cervone et al., 2015; Liu et al., 2015; Rodrigues et al., 2016; Bakhshi, Sadeh, 2016) to build the developed analysis upon these findings.

Evolution of PV support scheme in Poland

Driven by the EU directives (e.g. Directive 2009/28/EC) and strategies (e.g. Energy, 2020) the Polish energy sector has been undergoing constant changes (RES Law 2015, Energy Law 1997 with later changes). The brief history of the Polish support scheme in relation to EU and other EU Member States policies is presented.

With the adopted RES Law in June 2016 and Regulation of the Ministry of Economy on the reference price in 2016 Poland moved from quota obligations based on tradable green certificates to the auction-based system as an option of a feed-in tariff system. In 2005 (Ragwitz et al., 2005b) Poland was developing a certificate system to support its already existing obligation scheme. In the European Union also Sweden and Romania as well as Belgium, UK and Italy (in combination with other approaches) had a quota obligation systems (Ragwitz, 2013). It can be observed that the countries with the mixed systems have the most effective schemes, for which they were pro-actively searching. The studies delivered within the RE-SHAPING project, aiming at providing help to the EU Member States in the RES Directive imple-

mentation, showed the disproportion between the minimum to average solar PV generation costs ranging between 270 to 420 EUR/MWh and average to maximum remuneration is at the level of about 120 EUR/MWh in Poland. At the same time in Poland potential profit rate is assumed to be negative and the policy effectiveness indicator is 0%, according the RE-SHAPING studies. Taking the above into consideration together with the mentioned extremely low PV RES-E production in Poland, initiative towards the modification of the PV support scheme in the country is justified and substantiated.

Analysis of the situation on the electricity market in Poland within the framework of the operating support systems

Acting in Poland since 2005, the system of so called “green certificates” does not currently fulfil its function, primarily because the market price of certificates of energy origin is so low (43.91 PLN/MWh; based on the OZEX_A, access on the 12.10.2017) that in combination with the average price of electricity sold on the competitive market (162.50 PLN/MWh; based on Information of the President of the Energy Regulatory Office No. 65/2017 – average price for the second quarter of 2017) cannot guarantee the return of investment costs incurred in the case of many RES installations. Moreover, the prices of the green certificates have been decreasing dramatically over the past few years (see figure 1), and therefore in many cases the investment decisions concerning the construction of renewable electricity installations have been made under the assumptions of investment income that has not been matching the market realities.

In figure 1 the prices of the certificates of origin of electricity produced in renewable energy sources in the period from the 1st of March 2009 till the end of 2016 (PMOZE_A) are presented. Property rights to the certificates of origin of electricity produced in renewable energy sources prior the 1st of March 2009 are considered as different financial instrument and therefore they are not shown in figure 1.

These assumptions had sometimes led to calculations of the energy prices used for the RES investments’ analyses at the level of twice the current market price of energy sales. As a consequence, the actual revenues for a given period of many RES investments are less than the sum of operating costs and financial costs (the vast majority of investments use bank loans as an additional source of financing), leading to bankruptcy in the long run. Despite numerous market signals of a negative return on investment, so far no big wave of bankruptcies has yet occurred. This is due to the fact that almost every RES investment has been co-financed from the EU funds and in

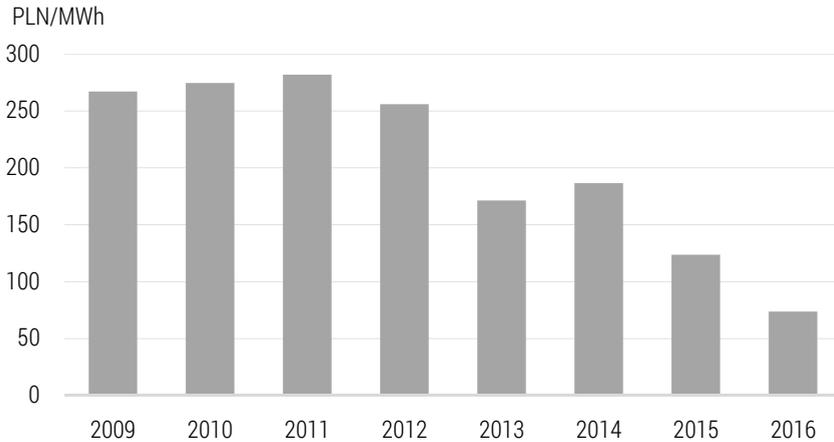


Figure 1. Average annual prices of property rights arising from certificates of origin for electricity from renewable sources ("green certificates") in Poland in 2009-2016 [PLN]

Source: author's own work based on TGE.

such case an investor would be required to return the subsidy received if the project long-term performance is not shown (usually in 5 years time). Therefore, it is often more financially justified to produce electricity at a loss demonstrating the long-term performance of the project than to terminate the activity.

The reason for such sharp falls in prices of certificates is their oversupply, which main reasons are as follows:

1. Granting of equal rights to biomass and coal co-firing technologies as well as other technologies for obtaining certificates of origin of electricity production – one certificate for one MWh of electricity (until 2016). The low investment required to implement this technology in relation to revenues from energy sales led to the rapid development of this technology and, consequently, the "production" of a large number of so-called green certificates.
2. Allowing substitute fees, regardless of the possibility of acquiring the certificates and the price of the property rights resulting from certificates of electricity production origin, has led to the situation where an entity obliged to present a certain amount of green certificates sometimes decided to pay a much higher replacement fee instead of buying certificates of origin. This decision was taken by small entities in view of the transaction costs associated with the complexity of the acquisition pro-

cess and the subsequent remission of certificates of electricity production origin.

3. The lasting validity of certificates of origin in the subsequent years after the year in which the energy was produced on one hand is the obvious consequence of giving the property rights to the producer for a unit of produced energy, on the other hand, causes the green certificates to accumulate on the market. This, coupled with the recent surpluses of their supply, has led to the ever-lower levels of the green certificates market prices.

The failure of this support system, limiting the possibilities of development of renewable energy sources in Poland, has forced action to reform it. As the result an auction system under the Renewable Energy Act of the 20th of February 2015 was introduced. This has had far-reaching consequences in the approach to investing in renewable energy sources in Poland. The investors, whose power plants have produced electricity since the 1st of July 2016, could already benefit from this support system based on the auction system. On the other hand, the investors who started electricity production before the 1st of July 2016 can theoretically choose whether they will continue to reckon up in the 'green certificates' system or whether they will benefit from the auction system. The difference, however, is that in the case of "new" producers the contract for the sale of energy is signed for 15 years, whereas in the case of existing installations, the length of the contract is 15 years counted from the start of energy production by the installation. This means de facto that for the existing installations the auction price is guaranteed for the number of years to complete the operation of a given installation up to 15 years. Thus, in the profitability analyses of different installations carried out with standard assumptions, revenue from the sale of electricity for each of the renewable energy generation technologies should be higher in the auction system than in the 'green certificates' scheme. Therefore, it could have been assumed that the auction system is absolutely superior to the system based on certificates of electricity production origin, as it guarantees higher return on investment and thus leads to the development of the RES market in Poland compared to the current situation. However, to determine whether this is the case in market reality, it is advisable to analyze the auctions that have already taken place and the ones that are planned within the framework of this system.

The first auctions in Poland were announced on the 30th of November 2016 and took place on the 30th of December 2016. These were auctions concerning the production of electricity in the following installations:

1. Existing installations with a power of no more than 1 MW using only agricultural biogas. Auction prices were between 502.23 PLN/MWh and 504.57 PLN/MWh.
2. Existing installations with a power greater than 1 MW using only agricultural biogas. The auction was not conducted because of too few bids.
3. New installations with a capacity of no more than 1 MW using other RES, such as photovoltaic, wind power, hydro power plants, etc. Auction prices received were between 253.50 PLN/MWh and 408.80 PLN/MWh.
4. Existing installations with an installed capacity of no more than 1 MW, meeting the criterion of the installed capacity of electric power above 3504 MWh/MW/year and with an emissivity of no more than 100 kg/MWh (in particular: some hydropower plants). Auction prices received were between 30.00 PLN/MWh and 468.00 PLN/MWh.

More auctions were announced on the 29th of May 2017 and took place on the 29th and 30th of June 2017. These were auctions related to the production of electricity in installations analogous to those in points 3 and 4 of the 2016 auctions presented above. The auctioned prices were at the level of 195.00-398.87 PLN/MWh and 290.00-474.00 PLN/MWh, respectively.

The other auctions scheduled for 2017 were announced on the 23rd of August 2017 and should have taken place on the 28th of September as well as on the 2nd, 4th and 6th of October 2017. These auctions were related to the production of electricity in existing installations:

1. with installed capacity of no more than 1 MW, meeting the criterion of the installed capacity of electric power above 3504 MWh/MW/year (in particular: non-agricultural biogas plants, biomass units and some hydro power plants),
2. with installed capacity of more than 1 MW, meeting the criterion of the installed capacity of electric power above 3504 MWh/MW/year (in particular: non-agricultural biogas plants, biomass units and some hydro power plants),
3. with installed capacity of no more than 1 MW using only agricultural biogas,
4. with installed capacity of more than 1 MW using only agricultural biogas.

However, due to the entry into force of the new regulation on the maximum quantity and value of electricity from renewable energy sources, which can be sold by auction in 2017, three of these auctions were cancelled (on the 2nd, 4th and 6th of October), and on the one, which actually took place, it was assumed that the volume of energy sales was 0 MWh.

After the first turbulent period, the auction system stabilized and the announced auctions were not canceled. However, this have not changed the fact that the prices obtained during these auctions has constituted a big

unknown for the owners of PV installations, especially those with a capacity above 1 MWp. In the auction announced on October 2, 2018, the maximum price obtained at the auction for PV installations with a capacity above 1 MWp was at the level of 216.99 PLN/kWh, while for installations with a capacity of up to 1 MWp, the price ranged from 288.99 to 364.99 PLN/MWh. Such a difference in no way reflects the difference in the unit costs of constructing a PV installation with a capacity below 1 MWp and above 1 MWp, which are comparable in both cases. However, it resulted mainly from the structure of the auction basket combining PV investments with wind farms and from the volume of energy intended for purchase under this auction.

Based on the analysis of prices obtained during the auctions in 2016 and in the mid 2017, it should be noted that they are significantly higher than those that could be obtainable under the green certificates scheme. However, the current functioning of the auction system indicates still a very high uncertainty of the RES market in Poland. Earlier, in the green certificates scheme, the uncertainty was related to the price of property rights and in the auction system it is related to the government preferred technology of energy production and quantity of contracted energy. For instance, photovoltaic technology for installations with a capacity of more than 1 MW in general is not foreseen for support in 2016 and 2017.

In the paper, however, it was decided to carry out an analysis of a photovoltaic installation with a power greater than 1 MW assuming that the technology would receive government support in the near future. In the absence of such support, the analysis remains valid as the investment and operating costs of installations of approximately 2 MW are proportionally higher than the most popular installations currently installed in Poland with a capacity of slightly less than 1 MW.

Method and assumptions

An important efficiency question related to the PV energy production arises: whether the larger incentive is sufficient to cause that in the conditions of the auction system, investors will create a photovoltaic farm based on the so-called 'trackers' (movable frames) instead of 'standard' power plant, in which cells are mounted on fixed racks. In order to answer this question a comparative analysis was conducted comparing financial parameters determining the profitability of investments involving construction of photovoltaic farm with a capacity of 1 MWp, where the cells are placed on a fixed racks, to the investments in the similar farms using 'trackers'. Main assumptions are presented in table 1.

Table 1. Assumptions used in the comparative analysis of financial parameters influencing the financial efficiency of a PV farm

Categories	fixed racks	mobile racks
Period of analysis [years]		15
Interest rate (discount rate) [%]		4
Investment costs [PLN]	2773522	3328226
PV panels, supporting construction, inverters, wires, etc. [PLN]	2511222	3021477
Supporting construction [PLN]	539016	1097992
Fence [PLN]	72450	101429
Monitoring [PLN]	43120	51744
Alarm system [PLN]	34230	41076
The design & paperwork for the project [PLN]	50000	50000
Connection to the energy grid [PLN]	62500	62500
Operational costs [PLN]	70625	125291
Insurance fee (0.4% of investment cost) [PLN]	10045	12086
Tax on construction (2% of the supporting construction value) [PLN]	10780	21960
Land mortgage [PLN]	20000	28000
Service [PLN]	12000	38325
Business activity property tax [PLN]	17800	24920
Subsidies (funding) [PLN]	1238505	1464189

Source: author's own work.

The presented in the table 1 financial assumptions are adopted based on the bidding offers from the constructors. The values represent the average values of 3 collected offers in 2019. A 15-years period of calculation is adopted due to the fact that the auction system guarantees the purchase of energy at a fixed price for 15 years starting from the launch of the electricity production facility.

Degradation rate of panels is estimated at the level of 0.8% per annum and it will be at the level of 80% of their performance after 25 years of usage, according to the warranty provided by the manufacturers about the performance of photovoltaic panels.

Insurance fee for a photovoltaic farm is assumed to be 0.4% of the value of the investment on the basis of information obtained from the insurance company Gothaer.

Tax on construction (2%) is calculated only with regard to the supporting structure according to the judgment of the Provincial Administrative Court in Opole of 13 June 2014 (ref. No. Act: I SA/Op 327/14).

The loan interest rate is assumed to be 4% based on the market analysis of investment credits for companies (adopted instalment annuity).

It is assumed that in the first year (year of the investment construction) it is necessary to take out a loan for the entire amount of gross investment. It is assumed that the repayment of the loan would occur after 2 months, when the funding from the European Union will be received.

To determine the amount of funding from the EU it is assumed that the entrepreneur obtains financing at level of 60% of the investment eligible costs, calculated on the basis of paragraph 41.6b of the EU Regulation No 651/2014. The regulation specifies that 'the cost of investment in the production of energy from renewable sources can be determined by reference to similar, less environmentally friendly investment, which would likely be carried out in the absence of the aid'. The difference between the costs of both investments determines the cost of renewable energy and constitutes the eligible costs of investment. The reference (benchmark) investment in the electricity production, according to the interpretation of the Polish Ministry of Infrastructure and Development, 'a traditional power plant with the same capacity in terms of effective production of energy' should be considered. Therefore, a power plant fuelled by natural gas, which is able to produce the same amount of electricity as a planned photovoltaic farm, is chosen as a benchmark investment in the analysis. So, according to the methodology the cost of natural gas power plant is deducted from the cost of the photovoltaic system (the specification of costs is based on the offer price of the manufacturer).

The calculations are made in fixed prices, the discount rate is assumed at 4% – based on the "Guidelines for issues related to the preparation of projects from 2014 to 2020". Depreciation is assumed linear at the level of 7%. However, it should be noted that from the point of view of calculating the income tax, only the part of the investment that has not been subsidized is subject to depreciation. It is assumed that in the case of 'trackers' the repair costs of moving parts amounts to an annual average of 1.5% of the total cost of frames (21 525 PLN). The initial price for 1 MWh of electricity is determined at the level of 385 PLN per MWh, based on the provisions of the Polish Law on Renewable Energy Sources (paragraph 39.1) and based on a draft of Regulation of the Ministry of Economy on the reference price in 2019, specifying the reference price for this type of installation, according to presented auction mechanism.

Basically, for all the above assumptions, the following sales prices for electricity are taken into consideration:

- for PV installations in the 'green certificates' scheme:
 - 391.72 PLN/KWh – for both types of PV panels set up: fixed racks and trackers,
 - 247.21 PLN/MWh – average selling price of electricity on the competitive market according to Q2 2019 (Statement of the President of the Energy Regulatory Office),
 - 144.51 PLN/MWh – price of the contract PMOZE_A ('green certificate') on the 5.11.2019,
- for PV installations with stationary frames in the auction system: 310.64 PLN/KWh,
- for PV installations with mobile racks in the auction system: 322.16 PLN/KWh.

Results

Taking into account the above assumptions, the basic financial parameters of investment in photovoltaic farm with installed capacity of 1 MWp with the fixed frames or with the 'trackers' are compared, both for the auction system and for the 'green certificates' system. The results are shown in table 2.

The analysis shows that the best investment in terms of earned income is the photovoltaic farm with mobile racks in the conditions of the green certificates. It is mostly due to the higher efficiency of the solution and higher electricity sales prices.

Just on the basis of electricity sales prices, it can be stated that, under current market conditions in 2019, a higher return on investment is guaranteed by the auction system compared to the 'green certificates' scheme. However, the efficiency related to the technology of installation (in this case the movable or fixed racks) is also important. Therefore, in order to assess changes in the costs and revenues related to the operation of the analysed PV systems, a sensitivity analysis of the financial results is carried out, recognizing the uncertainty surrounding the estimation of several parameters, which significantly affect the costs and return on investment. This enables to draw comprehensive conclusions about the impact of the current support system on the directions of development of photovoltaic power generation schemes in Poland.

Table 2. Comparison of discounted costs, revenues and profits from investment in PV 1 MWp farm with stationary (fixed) frames and mobile racks for both the auction and the 'green certificates' systems [PLN]

fixed frames in the 'green certificates' system															
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Revenues	391720	388586	385452	382319	379185	376051	372917	369784	366650	363516	360382	357249	354115	350981	347847
Discounted profit after tax	137065	135931	127900	120265	113006	106107	99549	93317	87397	81772	76429	71354	66535	61960	51701
Cumulative discounted profit from 15-years period	1 430 288														
fixed frames in the auction system															
Revenues	297535	295155	292774	290394	288014	285634	283253	280873	278493	276112	273732	271352	268972	266591	264211
Discounted profit after tax	63710	65961	61164	56617	52308	48225	44358	40695	37227	33944	30837	27897	25116	22486	14085
Cumulative discounted profit from 15-years period	624 628														
mobile racks within the 'green certificates' system															
Revenues	509236	505162	501088	497014	492940	488867	484793	480719	476645	472571	468497	464423	460349	456275	452202
Discounted profit after tax	161566	159992	150242	140979	132181	123824	115889	108355	101204	94416	87974	81862	76064	70564	58337
Cumulative discounted profit from 15-years period	1 663 449														
mobile racks in the auction system															
Revenues	397097	393920	390743	387566	384390	381213	378036	374859	371683	368506	365329	362152	358975	355799	352622
Discounted profit after tax	74227	76684	70784	65198	59912	54909	50177	45702	41470	37470	33691	30120	26749	23566	13550
Cumulative discounted profit from 15-years period	704 209														

Source: author's own work.

Sensitivity analysis was carried out taking into account the following parameters:

- annual costs associated with service and operation of mobile racks (in percentage of the supporting construction value),
- increase in energy yield when using mobile racks in relation to a fixed frames (in percentage),
- annual cost of land lease (in PLN per ha),
- annual rate of panels' degradation (in percentage),
- increase in investment costs of PV installation in case of the mobile racks in relation to the fixed frames (in percentage).

The results of the analysis are presented in table 3.

Table 3. Changes in the financial outcomes resulting from variations in selected parameters of the PV system

Parameter	fixed frames in the 'green certificates' system	fixed frames in the auction system	mobile racks within the 'green certificates' system	mobile racks in the auction system
Annual costs related to mobile racks (initially 1,5% of the supporting construction value)	0,1 percentage point increase of this costs leads to profit decrease of			
	not applicable	not applicable	1.78%	1.87%
Percentage increase in energy yield of PV installation with mobile racks in relation to the PV installations with fixed frames (initially 30%)	1 percentage point increase of the yield leads to profit increase of			
	not applicable	not applicable	1.83%	4.27%
Annual cost of land lease (initially 10000 PLN/ha)	1 percentage point increase of this cost leads to profit decrease of			
	0.13%	0.29%	0.15%	0.36%
Annual panel degradation rate (initially 0,8%)	for 0,1 percentage point (increase in the rate leads to profit decrease)			
	1.55%	3.58%	1.73%	4.12%
Percentage increase in investment costs of PV installations with mobile racks in relation to PV installations with fixed frames (initially 20%)	1 percentage point increase of this costs leads to profit decrease of			
	not applicable	not applicable	1.66%	3.91%

Source: own elaboration

It is important to determine the direction of the change with regard to parameters in table 3 when determining the change in return on investment. When several of the analysed parameters are considered at the same time, in order to obtain the final percentage change in the return on investment, it is sufficient to sum up the percentage changes in profit resulting from changes in individual parameters.

The conducted sensitivity analysis revealed that a change in each of the analyzed parameters would have a greater impact on the return on investment in case of the auction system than in case of the 'green certificates' scheme.

Discussion of results

It should be noted that the decisive factor for the profitability of investment in the photovoltaic farm with mobile racks is the cost of maintenance of the movable parts (frames). This cost has been adopted in the above calculation at the level of 1.5% of the initial value of the PV panels fixed system per year, but due to the short period of use of this technology and its marginal application in the climatic conditions of Poland, this value in the 15-years of operation can, in fact, differ significantly from the assumptions.

A photovoltaic farm with 'truckers', under the undertaken assumptions, will generate more profit than investment based on fixed frames, until the annual maintenance costs of movable parts will exceed approximately 2.2% of their initial value in the auction system and adequately 3.4% in the 'green certificate' scheme.

The analysed regulatory ecosystems of the PV investments (auction system versus 'green certificates' system) are among the important factors determining the profitability of PV investments. The slight changes in the conditions within such systems can have significant impacts on the investment profits.

Uncertainty applies to both green certificate prices (prices and their volatility cannot be predicted) as well as auction prices. In the second case, it is not known whether the auction for a given type of renewable energy will be announced, and when it is announced it is not known how the "basket" will be constructed (i.e., if wind and pv is included in one basket, this will lower the pv price). Another uncertainty concerns the reference price and another uncertainty is related to the price offered by other entities during the auction. Therefore, in both cases there are many factors that make the uncertainty of future prices high.

Conclusions

Under the current market conditions in Poland, the RES support scheme using auctions to determine the purchase price of electricity can generate lower returns on investments, from the construction of PV farm with a capacity of 1 MWp or more (assuming proportionality of investment and operating costs), than the RES support system using 'green certificates'.

The system of 'green certificates' creates a greater incentive to use movable frames in the construction of photovoltaic farm than the auction system, because the analysis showed that the profit in the system of 'green certificates' is greater by over 16% compared to fixed frames. Whereas in the case of the auction system and given the assumptions used in this analysis, the corresponding profit increase is over 12%.

For all the RES the auction system allows to perform much more accurate revenues forecasts than a system based on 'green certificates', in which the unpredictable parameter is the price of the property right.

Moreover, regardless of the RES support system, risk factor related to the level of additional maintenance costs of movable parts in the PV installations can limit the use of this technology. Given the uncertainty in the legal system in Poland concerning renewable energy sources and hence the structure of the support scheme, additional risk associated with the efficiency of technology with mobile racks might be too much for the investors to bear.

It should be remembered that the conducted analysis takes into account current market conditions for 2019. It is possible that the price of electricity on the free-competitive market will increase, and the reference prices, which are the initial value for the calculation of the adjusted price, will not change or will fall as a result of changes in the prices of technologies used in renewable energy sector. It is also possible that the price on the free-competitive market will fall and reference prices will rise, e.g. for political reasons. Therefore, from the point of view of the electricity producer, it is financially justified to use the auction system only when the energy price on the free-competitive market is lower than the adjusted price, which is calculated after taking into account the "correction" of the reference price related to co-financing per unit of energy produced in a contracted 15-year billing period. If the energy producer uses the "green certificates" system, the auction system will be more financially advantageous only if the adjusted price is higher than the sum of the energy price on the free-competitive market and the PMOZE_A price. Thus, green certificates will be more profitable than auctions as long as the price resulting from them (the price of the green certificate and the price of energy on the free-competitive market) is higher than the price from the auction.

The contribution of the authors

Both authors participated equally in conception, development, literature review, acquisition of data, analysis and interpretation of data.

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