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Article

"My Electricity" Program Effectiveness Supporting the Development of PV Installation in Poland

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Abstract: There are a lot of studies that show the legitimacy of subsidizing renewable energy; however, some mechanisms are defective, and there are problems with the appropriate allocation of funds. Therefore, this paper aims to look at the situation of allocating funds to photovoltaics (PV) micro-installations in Poland through the "My Electricity" program. The article presents the results of analyses aimed at identifying inequalities between provinces in the use of funds available under the "My Electricity" program and verifying whether these inequalities are getting worse and whether the intensity of support should not be territorially conditioned in terms of maximization an electricity production. As part of two editions of the "My Electricity" program (until 1 August 2020), over 64,000 PV micro-installations were created with an average power of approximately 5.7 kWp. The total installed PV capacity was 367.1 MWp (1st edition: 159.3 MWp, 2nd edition: 207.8 MWp). Financial resources (as a whole), in the second edition of "My Electricity" program, were distributed better than in the first edition. In the first edition, as much as 7.60% of funds were allocated inefficiently; in the second edition, it was only 3.88%. Allocation surpluses occur in provinces where the average disposable income is low and where there are a small number of households. There is a potential to introduce a territorial project selection criteria. The analysis shows that the criteria should promote provinces with higher disposable income and a larger number of households.

Keywords: photovoltaics; renewable energy sources; renewable energy; "My Electricity"; renewable energy policy; Poland; "Mój Prąd"; grant; renewable energy grants; renewable energy support

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1. Introduction

In climate policy, renewable energy has become the main contributor to mitigating climate change by reducing dependence on fossil fuels and carbon dioxide (CO_2) emissions. However, public policy aimed at supporting the production of energy from renewable sources (RES) has largely focused on encouraging investments in technologies using wind and solar resources, which has thus led to the recent increase in the capacity of installations supplied by these energy sources [1,2]. Moreover, many premises indicate that such a climate policy will be promoted in the future [3,4]. However, designing a renewable energy policy in an efficient, environmentally friendly, and socially equitable way requires an understanding of the impact of individual measures (support programs, subsidies, tax breaks, etc.) on the renewable energy market itself. Renewable energy growth in the energy mix usually has a twofold impact on the electricity market. Firstly, replacing conventional fossil technologies with generation from renewable sources leads to a reduction in CO_2 emissions in energy production (the so-called exchange effect). Secondly, there is a price effect by pushing producers with high marginal costs out of the market and a decline in the wholesale electricity price (which reduces the profits of energy producers using conventional energy technologies). Meanwhile, the consumers are in an ambivalent position—on the one hand, they can benefit from lower energy prices, and on the other hand, they face higher costs to the extent that renewable energy subsidies are refinanced by taxes. In the light of this, it seems extremely important to properly allocate aid funds in RES by specifying the criteria determining the intensity of support [2,5].

There is a lot of research about analyzing the policy support program for renewable electricity considering effective methods of promoting renewables, determining the intensity of support, and optimizing the distribution of financial support in relation to the effects they generate. For example, Nicolini and Tavoni [6], in their work, analyzed the influence of renewable energy support on promoting those technologies in France, Germany, Italy, the United Kingdom, and Spain, over the period 2000–2010. The analysis indicated that policy support positively affects the development of RES in the short and long term. However, in the short run, the feed-in tariff is more effective than the tradable green certificates mechanism in adopting renewable energy technologies. These studies are consistent with the results obtained by Dong [7], but his research focused only on the development of wind energy in Germany. Based on 92 renewable energy enterprises, Yang X. et al. [8] show that the government subsidies have a positive threshold effect on the level of investment in renewable energy in China. Their results show that Research & Development support and further technological changes are key factors in accelerating the widespread use of solar photovoltaics. The research showed that the tax incentives have a more significant impact on renewable energy investment than monetary subsidies. In addition, it has been shown that government subsidies are the main force supporting the development of medium, small, and micro renewable energy enterprises; therefore, it should focus on subsidizing these entities. Niesten et al. [9] research focuses on who uses support programs in renewable energy, based on the example of investments in onshore wind energy in the Netherlands. These analyses show the trends among people investing in wind energy as well as which mechanisms affect the size of investments and can indirectly be the starting point for activating individual groups of investors by creating financial support packages for their needs. Benalcazar et al. [10] analyzed the impact of different national support policies on renewable energy systems and hybrid micro-grid systems. The influence of weather conditions (wind speed and insolation) on the power of individual units of distributed generation was investigated. The authors showed that the final design of microgrid systems for electrifying rural areas depends on the amount of the capital subsidies as well as fuel prices variations. Lekavicius et al. [11] examine the impact of investment subsidies on the installation of renewable energy technologies that cover a large part of the investment costs in Lithuania and thus play an important role in household energy decisions. Although the analyzed support is energy-efficient, it increases social inequalities by promoting higher-income households. Thus, the subsidies spent in this way do not contribute to reducing the phenomenon of energy poverty due to the low investment capacity of the poorest households. A flat distribution of benefits could be achieved by considering the situation of households with lower income and taking into account other affordability issues. In addition, Kazak et al. [12] research shows that stimulating the energy transformation to create new and renovate existing renewable energy sources (RES) installations should be supported by allocating public financial support to achieve these goals. However, the results showed (for all sources) that there is no correlation between the high level of absorption of RES funds and the potential of energy production. The authors suggest that a similar study should be done in the context of each of the European Union member states. In contrast, the study by Bointner et al. [13] showed that the financing of renewable energy sources in the European Union takes place at the level of the Union (through the European Commission), as well as the member states themselves, with the latter spending more money on it. However, the European Commission allocates its funds more evenly between the various renewable energy sources than the member states themselves.

In light of greenhouse gas reduction, solar energy seems to be a very promising option [14,15] and (together with other renewable energy resources) has a key role in mitigation global warming by 1.5 °C [16,17]. However, the research shows numerous uncertainties and barriers connected with adopting solar technologies [18,19]. Considering only PV technologies, the most important hindrance is the financing of such installation and the uncertainty about the return on investment costs [14,20]. Vasseur and Kemp [21] showed that the perceived net cost of PV is strongly correlated with the choice to adopt (or not) of the technology that was analyzed. In addition, other studies showed that the cost is an important barrier to the adoption of PV installation and that some financial solutions provided by the government can lead to a significant increase in PV installations [22]. However, many solutions emphasize the importance of the optimal distribution of financing in relation to the effects they generate. Mundaca and Samahita [23] considered factors that influence the (non-)adoption of PV installation in the case of Sweden. The results show that both subsidies and peer effects are important factors influencing the likelihood of solar PV adoption. In addition, the work of Myojo and Ohashi [24] provided an empirical framework to assess the role of consumer subsidies in residential solar PV installations in Japan. Sue and Yoon [25] investigate how the subsidy policy influences the growth of investments in PV installations on the example of Korea. Their study shows that productivity growth is influenced by factors such as the total amount of the subsidy budget, interest rates, insolation, and land prices in each region. Interestingly, it has been shown that maximizing the installed capacity with the same subsidy budget is possible with the transition from a single subsidy for each region to a subsidized one depending on the characteristics of a given region. Balibrea-Iniesta [26] evaluated the subsidies production of electricity from photovoltaic installation with capacity greater than 100 kW installed in France. The evaluation shows that the subsidy budget should be increased to be able to develop large-scale installations. Sampedro et al. [27] show how the relocation of fossil fuel subsidies (FFS) to promote solar photovoltaics on the roof would reduce CO_2 emissions. It has been estimated that such action would reduce CO_2 emissions to 2.2% by 2030, and although this may not be the answer to all problems related to mitigating global warming, it can significantly contribute to promoting renewable energy and reducing environmental pollution without additional costs for the government (with only the transfer of funds from the FFS to RES). Torani K. et al. [28] in their work examined the prospects of solar photovoltaics (PV) in the residential and commercial sector in terms of the price of electricity and cost of solar. The developed stochastic dynamic model of adaptation solar PV showed that within 30 years, there will be a prevalent shift toward solar PV technologies both in residential and commercial sector. The result indicate that subsides and carbon price policies have little effect in accelerating adoption, and thus, an accelerating adoption may occur irrespective of these two factors.

Most of the studies discussed show the legitimacy of subsidizing renewable energy; however, some mechanisms are defective, and there are problems with the appropriate allocation of funds. Therefore, this paper aims to look at the situation of allocating funds to PV micro-installations in Poland. The article presents the results of analyses aimed at identifying inequalities between provinces in the use of funds available under the "My Electricity" program and verifying whether these inequalities are getting worse and whether the intensity of support should not be territorially conditioned, i.e., depend on the province where the project will be implemented.

Poland has average values of insolation in Europe, which in individual provinces are in the range from 900 to 1150 $kWh/m^2/year$ (according to the Typical Meteorological Year) [29,30]. The differences in insolation occurring in individual provinces lead to a thesis that the share of projects located in southern voivodships should be greater than those located in northern Polish provinces, because the greater value of insolation makes the installation more energy-productive and economically effective. In this context, the question arises as to whether this issue should not determine the intensity of support. The economic efficiency of the installation is also influenced by its size, which is related to the effects of scale. Therefore, the power of the installation may also determine the intensity of support in addition to insolation (availability of solar energy). It is possible to estimate what the support intensity should be in individual voivodships in order to use the funds available under the "My Electricity" program most effectively. For this purpose, a mathematical model has been built, which has been used to optimize the use of subsidies financed under the "My Electricity" program. Figure 1 shows the annual insolation for each province and the total installed capacity in the "My Electricity" program until 1 August 2020 (according to the approved ranking lists).

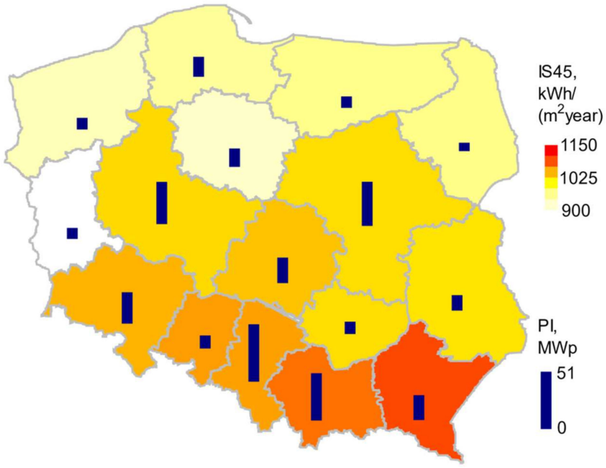

Figure 1. Insolation in Poland (for surface with tilt angle = 45° and south faced) and total photovoltaics (PV) installation power (Table 1. August 2020) [29,31].

Table 1. Average and standard deviation for PV installation power per province.

Province	Average PV Power, kWp			Standard Deviation, kWp	
	1st Edition	2nd Edition	1&2	1st Edition	2nd Edition
Lower Silesia	5.91	6.12	6.03	2.12	2.12
Kuyavian–Pomeranian	5.91	6.01	5.97	2.20	2.23
Lubelskie	5.35	5.28	5.32	2.03	2.05
Lubuskie	5.95	6.20	6.10	2.10	2.12
Łódzkie	5.96	6.08	6.02	2.18	2.21
Lesser Poland	5.40	5.60	5.52	1.84	1.89
Masowian	5.59	5.51	5.55	1.99	1.94
Opolskie	6.13	6.38	6.27	1.98	1.07
Podkarpackie	4.80	4.87	4.84	2.06	2.17
Podlaskie	5.32	5.39	5.35	1.62	1.63
Pomeranian	5.64	5.75	5.71	1.95	2.07
Silesian	5.66	5.75	5.71	2.05	2.17
Świętokrzyskie	5.08	5.15	5.11	2.01	2.06
Warmian–Masurian	5.63	5.90	5.79	1.91	2.04
Greater Poland	5.53	5.67	5.62	2.09	2.20
West Pomeranian	5.82	5.82	5.82	1.94	2.06

Color agenda: green—the highest value, red—the lower value. Source: own study.

The paper is structured as follows. In Section 2, the data about the subsidiary program "My Electricity" for co-financing photovoltaic micro-installation in households in Poland is presented. The data are collected for two editions of the "My Electricity" program and are given for different provinces in Poland. In addition, the data about the average yearly insolation for a 45° tilted surface south faced, average income in a household and the number of households in each of the voivodships is shown. Section 3 focuses on analysis and calculations, including the average power of PV installations and the average value of subsidies in each of the analysed provinces. In Section 4, an analysis of the subsidy program effectiveness is carried out in order to assess whether the funds transferred under the subsidy are optimally distributed in relation to the effects generated by the "My Electricity" program. For this purpose, data analyses have been carried out and a mathematical model has been built, using the statistical method of multiple regression allowing describing the covariance of several variables by fitting functions to them. The total power of PV installations (which received co-financing) in individual provinces has been assumed as the dependent variable. The explanatory variables have been the total number of households, the value of subsidies in the first edition of the "My Electricity" program, the average insolation, and the average disposable income in a household (analyzed at the province level). Additionally, the results of the analysis have been discussed. Finally, Section 5 discusses the economic and ecological implications of the "My Electricity" program on provinces in Poland, and conclusions are raised.

2. Data

The data available on the website of the PV micro-installations co-financing program "My Electricity" have been used for the purpose of this research (https://mojprad.gov.pl). The available data included the following information: name, surname, province, installation capacity (kWp), subsidy (PLN), rate (on a scale of 1 to 4 points).

In the first edition of the "My Electricity" program, there were 28,437 submitted and approved applications, and in the second edition, there were 35,914 applications (as of 1 August 2020). The summary of applications numbers divided into provinces and program editions is presented in Figure 2a.

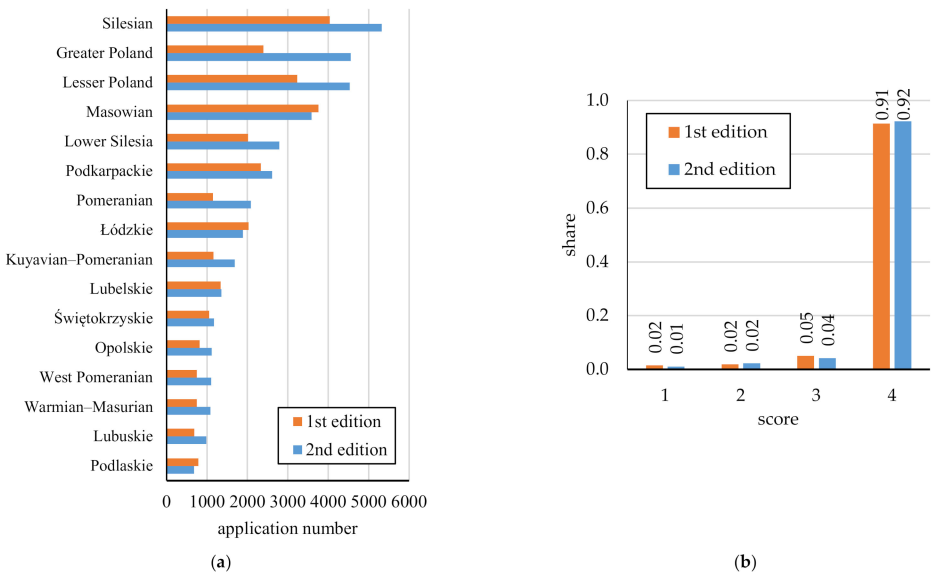

Figure 2. (**a**) Number of applications accepted in two editions of the "My Electricity" program (applications accepted until 1 August 2020) [31]; (**b**) Share of PV installations with a certain number of points among installations supported by both editions of the "My Electricity" program (applications accepted until 1 August 2020).

In both editions, the largest number of accepted applications came from the Silesian province. The lowest number of applications in the first edition was submitted in the Lubuskie province, and in the second edition, the lowest number of applications was submitted in the Podlasie province.

The information published as part of the ranking lists includes the number of points awarded depending on the installation unit price, which is expressed in PLN/kWp. When this price is lower than PLN 6000/kWp (1333 EUR/kWp, 1 EUR = 4.5 PLN), the evaluated application received 4 points. When the unit price was higher, a correspondingly smaller number of points were awarded (minimum 1). The vast majority (over 91%) of applications received 4 points—see Figure 2b.

The province with the highest score in the first edition was Opolskie: 3.91 (the average number of points awarded), and the province with the lowest province was Pomeranian: 3.79. In turn, in the second edition, the province with the highest average number of points awarded was Lubelskie with 3.92, and that with the lowest average number of points was Świętokrzyskie Province with 3.78. For both editions of the program, the Lubelskie province achieved the highest average number of points awarded: 3.91, and Pomeranian Province had the lowest: 3.80. Due to the over 90% share of applications with four points awarded, this issue was not analyzed in the following chapters. Some disproportions can be justified by the differences in the contracting price typical for each province [32], the size of the competition among assembly companies, as well as the size of installations expressed in kWp (Table 1).

The analysis is also based on the following data (for each province):

- Number of households, published by the Central Statistical Office [32].
- Average insolation as statistical climatic data for the area of Poland available on the archival website of the Ministry of Investment and Development [29].
- Value of disposable income published by the Central Statistical Office [33].

The numerical values for the above-mentioned data are presented in Table 2.

Table 2. The number of applications submitted in the second edition of the "My Electricity" program, the number of households (including in rural areas), the average insolation, and the value of disposable income in individual provinces.

Province	No. of Households, Thousand		Number of Applications	IS45	DR
	Total	Rural		kWh/m²/year	PLN/month
Lower Silesia	1100	275	4804	1086.1	5311
Kuyavian–Pomeranian	729	239	2842	930.3	4641
Lubelskie	742	356	2694	1049.8	4602
Lubuskie	365	115	1655	891.9	4605
Łódzkie	944	282	3919	1074.2	4864
Lesser Poland	1080	454	7758	1130.5	5156
Masowian	1943	557	7346	1055.3	6159
Opolskie	354	147	1931	1101.4	4788
Podkarpackie	649	336	4941	1151.6	4463
Podlaskie	417	145	1455	974.8	4645
Pomeranian	806	224	3231	962.8	5290
Silesian	1728	315	9353	1098.4	5200
Świętokrzyskie	429	208	2223	1054.8	4529
Warmian–Masurian	516	182	1827	973.6	4376
Greater Poland	1129	418	6946	1057.3	4756
West Pomeranian	639	170	1852	942.8	4872
Poland	13,568	4421	64,777		

IS45—average yearly insolation for 45° tilted surface south faced. DR—average disposable income in a household in 2018. Source: own study based on [29,31–33].

3. Analysis and Calculations

The total installed PV capacity for both editions of the program was 367.1 MWp (1st edition: 159.3 MWp, 2nd edition: 207.8 MWp).

In both editions, the average PV installation power of 5.69 kWp was achieved (5.57 kWp in the first edition and 5.79 kWp in the second edition). The standard deviation for the data from the first edition has a value of 2.01 kWp, and that for the second edition has a value of 2.07 kWp. The curves presenting the occurrence of specific installations sizes for both editions and also the maximum unit grant amount are presented in Figure 3.

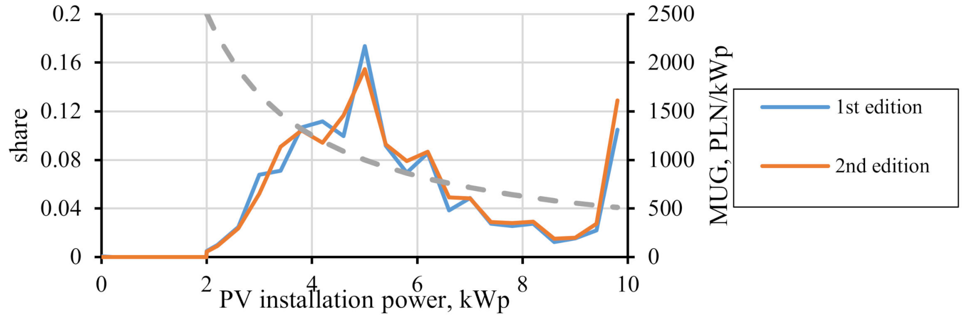

Figure 3. Share of PV installations of a certain capacity among installations installed in both editions of "My Electricity" program (applications accepted until 1 August 2020). MUG—maximum unit grant amount per kWp.

The average capacity for installations in the provinces scale are presented in Table 1.

In total, PLN 323.45 million was spent under the program, which is 32% of the entire program budget, amounting to PLN 1 billion. The average subsidy to the kWp amounted to PLN 881. The results for individual provinces are presented in Table 3.

Table 3. The average value of the subsidy and standard deviations within the subsidy to kWp.

Province	Average Unit Value of the Subsidy PLN/kWp			Standard Deviation, PLN/kWp	
	1st Edition	2nd Edition	1&2	1st Edition	2nd Edition
Lower Silesia	839.4	816.6	826.0	334.8	347.4
Kuyavian–Pomeranian	836.6	830.4	832.9	361.5	382.7
Lubelskie	924.4	945.4	934.9	387.8	381.0
Lubuskie	834.4	805.3	816.9	321.8	345.1
Łódzkie	831.5	820.3	826.0	351.9	361.2
Lesser Poland	922.3	891.8	904.2	324.5	333.6
Masowian	887.7	906.6	896.9	344.6	355.5
Opolskie	810.3	783.6	794.7	318.4	315.4
Podkarpackie	1 032.5	1 023.6	1 027.7	340.1	362.2
Podlaskie	927.0	928.3	927.6	377.1	377.3
Pomeranian	873.3	867.7	869.6	370.0	353.9
Silesian	878.5	869.1	873.2	351.5	347.3
Świętokrzyskie	974.8	970.0	972.3	388.5	391.0
Warmian–Masurian	876.8	845.8	858.1	362.4	378.8
Greater Poland	893.6	880.0	884.6	354.1	346.8
West Pomeranian	847.4	858.9	854.2	356.1	340.7

Color agenda: green—the highest value, red—the lower value. Source: own study.

As shown in Table 3, the highest average subsidies to power (expressed in kWp) were in Podkarpackie province and the lowest were in the Opolskie province. The difference in values of the unit subsidy between these provinces is over PLN 200/kWp, which is more than 20% of the average subsidy in the whole country. These differences are mainly due to the average installed capacity under the program in provinces (Table 1) and the maximum amount of the subsidy, which is PLN 5000 (Figure 3—MUG).

Similarly to the presented conclusions from the work of Olczak et al. [34], the relationship between the installed capacity and the number of provinces residents has been presented—see Figure 4.

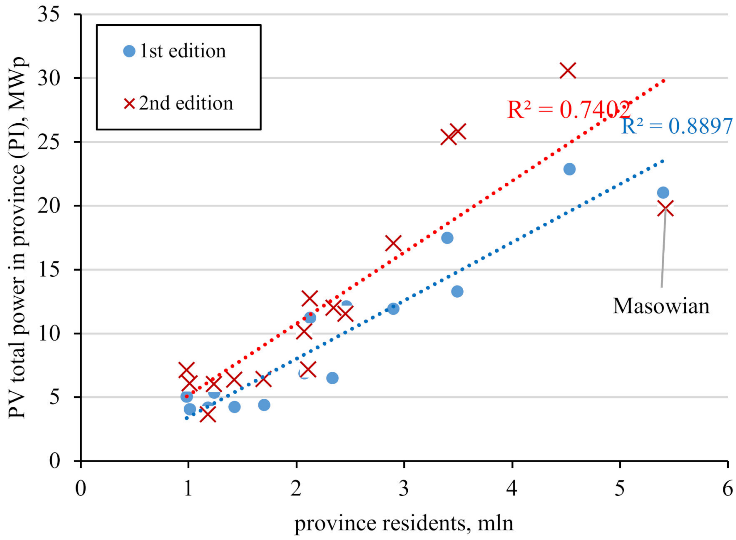

Figure 4. Dependence of installed capacity in the province on the number of residents in the province in both editions of the "My Electricity" program (applications accepted until 1 August 2020) [31].

The value of the R^2 coefficient (Figure 4) for second edition is much higher, without taking into account the Masowian province (point 5.42 million; 19.77 MWp in Figure 4), which is 0.91. In case of the first edition, eliminating from the calculation of the R^2 coefficient the above-mentioned province practically does not change the result. Due to the high correlation shown in Figure 4, the power index expressed in *Wp* per resident (*PPI*) [7] was calculated according to the formula below. The results are listed in Table 4.

$$PPI(prov.) = \frac{PI(prov.)}{LM(prov.)}, \frac{Wp}{inhab.} \quad (1)$$

where

PI—power of installations installed in the province;

L—number of residents in the province.

Table 4. Results of calculations of the PPI index (PV power per resident) for each province.

Province	PPI, Wp/inhab.		
	1st Edition	**2nd Edition**	**1&2**
Lower Silesia	4.11	5.88	9.99
Kuyavian–Pomeranian	3.29	4.89	8.18
Lubelskie	3.38	3.40	6.78
Lubuskie	4.06	5.99	10.05
Łódzkie	4.91	4.69	9.60
Lesser Poland	5.40	7.44	12.84
Masowian	3.89	3.65	7.53
Opolskie	5.08	7.22	12.30
Podkarpackie	5.26	5.98	11.24
Podlaskie	3.52	3.08	6.60
Pomeranian	2.77	5.12	7.89
Silesian	5.04	6.77	11.81
Świętokrzyskie	4.30	4.89	9.19
Warmian–Masurian	2.95	4.47	7.42
Greater Poland	3.79	7.38	11.17
West Pomeranian	2.56	3.78	6.35
Poland	4.12	5.41	9.54

Color agenda: green—the highest value, red—the lower value. Source: own study.

Then, the number of applications (PV installations created under the "My Electricity" program) per 1000 households (Table 5) was calculated, as well as the installed capacity per household (*PPH*) and per one rural household (*PPHC*):

$$PPH(prov.) = \frac{PI(prov.)}{LG(prov.)}, \frac{Wp}{household} \tag{2}$$

where
LG—the number of households in the province.

$$PPHC(prov.) = \frac{PI(prov.)}{LGW(prov.)}, \frac{Wp}{rural\ household}. \tag{3}$$

where
LGW—number of rural households in the province.

Table 5. Comparison of the number of applications with the number of households in the province.

Province	No. Applications/1000 Households	No. Applications/1000 Rural Households	PPH	PPHC
			Wp/Households.	Wp/Rural Households
Lower Silesia	4.4	17.5	26.4	105.3
Kuyavian–Pomeranian	3.9	11.9	23.3	71.0
Lubelskie	3.6	7.6	19.3	40.2
Lubuskie	4.5	14.4	27.9	88.6
Łódzkie	4.2	13.9	25.0	83.8
Lesser Poland	7.2	17.1	40.5	96.4
Masowian	3.8	13.2	21.0	73.2
Opolskie	5.5	13.2	34.2	82.6
Podkarpackie	7.6	14.7	36.9	71.3
Podlaskie	3.5	10.0	18.7	53.7
Pomeranian	4.0	14.5	22.9	82.6
Silesian	5.4	29.7	30.9	169.7
Świętokrzyskie	5.2	10.7	26.5	54.6
Warmian–Masurian	3.5	10.1	20.5	58.2
Greater Poland	6.2	16.6	34.6	93.4
West Pomeranian	2.9	10.9	16.9	63.6
Poland	4.8	14.7	27.0	82.8

Color agenda: green—the highest value, red—the lower value. Source: own study.

The lowest ratio of the installations number per 1000 households (PPH) has been achieved in the West Pomeranian province, which is 2.9, and the highest was in the Podkarpackie province, which is 7.6; nationwide, it is 4.8. Taking into account rural households, the lowest rate was achieved in the Lublin province, which is 7.6, and the highest was in the Silesian province, which is 29.7. The highest PPH index was achieved for the Lesser Poland province and the lowest was achieved for the West Pomeranian province. In turn, in the case of the PPHC indicator: the maximum was in the Silesian province, 169.7, and the lowest was in the Lublin province: 40.2.

4. Analysis of the Effectiveness of the Subsidy Program

4.1. Analysis

In order to assess whether the funds transferred as part of the subsidy are optimally distributed in relation to the effects generated by the "My Electricity" program, data analysis was carried out, and a mathematical model was built. For this purpose, the statistical method of multiple regression was used, allowing describing the covariance of several variables by fitting functions to them. The dependent variable was the sum of the capacity of PV installations (which received co-financing) in individual provinces. The explanatory variables were: the sum of the subsidies value in the first edition of the "My Electricity" program, the average value of a subsidy per household, the average insolation, and the average disposable income in a household. Values for the explanatory variables and the dependent variable were registered at the province level.

The collinearity of explanatory variables was examined. The results are shown in Figure 5. The collinearity of the variables was not found. The values of the Variance Inflation Factor (VIF) indicators for all analyzed variables are below 6. Due to the transformations of the variables used to build the model, structural multicollinearity was observed, but it does not affect the quality of forecasting the value of the explained variable, which is crucial for this work. Structural multicollinearity is important for the interpretation of model parameters; however, this issue has no significance for the research problem being solved.

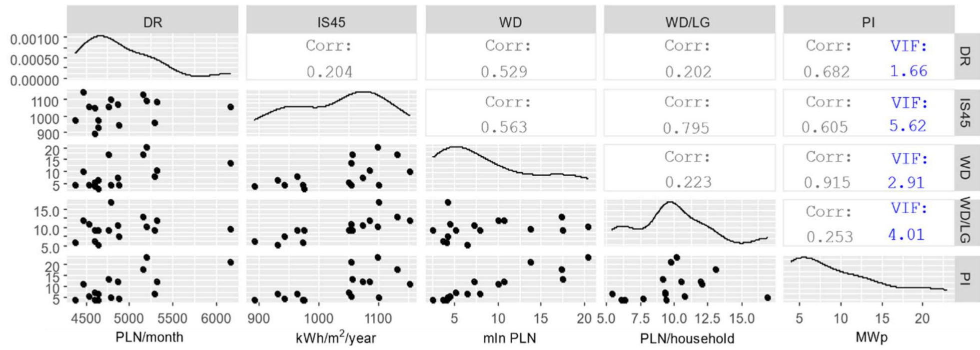

Figure 5. Correlation and collinearity of explanatory variables. VIF—Variance Inflation Factor.

Backward stepwise regression technique was used. The parameters for the model meeting the conditions of linear regression analysis are presented in Table 6. Table 7 presents the expected values of the dependent variable (installed capacity in individual provinces) and the values of the residual component.

Table 6. Regression model statistics.

Variable	Coefficient	Standard Error	t Stat	p-Value	Lower 95%	Upper 95%
Intercept	8255.22	1783.39	4.63	0.001238	4220.92	12,289.52
DR IS45	−0.002091	0.000538	−3.887968	0.003686	−0.003307	−0.000874
WD IS45	1.963×10^{-6}	2.171×10^{-7}	9.045	8.195×10^{-6}	1.472×10^{-6}	2.455×10^{-6}
WD WD/LG	-4.030×10^{-8}	1033×10^{-8}	−3.902	3.610×10^{-3}	-6.366×10^{-8}	-1.693×10^{-8}
IS45 WD/LG	−0.001691	0.000305	−5.537807	0.000362	−0.002382	−0.001000
DR IS45 WD	-1.086×10^{-10}	3.164×10^{-11}	−3.432	7.487×10^{-3}	-1.802×10^{-10}	-3.701×10^{-11}
DR IS45 WD/LG	4.031×10^{-7}	7.869×10^{-8}	5.122	6.261×10^{-4}	2.251×10^{-7}	5.811×10^{-7}
	df	SS	MS	F	F materiality level	
Regression	6	586,011,923	97,668,654	1233.42	1.3534×10^{-12}	
Residual	9	712,670	79,186			
Total	15	586,724,592				
Regression Statistics						
R multiples	0.9994					
R square	0.9988					
Adjusted R-squared	0.9980					
Standard error	281.40					
Trials	16					

Where: *LG*—total number of households (in thousands); *WD*—the sum of the subsidies in the first edition of "My Electricity" program (PLN); *IS45*—average insolation calculated on a plane inclined to the horizontal at an angle of 45° to the south (kWh/m^2/year); *DR*—average disposable income in a household in 2018 (PLN/month). Source: own study.

Table 7. Predicted and residual values.

Observation	Province	Predicted Power of PV Installation, kWp	Residual Values
1	Lower Silesia	12,035.86	−120.56
2	Kuyavian–Pomeranian	6496.75	340.33
3	Lubelskie	7486.66	−319.94
4	Lubuskie	4168.02	−52.06
5	Łódzkie	11,589.85	509.02
6	Lesser Poland	18,457.67	−87.28
7	Masowian	20,940.80	58.89
8	Opolskie	4826.05	184.31
9	Podkarpackie	11,105.44	86.00
10	Podlaskie	4464.94	−309.10
11	Pomeranian	6541.13	−73.42
12	Silesian	22,910.45	−80.00
13	Świętokrzyskie	5520.53	−183.52
14	Warmian–Masurian	4140.21	71.45
15	Greater Poland	13,352.24	−110.21
16	West Pomeranian	4275.45	86.10
Sum		158,312.04	0.00

Color agenda: green—the highest value, red—the lower value. Source: own study.

The obtained results indicate that the constructed linear regression equation for the sum of installed PV power is correct because of the following:

(1) All explanatory variables were correctly captured in the linear regression model because the *p*-value of the Student's *t*-test for these variables was less than the significance level of 0.05.
(2) The *p*-value of the F test calculated for the linear regression model was 1.3534×10^{-12}, and it is less than the significance level of 0.05.
(3) The alignment factor R^2 was 0.9994, which is very high, and it can be interpreted as follows: the exploitation factor *a* was almost 100% as explained by the explanatory variables.

In addition, all formal requirements for classical linear regression analysis have been met:

(1) Explanatory variables are exogenous, which means that the values of the random term are not a function of the explanatory variables of the linear regression equation.
(2) There is a linear relationship between the explanatory variables and the dependent variable.
(3) The number of observations *n* is greater than the number of structural parameters of the regression equation.
(4) Explanatory variables are non-random.
(5) The expected value of the random component is zero (Table 7).
(6) Values of the random component have a distribution close to the normal distribution N (0, σ), which has been confirmed by the Shapiro–Wilk statistical test, for residuals W = 0.94051, *p*-value = 0.3553.

Knowing the power of PV installations in the province and the average annual insolation, it is possible to determine the theoretical annual electricity production.

The model has been used to determine the value of the subsidy for each province, which with a given value of subsidy (the sum of subsidies for the first edition of "My Electricity" program equal to 140 million PLN) will maximize the total value of the theoretical annual electricity production. In this way, it was determined how optimally the subsidy should be distributed to individual provinces, which thus provides grounds for determining the territorial criteria for selecting projects for co-financing under the "My Electricity" program.

4.2. Discussion of the Analysis Results

The results of the analysis indicate that it is possible to improve the efficiency of using funds under the "My Electricity" program. The optimal distribution of subsidies allows increasing the theoretical (average annual) electricity production by 1.68% (first edition) and 3.26% (second edition).

Table 8 presents the value of subsidies for each province under the first and second editions of the "My Electricity" program. Table 9 presents the amount of subsidies for optimal variants (while maintaining the theoretical electricity production at the same level).

Table 8. The amount of the subsidy (WD), PLN.

Province	1st Edition	2nd Edition
Lower Silesia	10,001,972	13,933,500
Kuyavian–Pomeranian	5,719,621	8,413,577
Lubelskie	6,624,871	6,769,633
Lubuskie	3,365,275	4,879,917
Łódzkie	10,043,978	9,447,032
Lesser Poland	16,086,613	22,621,446
Masowian	18,640,837	17,930,030
Opolskie	4,060,058	5,561,416
Podkarpackie	11,555,170	13,021,064
Podlaskie	3,852,511	3,369,764
Pomeranian	5,647,971	10,403,653
Silesian	20,057,216	26,580,026
Świętokrzyskie	5,202,406	5,849,303
Warmian–Masurian	3,692,589	5,383,188
Greater Poland	11,833,316	22,712,726
West Pomeranian	3,696,053	5,509,597
Sum	140,080,457	182,385,872

Color agenda: green—the highest value, red—the lower value. Source: own study.

Table 9. The size of the subsidy calculated for optimal variants, PLN.

Province	Optimal Variant for 1st Edition	Optimal Variant for 2nd Edition
Lower Silesia	13,402,642	17,138,203
Kuyavian–Pomeranian	4,118,127	5,132,281
Lubelskie	7,088,612	9,003,611
Lubuskie	2,389,345	3,025,548
Łódzkie	10,144,416	12,942,433
Lesser Poland	14,156,216	18,323,371
Masowian	19,200,057	24,564,138
Opolskie	6,090,087	7,785,982
Podkarpackie	7,857,514	10,156,430
Podlaskie	3,929,561	5,088,344
Pomeranian	7,737,720	9,779,434
Silesian	17,850,917	22,858,816
Świętokrzyskie	4,682,165	6,024,782
Warmian–Masurian	3,249,478	4,091,223
Greater Poland	10,413,316	13,400,508
West Pomeranian	5,063,593	6,391,132
Sum	137,373,767	175,706,238

Color agenda: green—the highest value, red—the lower value. Source: own study.

The analysis proved that it is possible to maintain the theoretical electricity production at the same level with a lower total value of the subsidy. In case of the first edition of the "My Electricity" program, it was possible to achieve the same theoretical electricity production with the subsidy value lower by 1.93%, and in the second edition, it was possible with the value lower by 3.66%. So, the funds in the second edition of the "My Electricity" program were distributed less effectively than those in the first edition.

When analyzing individual provinces in terms of the optimal level of subsidies, it was found that in case of first edition, the subsidy deficit (at the level of 7.20% of the total value of subsidies for edition 1) occurred in eight provinces. However, in the case of the second edition, the deficit of subsidies (at the level of 11.28% of the total value of subsidies for second edition) occurred in eight provinces. The surplus and deficits of subsidies in individual provinces are presented in Tables 10 and 11.

Table 10. Surpluses (positive value) and deficits (negative value) in subsidizing individual provinces, percentage. Value calculated in relation to the value of subsidies for individual provinces.

Province	1st Edition	2nd Edition
Lower Silesia	34	23
Kuyavian–Pomeranian	−28	−39
Lubelskie	7	33
Lubuskie	−29	−38
Łódzkie	1	37
Lesser Poland	−12	−19
Masowian	3	37
Opolskie	50	40
Podkarpackie	−32	−22
Podlaskie	2	51
Pomeranian	37	−6
Silesian	−11	−14
Świętokrzyskie	−10	3
Warmian–Masurian	−12	−24
Greater Poland	−12	−41
West Pomeranian	37	16

Color agenda: green—the highest value, red—the lower value. Source: own study.

Table 11. Surpluses (positive value) and deficits (negative value) in subsidizing individual provinces, percentage. The value is calculated in relation to the total value of the subsidy (total for Poland).

Province	1st Edition	2nd Edition
Lower Silesia	−2.43	−1.76
Kuyavian–Pomeranian	1.14	1.8
Lubelskie	−0.33	−1.22
Lubuskie	0.7	1.02
Łódzkie	−0.07	−1.92
Lesser Poland	1.38	2.36
Masowian	−0.4	−3.64
Opolskie	−1.45	−1.22
Podkarpackie	2.64	1.57
Podlaskie	−0.06	−0.94
Pomeranian	−1.49	0.34
Silesian	1.58	2.04
Świętokrzyskie	0.37	−0.1
Warmian–Masurian	0.32	0.71
Greater Poland	1.01	5.11
West Pomeranian	−0.98	−0.48

Color agenda: green—the highest value, red—the lower value. Source: own study.

The total value of the surplus subsidies in the first edition was 9.13% of the total value of the subsidy allocated in the first edition. In the case of the second edition, this surplus was 14.94%. These values can be equated with monetary value, which were incorrectly/ineffectively distributed. In case of the second edition, the inequality in the distribution of funds between provinces slightly increased compared to the first edition, as measured by the Herfindahl–Hirschman index (HHI). For the data from the first edition, the HHI index amounted 0.0861, and for the second edition, it was 0.0870. The HHI value for the optimal cash distribution in the first edition amounts 0.0839, and in the second one, it was 0.0842. Therefore, the optimal distribution of subsidies between provinces should be more uneven than it was in both editions.

Correlation analysis showed that the values of surpluses and deficits correlate with the value of the average disposable (DR) income in individual provinces and subsidies value (WD) and average value of a subsidy per household (WD/LG) (Table 12).

Table 12. Values of correlation coefficients of subsidies surpluses/deficits in individual provinces and disposable income, the number of households and insolation, average value of a subsidy per household.

Parameter	1st Edition	2nd Edition
DR—average disposable income in a household	−0.35	−0.40
IS45—Insolation	0.20	0.01
WD—Subsidies value	0.36	0.43
LG—Number of households	0.08	−0.06
WD/LG—Average value of a subsidy per household	−0.19	−0.20

Source: own study.

Allocation surpluses occur in provinces where the average disposable income is low, and deficits where the average income value is high. The situation is similar in the case of an average value of a subsidy per household: allocation surpluses occur in provinces with a low-value subsidy per household, and deficits occur with a large-value subsidy per household. The value of insolation (IS45) and number of households (LG) is very slightly correlated with surpluses/deficits of subsidies. It is also worth noting that allocation surpluses occur in voivodships where the amount of the subsidy granted was high. It is characteristic that in the second edition of the "My Electricity" program, the above-mentioned correlations increased. This may indicate the saturation of the household sector with photovoltaic installations (an increase in the correlation coefficient for subsidies value (WD)), which means that less and less effective investments are undertaken (perhaps smaller and worse located). Thus, the importance of parameters such as average disposable income in a household is growing. Conclusions that can be drawn on this basis indicate that it would be reasonable to introduce a territorial project selection criterion that would allow increasing the allocation level in provinces with higher disposable income and in voivodships where the average value of a subsidy per household is high. Households with a higher value of disposable income invest in installations with a greater capacity, thanks to which the subsidy is better used due to the positive economies of scale, which is decreasing unit costs of purchasing PV installations along with the increase in the capacity of PV installations. Although the average value of subsidies per household (WD/LG) is poorly correlated with subsidies surpluses/deficits in individual provinces (the value of the correlation coefficient is around −0.2), the nature of this relationship is surprising and difficult to explain. It most probably results from social conditions (education, imitation, territorial, and social segmentation), which cause the "snowball effect". This issue requires in-depth research.

5. Summary

As part of two editions of the "My Electricity" program (until 1 August 2020), over 64,000 PV micro-installations were created, with an average power of approximately 5.7 kWp. The total installed PV capacity was 367.1 MWp (1st edition: 159.3 MWp. 2nd edition: 207.8 MWp).

The highest subsidies to the kWp were achieved in the Podkarpackie province with practically the highest productivity (which brings additional benefits for the household). On the one hand, every PLN spent in the Podkarpackie province contributes to higher ecological and economic effects than, for example, in the northern provinces. This work has shown that a different way of distributing the subsidy (other criteria) would contribute to the same effects in terms of energy productivity, generating savings in the form of PLN 2.7 million in the case of the first edition and PLN 6.7 million in the case of the second edition of the program.

Financial resources (as a whole) in the second edition of the "My Electricity" program were distributed worse than in the first edition. In the first edition, as much as 1.93% of funds were allocated inefficiently; in the second edition, it was only 3.66%. However, if we analyze and compare each province, the inequality in the allocation of funds in the second edition increased in comparison to the first edition.

Allocation surpluses occur in provinces where the average disposable income is low and where there is a high value of subsidies per household.

There is a potential to introduce a territorial project selection criteria. The analysis shows that the criteria should promote provinces with higher disposable income and high-value household subsidies. However, the significance of the latter parameter should be clearly explained. The "My Electricity" program is coming to an end. In the future, research should be planned to take into account of the complete data for both editions of the program. Moreover, the research should be extended to the analysis of the optimal allocation of subsidies from the point of view of various parties, i.e., applicants, the state, and the society. The research results may be helpful in designing a new PV technology support program (in 2021).

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Abbreviations

DR	average disposable income in a household in 2018, PLN/month
HHI	Herfindahl–Hirschman index
IS45	average yearly insolation for 45° tilted surface south faced, kWh/m^2/year
LG	number of households in the province
LGW	number of rural households in the province
LM	number of residents in the province
MUG	maximum unit grant amount per kWp, PLN/kWp
PI	total sum of PV power in province, MWp
PLN	Polish monetary unit
PPH	installed capacity per household, Wp/household
PPHC	installed capacity per rural household, Wp/rural household
PPI	the power index expressed in Wp per resident, Wp/inhab.
Prov.	province
PV	photovoltaic
VIF	Variance Inflation Factor
WD	sum of the subsidies in the first edition of "My Electricity" program, PLN

References

1. REN21 Renewables 2018 Global Status Report (Paris: REN21 Secretariat). Available online: http://www.ren21.net/gsr-2018/ (accessed on 12 November 2020).
2. Abrell, J.; Kosch, M.; Rausch, S. Carbon abatement with renewables: Evaluating wind and solar subsidies in Germany and Spain. *J. Public Econ.* **2019**, *169*, 172–202. [CrossRef]
3. Fischer, C.; Newell, R.G. Environmental and technology policies for climate mitigation. *J. Environ. Econ. Manag.* **2008**, *55*, 142–162. [CrossRef]
4. Meckling, J.; Sterner, T.; Wagner, G. Policy sequencing toward decarbonization. *Nat. Energy* **2017**, *2*, 918–922. [CrossRef]
5. Abrell, J.; Rausch, S.; Streitberger, C. The economics of renewable energy support. *J. Public Econ.* **2019**, *176*, 94–117. [CrossRef]
6. Nicolini, M.; Tavoni, M. Are renewable energy subsidies effective? Evidence from Europe. *Renew. Sustain. Energy Rev.* **2017**, *74*, 412–423. [CrossRef]

7. Dong, C.G. Feed-in tariff vs. renewable portfolio standard: An empirical test of their relative effectiveness in promoting wind capacity development. *Energy Policy* **2012**, *42*, 476–485. [CrossRef]
8. Yang, X.; He, L.; Xia, Y.; Chen, Y. Effect of government subsidies on renewable energy investments: The threshold effect. *Energy Policy* **2019**, *132*, 156–166. [CrossRef]
9. Niesten, E.; Jolink, A.; Chappin, M. Investments in the Dutch onshore wind energy industry: A review of investor profiles and the impact of renewable energy subsidies. *Renew. Sustain. Energy Rev.* **2018**, *81*, 2519–2525. [CrossRef]
10. Benalcazar, P.; Suski, A.; Kamiński, J. The Effects of Capital and Energy Subsidies on the Optimal Design of Microgrid Systems. *Energies* **2020**, *13*, 955. [CrossRef]
11. Lekavičius, V.; Bobinaitė, V.; Galinis, A.; Pažėraitė, A. Distributional impacts of investment subsidies for residential energy technologies. *Renew. Sustain. Energy Rev.* **2020**, *130*, 109961. [CrossRef]
12. Kazak, J.K.; Kamińska, J.A.; Madej, R.; Bochenkiewicz, M. Where renewable energy sources funds are invested? spatial analysis of energy production potential and public support. *Energies* **2020**, *13*, 5551. [CrossRef]
13. Bointner, R.; Pezzutto, S.; Grilli, G.; Sparber, W. Financing innovations for the renewable energy transition in Europe. *Energies* **2016**, *9*, 990. [CrossRef]
14. Mitchell, C.; Sawin, J.L.; Pokharel, G.R.; Kammen, D.; Wang, Z.; Fifita, S.; Jaccard, M.; Langniss, O.; Lucas, H.; Nadai, A.; et al. Policy, Financing and Implementation. In *Renewable Energy Sources and Climate Change Mitigation*; Cambridge University Press: Cambridge, UK, 2011.
15. Jacobson, M.Z.; Delucchi, M.A.; Bauer, Z.A.F.; Goodman, S.C.; Chapman, W.E.; Cameron, M.A.; Bozonnat, C.; Chobadi, L.; Clonts, H.A.; Enevoldsen, P.; et al. 100% Clean and Renewable Wind, Water, and Sunlight All-Sector Energy Roadmaps for 139 Countries of the World. *Joule* **2017**, *1*, 108–121. [CrossRef]
16. Arvizu, D.; Bruckner, T.; Chum, H.; Edenhofer, O.; Pichs-Madruga, R.; Sokona, Y.; Seyboth, K.; Eickemeier, P.; Matschoss, P.; Hansen, G.; et al. IPCC, 2011: Summary for Policymakers. In *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*; IPCC: Geneva, Switzerland, 2011; ISBN 9789291691319.
17. Canales, F.A.; Jadwiszczak, P.; Jurasz, J.; Wdowikowski, M.; Ciapała, B.; Kaźmierczak, B. The impact of long-term changes in air temperature on renewable energy in Poland. *Sci. Total Environ.* **2020**, *729*, 138965. [CrossRef]
18. Rai, V.; Reeves, D.C.; Margolis, R. Overcoming barriers and uncertainties in the adoption of residential solar PV. *Renew. Energy* **2016**, *89*, 498–505. [CrossRef]
19. Sahu, B.K. A study on global solar PV energy developments and policies with special focus on the top ten solar PV power producing countries. *Renew. Sustain. Energy Rev.* **2015**, *43*, 621–634. [CrossRef]
20. Zelazna, A.; Gołębiowska, J.; Zdyb, A.; Pawłowski, A. A hybrid vs. on-grid photovoltaic system: Multicriteria analysis of environmental, economic, and technical aspects in life cycle perspective. *Energies* **2020**, *15*, 3978. [CrossRef]
21. Vasseur, V.; Kemp, R. The adoption of PV in the Netherlands: A statistical analysis of adoption factors. *Renew. Sustain. Energy Rev.* **2015**, *41*, 483–494. [CrossRef]
22. Faiers, A.; Neame, C. Consumer attitudes towards domestic solar power systems. *Energy Policy* **2006**, *34*, 1797–1806. [CrossRef]
23. Mundaca, L.; Samahita, M. What drives home solar PV uptake? Subsidies, peer effects and visibility in Sweden. *Energy Res. Soc. Sci.* **2020**, *60*, 101319. [CrossRef]
24. Myojo, S.; Ohashi, H. Effects of consumer subsidies for renewable energy on industry growth and social welfare: The case of solar photovoltaic systems in Japan. *J. Jpn. Int. Econ.* **2018**, *48*, 55–67. [CrossRef]
25. Suh, J.; Yoon, S.G. Maximizing solar PV dissemination under differential subsidy policy across regions. *Energies* **2020**, *13*, 2763. [CrossRef]
26. Balibrea-Iniesta, J. Economic analysis of renewable energy regulation in France: A case study for photovoltaic plants based on real options. *Energies* **2020**, *13*, 2760. [CrossRef]
27. Sampedro, J.; Arto, I.; González-Eguino, M. Implications of switching fossil fuel subsidies to solar: A case study for the European Union. *Sustainability* **2017**, *10*, 50. [CrossRef]
28. Torani, K.; Rausser, G.; Zilberman, D. Innovation subsidies versus consumer subsidies: A real options analysis of solar energy. *Energy Policy* **2016**, *92*, 255–269. [CrossRef]
29. Ministry of Development Typical Reference Year. Available online: https://www.gov.pl/web/fundusze-regiony/dane-do-obliczen-energetycznych-budynkow (accessed on 18 December 2019).
30. Olczak, P.; Matuszewska, D.; Zabagło, J. The Comparison of Solar Energy Gaining Effectiveness between Flat Plate Collectors and Evacuated Tube Collectors with Heat Pipe: Case Study. *Energies* **2020**, *13*, 1829. [CrossRef]
31. NFOŚiGW Mój Prąd. Available online: https://mojprad.gov.pl/wyniki-1-naboru-2019/ (accessed on 7 April 2020).
32. CSO. *National Census*; Central Statistical Office: Warsaw, Poland, 2014.
33. CSO. *Household Budget Survey in 2018*; Central Statistical Office: Warsaw, Poland, 2019.
34. Olczak, P.; Matuszewska, D.; Kryzia, D. "Mój Prąd" as an example of the photovoltaic one off grant program in Poland. *Energy Policy J.* **2020**, *23*, 123–138. [CrossRef]