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Rural–Urban Differences in Solar Renewable Energy Investments Supported by Public Finance in Poland

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Abstract: The deployment of renewable energy (RE) needs to be policy-driven and supported by public funds. Hence, the aim of this study was to find out whether urban and rural areas benefit from public funds for RE deployment equally and whether factors determining other types of investments also determine investments in RES. To do so, we carried out: (i) comparative analyses of qualitative and quantitative data describing 2642 investments in solar RE supported by the European Union funds and carried out in Poland under operational programmes in 2014–2020; (ii) multiple linear regressions, evaluating the predictions. Findings showed that principles of supporting solar RE investments were the same for all kinds of beneficiaries in both urban and rural areas. However, in rural areas, most RE investments cumulated in eastern, north-eastern and south-eastern parts of Poland, and depended only on few socio-economic characteristics. RE investments in urban areas were dispersed all over the country rather evenly and did not depend on any of the socio-economic characteristics. Individual households appeared to be important silent partners to RE investments carried out by local governments. Thus, future policies should focus on them more to increase the deployment and use of solar RE.

Keywords: solar renewable energy; public finance; rural areas; urban areas

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1. Introduction

In many social and economic contexts, including the European Union [1–8], it has been proved and broadly acknowledged that the deployment of renewable energy needs to be policy driven and supported by public funds in order to eliminate barriers and accelerate the use of renewable energy sources [9–12].

Although in the European Union there was continuous progress and an upward trend in renewables, there has been a significant slowdown in renewable energy investments since 2015 [13], and so the process of renewable energy deployment has been assessed to be too slow [14]. The yet-unsatisfying pace of renewable energy deployment in the EU as a whole, and in its individual member states, results from various barriers, which are recognised as technical, administrative, legal, financial and—last but least—social [15–17].

These facts raise serious concerns about achieving the 2030 renewable and sustainable energy targets [18,19], the goals of the resilient Energy Union [20] and consequently, effective climate-change prevention [13]. They also explain why the support for the deployment of renewable energy sources has become one of the main aims of the EU during the transition to a low-carbon economy [21–23] and provides a rationale for maintaining this aim as a development priority.

The EU offers financial support to its member states for the development of renewables [24–26] under regional and cohesion policy [27,28], aimed at public intervention at the territory level. The instruments used for this purpose are mainly structural and investment funds, which are also one of the main elements of the intervention policy.

They are increasingly becoming the driving forces of state and regional governance, supporting the implementation of operational programmes aimed at achieving stable economic development and reducing divergence. As described by Swiader et al. [29], Poland has been obliged to take actions to increase the renewable energy in the energy mix, and the operational programmes were indicated as the main financial instruments to achieve it. EU funds are non-commercial and non-refundable public funds [30] addressed in Poland to different groups of potential beneficiaries all over the country, under either nationwide or regional operational programmes.

However, urban and rural areas, having different development needs and potential [31], may benefit from this support differently. Thus, in order to create a more efficient and effective renewable energy deployment policy design, affecting positively and strongly both urban and rural areas, it is crucial to acquire a more comprehensive understanding of the effects so far of EU public funds on solar renewable energy investments in urban and rural areas, as well as factors conditioning these effects. Despite the importance of such understanding, the facts about the effects of EU funds on the renewable energy investments have not been investigated holistically yet. This study was performed to fill in this gap through an exploratory and explanatory contribution, based on answers to the following research questions:

Q1. Did the operational programmes of 2014–2020 define the same or different principles of the EU funding for investments in solar renewable energy for different groups of potential beneficiaries?

Q2. What are the main outcomes of the analysed investments in solar renewable energy in urban and rural areas?

Q3. Were there any differences in the value of EU funding or the number of solar renewable energy investments among urban areas and among rural areas (intra-case analyses)?

Q4. Did the value of EU funding depend on selected social and economic characteristics of the urban and rural municipalities where the solar renewable energy investments were located?

To answer these questions, we chose to analyse solar renewable energy (SRE) investments because: (i) solar energy is most available in Poland, and photovoltaics have been the most important sector for investments in RES in Poland [32]; (ii) deployment of solar renewable energy is conditioned by quite similar conditions in urban and rural areas all over the country; (iii) the deployment of solar renewable energy is pointed to as a very important factor for the development of urban and rural areas in Poland, since it is the main renewable energy source for the country.

Answers to the research questions may contribute both to science and to practice by: (i) finding out what outcomes public funds cause in urban and in rural areas when they are addressed to certain potential beneficiaries under operational programmes rules, (ii) investigating the rural and urban differences in these outcomes, and (iii) verifying whether the selected socio-economic characteristics of rural and urban communities, defining their levels of development, influence the absorption of EU funds supporting solar RE investments.

2. Literature Review

2.1. Significance of Renewable Energy Deployment for Urban and Rural Development

The diffusion of renewable energy sources will transform economies on a macro and micro scale, both urban and rural areas. The International Renewable Energy Agency (IRENA) forecasted that the share of renewable energy in the primary energy supply will grow from one-sixth in 2020 to nearly two-thirds in 2050 [33]. Several changes will take place regionally and locally; however, as highlighted by Young and Brans [34], such changes will occur on the local level especially. Several publications assumed and reported positive and negative impacts on both supply and demand sides, including many trade-offs. The changes are reported to affect socio-economic, environmental and institutional factors.

From the socio-economic point of view, the slow revolution towards renewable energy production and consumption causes diversification of economic activities and new sources of income [35]. Renewable energy deployment creates opportunities for the development of public and private businesses, both in developed localities, such as metropolitan areas [36], and in developing peripheral territories [37]. The development of businesses will additionally cause an increase in the demand for labour [38,39].

On the regional scale, renewable energy production will impact decentralization of energy production and supplies [40] and enable a step-down to community-owned energy sources [41]. As reported by several scholars, renewable energy production also causes positive externalities for the environment. As claimed by Oudes and Stremke [42], renewable energy production transforms the existing landscapes by changing their structures and composition, along with their functions. Picchi et al. [43] highlighted that it also impacts ecosystem services. Additionally, Mathiesen et al. claim that such activities positively impact the health of local inhabitants [44]. Nonetheless, as argued by Santangeli et al. [45], the increasing renewable energy deployment may spur conflicts over the use of limited land for energy production as opposed to biodiversity conservation.

2.2. The Need of Public Financial Support for Faster and More Widespread Renewable Energy Deployment

Many studies proved that financial barriers are among the greatest bottlenecks hindering the deployment of renewable energy in many regions [15,46] and countries of the world [47,48], in urban and rural areas and in different social and economic conditions [49–52]. A lack or shortage of funding is also an obstacle in the deployment of renewable energy in EU member states. It may hinder renewable energy investments by, e.g., enterprises, or by local and regional authorities [53].

Investments in renewable energy sources, in particular, in photovoltaic technologies, are financed from various sources [54]. Financing investment projects related to renewable energy requires the involvement of many entities, not only in technical and organizational terms but in financial terms. The literature sources indicate the use of an extensive spectrum of financial mechanisms, from private, through community, to public ones [55–57]. The most frequently used financial mechanisms in solar energy investments are various types of combinations of the investor's equity capital with external capital [58,59]. Among these solutions, the grants and the subsidies are dominating [60–62]. These public funds, apart from their investment role, also play the role of promoting solutions that are consistent with state policy and are a source of innovation diffusion [63,64]. The various types of financial mechanisms based on bonds play an important role in financing renewable energy investments, including solar equipment. Often, these are in the form of social or community bonds [65,66] or specific bonds called green bonds [67], pointing to the important role of social involvement in renewable energy issues. Public–private partnerships also play an important role in this respect [59]. Crowd funding mechanisms are a particular innovation in terms of financing investments in green energy sources [68]. This option gives an opportunity to small investors to offer financial support, often a loan with low interest rate and a long debt tenor. The increase in popularity of such solutions results not only from factors related to the growing awareness and proactivity of the society, but also from government incentives related to tax cuts [69]. Apart from innovative financial instruments, classic bank support is evidenced, but this instrument has a less important role in relation to cheaper sources of capital [70]. Literature sources also indicate the existence of other financial instruments used in investing renewable energy, such as venture capitalists [71] and foreign direct investment [72]. It is important to keep in mind that financing for renewable energy involving multi-actor activities and practices, often along with implementation of innovative financial instruments, is associated with several risks which investors should take into account [73,74].

At the same time, it should be remembered that regardless of the adopted level of risk and the investment model used, the implemented investments bring specific benefits, both private and public. In particular, many authors point to the benefits of using public funds in investments of this type—primarily subsidies. Several studies indicate the role of public funds in supporting solar energy investments and achieving spillover effects. The results of the involvement of public funds are not only the development of renewable energy sources, but also economic growth [64,75] and job creation [76]. Some authors point to issues of energy efficiency [77] and ecological sustainability [63,78], and other authors emphasize the roles of economy deregulation and educational transformations [79].

All these provide a rationale for supporting renewable energy investments from public funds, if they are available.

3. Materials and Methods

3.1. Data Sources

To investigate and discuss the differences in urban and rural solar renewable energy investments supported by public funds, this study was based on a complete set of data describing the outcomes of solar renewable energy investments carried out in Poland and co-financed by the EU's regional policy funds under operational programmes in 2014–2020, as of 31 May 2021.

The theoretical background was elaborated based on a review of the literature, legal acts, and qualitative data retrieved from operational programs in 2014–2020. The quantitative data were obtained from sources listed and described in Table 1.

Table 1. Data categories and sources.

Data Categories	Description and Sources
Qualitative data explaining: Who could be the beneficiary of solar renewable energy investments in urban and in rural areas? Where could the projects be located? What were the rules for obtaining EU funds in rural and in urban areas?	The data was extracted from the operational programmes 2014–2020 that provided EU fund to co-finance solar renewable energy investments, the programmes were retrieved from [80], the governmental portal dedicated to EU regional policy funds in Poland
Qualitative and quantitative data on each solar renewable energy investment, including: The total value (Polish zloties), EU funds (Polish zloties) Location of the investment Type of the leading beneficiary Category of the investment	Qualitative and quantitative data on 3362 solar renewable energy investments carried out in Poland under Operational Programmes 2014–2020. The original SL 2014 data basis included 203,505 entries describing all kinds of investment as of 31 May 2021 and was retrieved on 1 June 2021 from [81] the Central Teleinformation System SL 2014, run by the Ministry of Funds and Regional Policy.
Types of municipalities by the degree of urbanisation (DEGURBA) to delineate urban and rural areas	The degree of urbanization (DEGURBA) classification categorizes municipalities into the three categories: Code 1—cities, or: densely populated areas Code 2—towns and suburbs, or: intermediate density areas Code 3—rural areas, or: thinly populated areas retrieved on 30 June 2020 from [82]
Tax ID of municipalities	National Court Register [83] accessed on 15 January 2021.
TERYT codes, names and types of administrative units	Database retrieved from the National Official Register of the Territorial Division of the Country (TERYT) [84].
Share of the unemployed in population of working age	Data, as of 31 December for every year 2014–2020, retrieved from the Local Data Bank, Statistics Poland [85] on 1 June 2021
Population	
Share of working age population in total population	
Share of post-working age population in total population	
Density of population, persons per 1 square km	
Number of businesses per 10,000 population of working age	
Total municipality budget revenues, PLN per 1 inhabitant	
Municipality budget revenues from Personal Income Tax, PLN per 1 inhabitant	
Municipality budget revenues from Corporate Income Tax, PLN per 1 inhabitant	
Average age of municipality council members	
Beneficiaries of social assistance per 10,000 inhabitants	
% of population using sewers	Data, as of 31 December 2019 (the latest available data), retrieved from [85] on 1 June 2021
% of population using water from waterworks	
% of population using gas from gas pipelines	

3.2. Methods—Rationale for Selection of Variables

In the first stage, the datasets from different sources (Table 1) were verified, completed, cross checked and merged into one database, using TERYT code and categories of administrative units by DEGURBA classification.

To answer Q1 (Table 2), we concluded an analysis based on the qualitative data listed in Table 1, using standard qualitative analysis tools [86–89].

Table 2. Methodological framework.

Stage	Research Questions	Method
I	Q1. Did the operational programmes 2014–2020 define the same or different principles of the EU funding support for investments in solar renewable energy for different groups of potential beneficiaries in urban and rural areas?	qualitative analysis
II	Q2. What are the main outcomes of the analysed investments in solar renewable energy in urban and rural areas?	descriptive statistics
III	Q3. Were there any differences in the value of EU funding and the number of solar renewable energy investments within urban and within rural areas?	descriptive statistics, intra-case analysis cartograms
IV	Q4. How did the total value of investments in solar renewable energy depend on the EU funding obtained by different groups of beneficiaries in urban areas and in rural areas? Q5. Did the value of EU funding depend on selected social and economic characteristics of the urban and rural municipalities where the solar renewable energy investments were located?	multiple linear regressions

To answer Q2–Q5, we applied descriptive statistics. To answer Q3, we elaborated maps (Figures 1 and 2) showing differences in the value of EU funding supporting solar renewable energy investments within individual urban and rural municipalities (intra-case analysis).

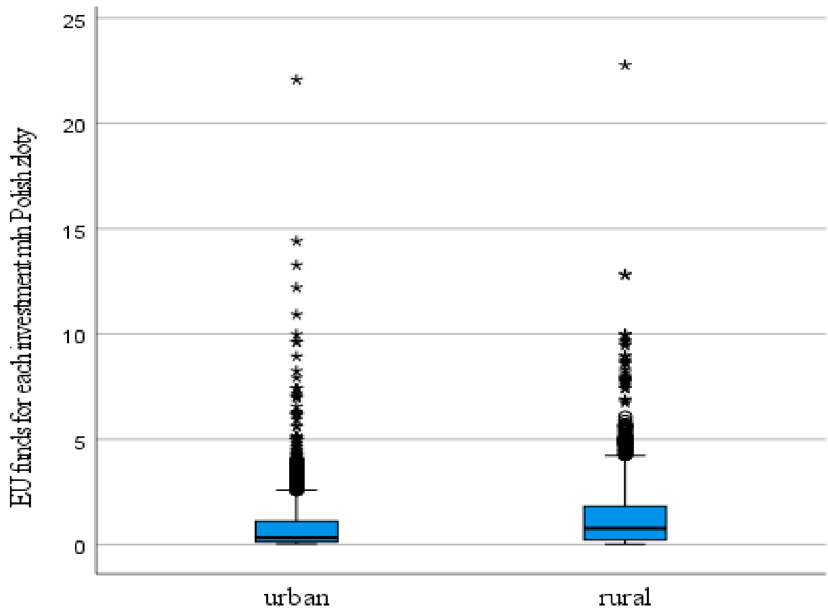

Figure 1. Boxplots of EU funds per solar renewable energy investment under operational programmes in 2014–2020 in urban and rural areas. Explanation: * shows the value of EU funding in mln Polish zloty for each solar RE investment in urban and in rural areas.

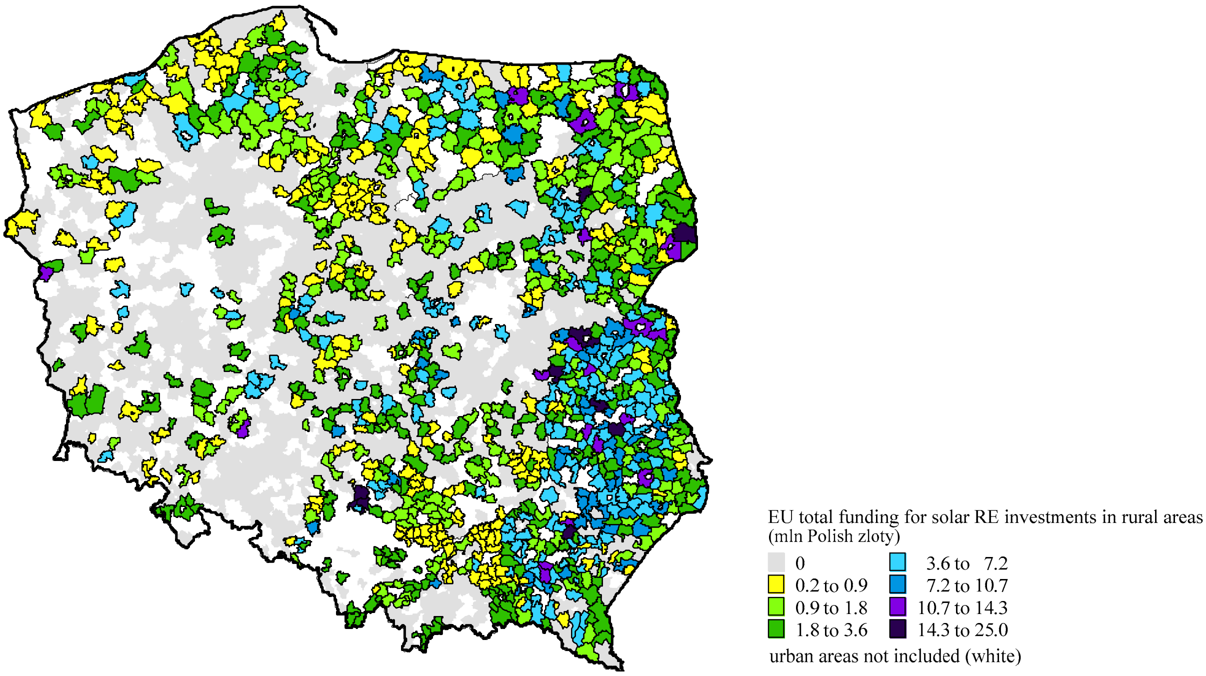

Figure 2. Total value of EU funds for solar RE investments in rural areas under operational programmes in 2014–2020, mln Polish zloty, as of 31 May 2021.

Next, to explore the relationships between the selected dependent variable and independent variables (predictors), we applied multiple linear regression.

To answer if the value of the absorbed EU funding depended on selected social and economic characteristics of the urban and rural municipalities where the solar renewable energy investments were located (Q4), we carried out two multiple linear regressions. In the case of linear regression for urban areas, the value of EU funding obtained for each analysed investment in urban municipalities was a dependent variable (DV1); and data categories describing socio-demographics, living conditions and economic conditions were predictors, listed in Table 3 as x_6–x_{19}. The same design was used for rural areas, where the values of EU funding obtained for the analysed investments in rural municipalities was a dependent variable (DV2) and x_6–x_{19} (Table 3) were predictors. The predictors are the key characteristics defining the level of development of communities. They were selected based on the literature review and authors' research experience.

Table 3. Definitions of predictors used in multiple linear regressions.

Designation of Predictors	Predictors Names and Units (Quantitative Data)
	Socio-demographics and living conditions
x_1	Average population in 2014–2020
x_2	Average share of working age population in total population in 2014–2020
x_3	Average share of post-working age population in total population in 2014–2020
x_4	Average density of population, persons per 1 square km in 2014–2020
x_5	Average age of municipality council members
x_6	Share of population using sewers in 2019, % of total population
x_7	Share of population using water from waterworks in 2019, % of total population
x_8	Share of population using gas from gas pipelines in 2019, % of total population
x_9	Average number of beneficiaries of social assistance per 10,000 inhabitants in 2014–2020
	Economic Conditions
x_{10}	Average number of enterprises per 10,000 inhabitants in 2014–2020
x_{11}	Average number of the registered unemployed in 2014–2020
x_{12}	Average municipality budget total revenues in 2014–2020, PLN per 1 inhabitant
x_{13}	Average municipality budget revenues from Personal Income Tax in 2014–2020, PLN per 1 inhabitant
x_{14}	Average municipality budget revenues from Corporate Income Tax in 2014–2020, PLN per 1 inhabitant

4. Results

4.1. The Main Socio-Economic Characteristics of Rural and Urban Areas in Poland

Taking into consideration administrative division at the local level and applying DEGURBA classification, urban areas comprise 601 municipalities, and rural areas, 1878. Consequently, there were 601 local governments in urban areas and 1878 in rural areas that could be potential beneficiaries of EU funds supporting the deployment of renewable energy.

Urban areas in Poland are inhabited by 64% of total population, which gives the average density of 691 persons per 1 km^2. Rural areas are inhabited by 34% of total population. The average density is 67 persons per 1 km^2. The share of old population in urban areas is by 2 percentage points (pp) higher than in rural areas, and the share of the population of working age is 1.7 pp lower. The members of urban local authorities are on average 1 year older than those in rural municipalities (Table 4).

The population in rural areas is poorer and more dependent on social assistance—in rural areas there were on average 372 beneficiaries of state social assistance per 10,000 inhabitants more than in urban areas. Rural areas also have higher registered unemployment rates.

Taking into consideration technical infrastructure, the standard of living in urban areas is higher, as 93% of dwellings are connected to the sewerage system, 78% to water supply systems and 57.5% to gas supply lines. These indices are lower in rural areas by 6.4, 37.6 and 40.7 percentage points, correspondingly.

More businesses are located in urban than in rural areas, so both the average PIT and CIT municipality budget revenues per capita were higher in urban than in rural areas. However, the average total municipality budget revenues per capita were slightly (by 11.5 Polish zloties) higher in rural than in urban areas.

Table 4. Main characteristics of urban and rural areas in Poland.

Characteristics	Urban Areas	Rural Areas
Number of municipalities as of 31 December 2020	601	1878
Average * population	24,623,664	13,779,614
Average * density of population	690.5	66.8
The share of old population (post-working age) as of 31 December 2020	22.3	20.1
The share of population of working age	59.5	61.2
Average * total municipality budget revenues per capita (Polish zloties)	4261.2	4272.7
Average * number of businesses per 10,000 population	1804.9	1184
Average * PIT municipality budget revenues per capita (Polish zloties)	883.6	500.8
Average * CIT municipality budget revenues per capita (Polish zloties)	48.0	14.4
Average * age of members of local authorities	51.6	50.6
Average * registered unemployment index	5.4	6.4
Average * number of beneficiaries of the state social assistance per 10,000 inhabitants	556.6	929.4
The share of dwellings connected to sewer system, as of 31 December 2019	92.8	86.4
The share of dwellings connected to water supply system, as of 31 December 2019	77.7	40.1
The share of dwellings connected to gas supply system, as of 31 December 2019	57.5	16.8

* All average values were calculated for 2014–2020 based on data as of 31 December for each included year; other categories present the latest available data.

4.2. The Main Assumptions of Operational Programmes in 2014–2020 about the EU Funding for Solar Renewable Energy Investments

The first part of the study on the assumptions of the operational programs of 2014–2020 about co-funding the solar renewable energy investments in Poland was based on the analysis of all operational programs. The cross check with the SL 2014 database, showing all investments, confirmed that the Operational Program Infrastructure and Environment

2014–2020 and 16 regional operational programs were sources of EU funds supporting this objective.

Operational Programme Infrastructure and Environment 2014–2020 was a national programme to support low carbon economy, environmental protection, adaptation to climate change, transport and energy security. EU funds from this programme were used also for investment in the health and cultural heritage [85]. The programme assumed the reduction of carbon emission through utilisation of existing and development of potential solutions with the highest energy efficiency, with an emphasis of complex and networking solutions. Due to the fact that the intervention was of a horizontal nature and affected the entire country, supported target groups were individual users and businesses using the electricity, natural gas (biogas) and heat networks. Within priority axis 1, "Decreasing the emission intensity of the economy," there was a dedicated action aimed at supporting investments in the production of energy from renewable sources. The main aim of this action was to support the implementation of investment projects concerning: construction or reconstruction of generating units resulting in an increase in energy production from renewable sources, including connection of these sources to the distribution and transmission network.

Voivodship self-governments received almost 40% of the total of EUR 72.9 billion allocated to Poland from the EU Cohesion Policy budget for 2014–2020. Regional authorities could allocate these funds under regional operational programmes to meet the most vital development needs, including the deployment of RE. This way, regional operational programmes became another core mechanism in Poland, providing public funds supporting investments in the production of RE. Additionally, the role of regions in the management of EU funds has been increased.

Dedicated support activities focused mainly on projects related to the construction of new generation sources—thermal and electricity generation. The group of generation sources included primarily geothermal, wind, water, solar, biomass and biogas energy. The implementation of investments in this area aimed to increase the number of new renewable energy source installations and the level of energy production from renewable sources, which significantly strengthened local energy security and increased new generation capacities.

The analysis of the strategic approach of particular measures dedicated to renewable energy installations under actions of the Operational Programme Infrastructure and Environment 2014–2020 as a country-wide programme and sixteen regional operational programmes (Table 5) indicated significant similarities, with only a few differences. All of the analysed programmes focused on projects aimed at increasing the production of electricity and heat from renewable sources by implementing investments in the construction or reconstruction of electricity and heat generation units. First of all, the use of small energy sources, located close to the recipient, reducing transmission losses and ensuring the ecological effect by increasing the share of renewable energy in consumption (distributed energy), was promoted. In all analysed regions, the measures were dedicated to both public and private entities. Only in two cases (Świętokrzyskie and Małopolskie), there was an additional indication to support rural areas. In six of the analysed regional operational programmes (for voivodships: Dolnośląskie, Lubelskie, Małopolskie, Podlaskie, Podkarpackie and Świętokrzyskie) special attention was paid to less developed areas.

Summing up, the requirements for obtaining EU funds from different groups of rural and urban beneficiaries were the same in all operational programmes (answer to research question 1—Q1). Private and public entities, self-government entities, churches, educational institutions, cultural institutions and farmers were all eligible for support.

Table 5. Strategic approach of particular measures dedicated to renewable energy installations in Poland in the years 2014–2020.

Operational Programme (OP) and Regional Operational Programme (ROP)	Activity
OP Infrastructure and Environment 2014–2020	1.1. Supporting the production and distribution of energy derived from renewable sources
ROP for Lubuskie Voivodeship 2014–2020	3.1. Renewable energy sources
ROP for Dolnośląskie Voivodeship 2014–2020	3.1. Production and distribution of energy from renewable sources and 3.2. Energy efficiency in SMEs
ROP for Kujawsko-Pomorskie Voivodeship 2014–2020	3.1. Supporting the production and distribution of energy derived from renewable sources
ROP for Lubelskie Voivodeship 2014–2020	4.1. Support for the use of renewable energy
	4.2. RES energy production in enterprises
ROP for Łódzkie Voivodeship 2014–2020	4.1. Renewable energy sources
ROP for Małopolskie Voivodeship 2014–2020	4.1. Increasing the use of renewable energy sources
ROP for Mazowieckie Voivodeship 2014–2020	4.1. Renewable energy sources
ROP for Podkarpackie Voivodeship 2014–2020	3.1. Renewable energy sources development
	3.2. Energy modernization of buildings
ROP for Podlaskie Voivodeship 2014–2020	5.1. Energy based on renewable energy sources
ROP for Pomorskie Voivodeship 2014–2020	10.3. Renewable energy sources
ROP for Śląskie Voivodeship 2014–2020	4.1. Renewable energy sources
	4.3. Energy efficiency and renewable energy sources in public and housing infrastructure
ROP for Świętokrzyskie Voivodeship 2014–2020	3.1. Production and distribution of energy from renewable sources
ROP for Warmińsko-Mazurskie Voivodeship 2014–2020	4.1. Supporting the production and distribution of energy derived from renewable sources
ROP for Zachodniopomorskie Voivodeship 2014–2020	2.10. Increasing the use of renewable sources
	2.9. Replacing conventional energy sources with renewable sources
ROP for Wielkopolskie Voivodeship 2014–2020	3.1. Production and distribution of energy from renewable sources

4.3. The Main Rural-Urban Differences in Solar RE Investments Carried Out under Operational Programmes 2014–2020 (Inter-Case Analysis)

The EU funds co-financed 3362 investments in solar renewable energy carried out under operational programmes 2014–2020. The EU funding equalled 4047.1 million Polish zloty and constituted 60% of the total value of these investments.

Results referring to research question 2 (Q2) show that a majority (64%) of the analysed investments were located in rural areas, and also a majority (71%) of EU funds supporting solar renewable energy were invested in rural areas (Table 6). Urban areas accommodated the remaining 36% of investments and had a share of 29% of the total of EU funding obtained for this aim. However, the average value of EU funds per investment in urban areas was higher than in rural areas.

The boxplots shown in Figure 2 display the distribution of EU funds per solar renewable energy investment carried out under operational programmes of 2014–2020 in urban and in rural areas.

Table 6. The main rural–urban differences in absorption of 2014–2020 EU funding for solar RE investments.

Data Category	Urban Areas	Rural Areas
Number of investments	1201 (=100%)	2161 (=100%)
The share of investments by leading beneficiaries:		
small and medium-sized enterprises	55.7%	40.3%
big enterprises	9.8%	4.6%
local and regional authorities	26.5%	50.2%
NGO	5.1%	4.5%
other	2.9%	0.4%
Descriptive statistics for the value of obtained EU funding, mln PLN		
total	1178.1	2868.3
min	0.03	0.02
max	22.1	22.8
range	22.0	22.7
std. dev	1.7	0.03
mean	1.0	1.3
median	0.3	0.8
The average value of EU funds per 1 investment, mln PLN	1.02	0.75
Number of municipalities, where investments were located	350	1010
of which the share of municipalities with:		
1 investment	45.0%	53.4%
2 investments	19.4%	20.9%
3–4	15.7%	17.1%
5–10	13.7%	7.6%
10–19	5.1%	1%
23–60	1.1%	–
Number of investments per 10,000 inhabitants	1.2	2.9
The average share of EU funds in total costs of investments	59%	61%
The average value of EU funds per 1 inhabitant PLN	12.5	172.2
Number of leading beneficiaries	937	1464

4.4. The Main Differences in Solar RE Investments in Rural and in Urban Areas under Operational Programmes in 2014–2020

This subsection presents results on the differences in the value of EU funding and the number of solar renewable energy investments within urban and within rural areas based on intra-case analyses. Thus, the results provide answers to research question 3 (Q3).

4.4.1. Intra-Case Analysis 1—The Main Differences in Solar RE Investments Carried Out in Rural Areas under Operational Programmes in 2014–2020

The 2161 SRE investments were located in 1010 municipalities, i.e., 53% of all rural municipalities. The SRE investments' total value ranged from 0.05 to 40.5 mln PLN, and the value of EU funding ranged from 0.03 to 24.9 mln PLN, giving the share of EU funding in total of 23% to 85%.

In 7% of rural municipalities, the SRE investments were co-financed by less than 1 mln PLN of EU funding, in 60% by 1 to 5 mln PLN of EU funding, in 32% by from 5 to 20 mln PLN, and lastly in 2% of rural municipalities by 20 to 24.9 mln PLN.

In 2014–2020, in 53% of rural municipalities only one SRE investment was given, in 38% from 2 to 4 investments and in 7% of them from 5 to 7 investments.

Most analysed SRE investment cumulated in eastern, north-eastern and south-eastern rural areas of Poland. Investments in solar renewable energy co-financed by EU funds were not located in many rural municipalities of western, south-western and central Poland. Most of the highest values of EU funding were in the south-eastern rural areas of the country (Figure 2).

4.4.2. Intra-Case Analysis 2—The Main Differences in Solar RE Investments Carried Out in Urban Areas under Operational Programmes 2014–2020

The 1201 SRE investments were located in 350, i.e., 58%, of urban municipalities. Their total value ranged from 0.06 to 41.6 mln PLN, and the value of EU funding for SRE investments ranged from 0.04 to 24.3 mln PLN, giving the shares of EU funding in total of 23% to 85%.

In 28% of urban municipalities, the SRE investments were co-financed by less than 1 mln PLN of EU funding, in 51% by 1 to 5 mln PLN of EU funding, in 20% by 5 to 20 mln PLN funding and in 1% of these municipalities by 20 to 24.9 mln PLN funding.

In 2014–2020, in 45% of urban municipalities only one SRE investment was given, in 35% from 2 to 4 investments and in 23% of them from 5 to 7 investments. Urban areas accommodated also leaders—the municipalities where 23 to 60 SRE investments were located.

The analysed SRE investments were dispersed in urban areas all around the country rather evenly, compared to the locations of all urban municipalities (Figure 3).

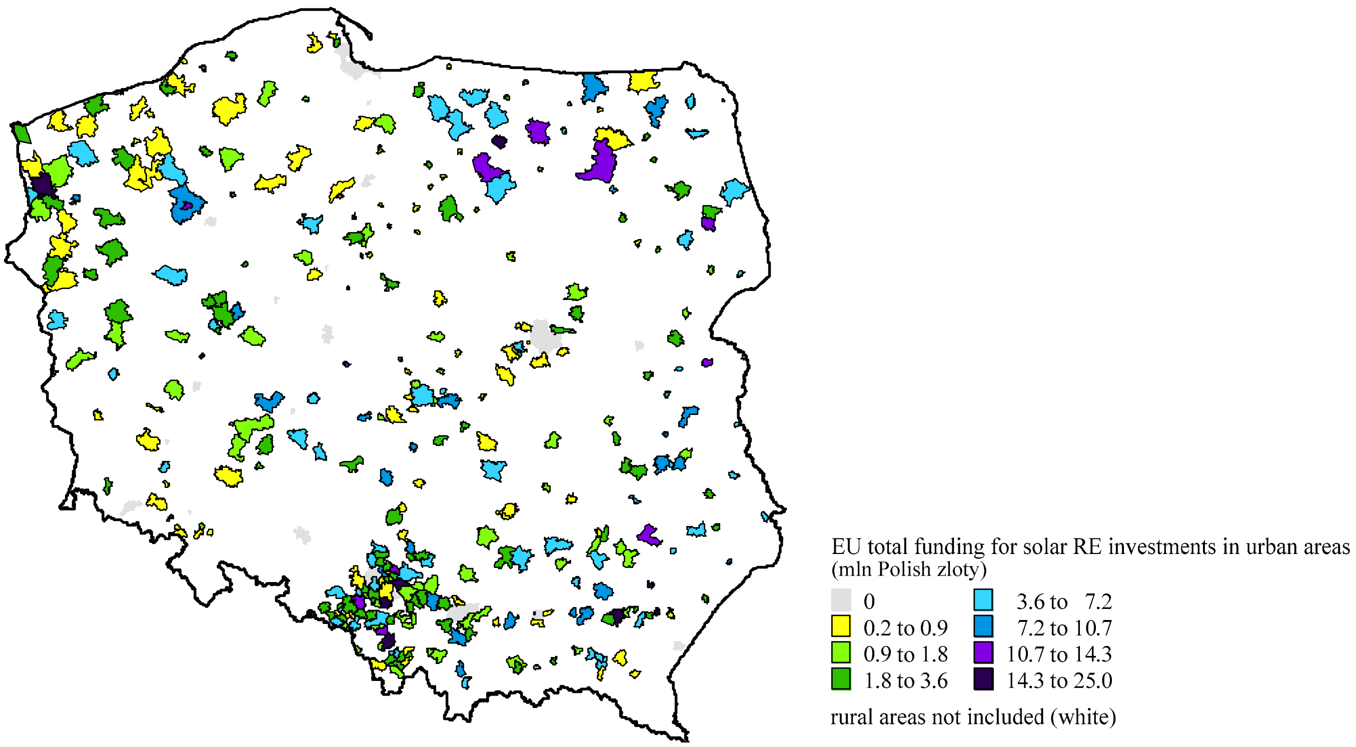

Figure 3. Total value of EU funds for solar RE investments in urban areas under operational programmes 2014–2020, mln Polish zloty, as of 31 May 2021.

4.5. Relations between the Value of EU Funding for Solar Renewable Energy Investments in Urban and Rural Areas and Their Main Socio-Economic Characteristics—Multiple Linear Regression Models for Rural and Urban Areas

To predict the value of EU funding for investments in solar renewable energy from selected socio-economic characteristics of urban municipalities (dependent variable in model 1 = DV1) and of rural municipalities (dependent variable in model 2 = DV2), we calculated two multiple linear regressions based on predictors x_6–x_{19} (Table 3), using the enter method. The enter method (or: forced entry) is a method in which all predictors are forced into the model simultaneously. Descriptive statistics for urban (N = 350) and rural (N = 1010) municipalities where solar renewable investments were located are shown in Table 7. This part of the study provides the answer to question 6: "Did the value of EU funding depend on selected social and economic characteristics of the urban and rural municipalities where the solar renewable energy investments were located?"

Table 7. Descriptive statistics for urban (N = 350) and rural (N = 1010) municipalities where solar renewable investments were located.

Variables	Municipalities of			
	Urban Areas N = 350		Rural Areas N = 1010	
	Mean	Std. Dev.	Mean	Std. Dev.
Total value of renewable energy investments (mln PLN)	5.7	6.4	4.6	4.9
EU funds invested in solar renewable energy (mln PLN)	3.38	3.74	2.84	2.91
x_1	42,840	74,919	7460	4521
x_2	59.5	1.7	61.2	1.8
x_3	22.7	3.1	20.4	3.2
x_4	715	698	70	82
x_5	51.5	3.3	50.7	3.5
x_6	92.9	11.7	84.3	19.8
x_7	78.5	17.6	39.3	25.2
x_8	60.0	32.1	18.8	26.3
x_9	586	260	993	456
x_{10}	1721	476	1145	431
x_{11}	1309	2086	297	197
x_{12}	4215	799	4316.5	1560.5
x_{13}	868	312	479.6	229.9
x_{14}	45	45	14.47	69.9

For urban municipalities, we found that the model is not significant ($F(14, 335) = 1.696$, $p > 0.005$).

In case of rural municipalities, we found that the model is significant but explains only 6.1% of the variance in the value of EU funding for investments in solar renewable energy ($F(14, 995) = 2708.760$ *, $p < .001$), with an R^2 of 0.061 (Table 8).

The significance associated with *b*-values of the independent variables (Table 9) show that only four predictors, i.e., x_{12} and x_{14}–x_{16}, made a contribution to the model. Other predictors do not make such contributions, as their *p*-values are greater than 0.005.

The magnitudes of *t*-statistics for x_{12} and x_{14}–x_{16} showed that for x_{14} the average number of beneficiaries of social assistance per 10,000 inhabitants in 2014–2020 ($t(995) = -3.058$, $p = 0.002$) had the strongest negative impact on the value of EU funding for investments in solar renewable energy in rural municipalities (explaining 0.9% of the change in DV2).

Next—in decreasing order of impact—was x_{16}, the average number of the unemployed ($t(995) = 2.840$, $p = 0.005$), explaining 0.8% of the change in DV2; then came x_{12}, the share of population using water from waterworks in 2019 ($t(995) = -2.774$, $p = 0.006$), explaining 0.7% of the change in DV2 and x_{15}, the average number of enterprises per 10,000 inhabitants in 2014–2020 ($t(995) = 2.774$, $p = 0.006$), explaining 0.7% of the change in DV2.

Based on the results, we can define the model as follows:

$$DV1 = 2632941.526 - 11669.364x_{12} - 715.697x_{14} - 976.889x_{15} + 2072.922x_{16}$$

Table 8. Model 1 and model 2 summary [a,b].

	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
Model 1 urban areas	0.257 [a]	0.066	0.027	3,692,519.126	1.901
Model 2 rural areas	0.247 [a]	0.061	0.048	2,837,418.433	2.042

[a]. Predictors: independent variables x_1–x_{14} listed in Table 2. [b]. Dependent variable: amount of EU funding co-financing solar renewable energy investments, Polish zloties.

Table 9. Model 1 and model 2 coefficients [a,b].

	Variable	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations			Colinearity Statistics	
		B	Standard Error	Beta			Zero-Order	Partial	Part	Tolerance	VIF
	(Const.)	−3,859,098.951	16,381,484.51		−0.236	0.814					
Model 3 Urban areas	x_1	11.158	6.551	0.223	1.703	0.089	0.227	0.093	0.090	0.163	6.153
	x_2	49,458.650	228,002.105	0.023	0.217	0.828	−0.042	0.012	0.011	0.258	3.876
	x_3	−18,773.635	111,859.865	−0.016	−0.168	0.867	0.051	−0.009	−0.009	0.320	3.124
	x_4	72.648	406.095	0.014	0.179	0.858	0.103	0.010	0.009	0.487	2.054
	x_5	87,145.895	64,126.646	0.077	1.359	0.175	0.012	0.074	0.072	0.879	1.138
	x_6	18,548.184	18,328.183	0.058	1.012	0.312	0.064	0.055	0.053	0.857	1.166
	x_7	−5061.897	14,048.645	−0.024	−0.360	0.719	0.027	−0.020	−0.019	0.636	1.573
	x_8	186.868	7254.346	0.002	0.026	0.979	0.055	0.001	0.001	0.720	1.389
	x_9	−658.897	990.602	−0.046	−0.665	0.506	−0.075	−0.036	−0.035	0.572	1.750
	x_{10}	−363.586	621.228	−0.047	−0.585	0.559	0.029	−0.032	−0.031	0.435	2.299
	x_{11}	115.049	220.537	0.064	0.522	0.602	0.214	0.028	0.028	0.185	5.409
	x_{12}	−158.900	375.480	−0.034	−0.423	0.672	0.072	−0.023	−0.022	0.420	2.382
	x_{13}	−73.936	1154.223	−0.006	−0.064	0.949	0.076	−0.003	−0.003	0.301	3.320
	x_{14}	−1074.719	5705.463	−0.013	−0.188	0.851	0.069	−0.010	−0.010	0.573	1.745
	(Const.)	2,632,941.526	5,437,778.694		0.484	0.628					
Model 4 Rural areas	x_1	59.573	38.354	0.093	1.553	0.121	0.148	0.049	0.048	0.262	3.811
	x_2	−17,807.304	73,327.381	−0.011	−0.243	0.808	0.001	−0.008	−0.007	0.436	2.292
	x_3	−5869.573	44,303.123	−0.007	−0.132	0.895	−0.011	−0.004	−0.004	0.389	2.572
	x_4	−2070.027	1305.123	−0.058	−1.586	0.113	0.002	−0.050	−0.049	0.699	1.431
	x_5	35,368.511	26,253.197	0.042	1.347	0.178	0.056	0.043	0.041	0.950	1.053
	x_6	−801.576	4858.343	−0.005	−0.165	0.869	−0.023	−0.005	−0.005	0.862	1.160
	x_7	−11,669.364	4206.343	−0.101	−2.774	0.006	−0.068	−0.088	−0.085	0.710	1.409
	x_8	1470.024	4220.059	0.013	0.348	0.728	0.051	0.011	0.011	0.647	1.545
	x_9	−715.697	234.018	−0.116	−3.058	0.002	−0.086	−0.097	−0.094	0.657	1.522
	x_{10}	−976.889	356.241	−0.145	−2.742	0.006	−0.053	−0.087	−0.084	0.335	2.982
	x_{11}	2072.922	729.872	0.140	2.840	0.005	0.163	0.090	0.087	0.386	2.591
	x_{12}	172.521	145.630	0.092	1.185	0.236	−0.051	0.038	0.036	0.155	6.461
	x_{13}	702.108	697.662	0.056	1.006	0.314	0.010	0.032	0.031	0.310	3.224
	x_{14}	−3609.816	3112.139	−0.087	−1.160	0.246	−0.010	−0.037	−0.036	0.169	5.923

[a]. Predictors: independent variables x_1–x_{14} listed in Table 2. [b]. Dependent variable: total value of solar renewable energy investments, Polish zloties.

5. Conclusions and Discussion

Public funds supporting the deployment of solar renewable energy under the EU's regional policy were available in Poland to a wide range of urban and rural beneficiaries on the same terms. The total value of investments in solar renewable energy was most strongly predicted by the value of EU funding obtained by small and medium-sized enterprises and by local and regional authorities both in urban and in rural areas. These two groups of beneficiaries contributed most to the deployment of renewable energy supported by EU funding, in both urban and rural areas. However, it needs to be stressed that local authorities often represent local households when applying for financial support under operational programmes. Consequently, in practice, there is one more group of beneficiaries—households—who are not listed as partners of the projects, but who participate in the deployment of solar renewable energy as well. This proves that Polish consumers are willing to pay for green electricity [90], like households in other central European countries [91].

There were significant differences in the spatial layout of EU solar renewable energy investments in rural areas, whereas in urban areas the investments were dispersed all around the country rather evenly. This pattern reflects quite well the pattern of absorption of EU funds in general.

The value of EU funding invested in solar renewable energy projects in urban areas did not depend on their socio-economic characteristics, and in rural areas it depended only on four out of 14 socio-economic characteristics. Additionally, these characteristics, namely, the share of population using water from waterworks, the average number of beneficiaries of social assistance per 10,000 inhabitants in 2014–2020 and the average number of enterprises per 10,000 inhabitants in 2014–2020, explained only a small part of the change in the value of EU funds. This shows that the absorption of EU funding supporting solar RE investments does not depend on the selected socio-economic characteristics, which are the key factors determining the level of local development at the same time. In the situation where local governments are one of the two main groups of beneficiaries, this lack of relation can be explained by the financial contribution of households participating in the solar RE investments under operational programmes 2014–2020. This source of domestic funding makes solar RE investments under operational programmes 2014–2020 totally independent from communities' budgets and thus allows local governments to carry out solar RE investments independently of communities' priority tasks, e.g., the development of infrastructure [92].

The deployment of solar renewable energy proved to be based on and depend on endogenous factors, mostly the will and financial resources of potential beneficiaries, in both urban and in rural areas.

In programmes supporting the production of energy from renewable sources in Poland within 2014–2020, the importance of using micro-innovations and technologies with a small scale of impact was noticed, as in previous work [93]. The investment in solar installations especially significantly impacted the landscape of different territories in Poland and resulted in a change in land use patterns of large areas [94]. It is also important that investments in the production of energy from renewable sources on local levels in Poland [95,96], similarly to other countries [97], resulted not only from the policy intervention, but also from local knowledge and networking level, which significantly accelerated the uptake of funds and diffusion of new technologies. That was also the policy intervention objective of the European Union [26].

Summing up, we would like to stress that solving the problem of replacing fossil energy with green energy supplies by solar installations causes serious concerns about the amount of PV panel waste. As the International Renewable Energy Agency and the International Energy Agency Photovoltaic Power Systems Program predict, solar PV panels could generate as much as 78 million tones of waste by 2050 [98]. If not tackled effectively, it will pose serious challenges to circular economy development and the environment [99,100]. Thus, it is evident that supporting the deployment of solar renewable energy through different types of installation requires forward thinking and planning about the recycling of the used devices and their components, and thus designing an effective management scheme for solar or photovoltaic waste [101].

6. Recommendations

Based on the findings and conclusions of this study, we recommend: (i) investigation into the causes of rural–urban differences concerning the cumulation of SRE investments in some parts of rural areas and the lack of such investments in other parts of the country; (ii) looking into the reasons for the much lesser contributions of such groups of beneficiaries such as big enterprises, NGOs and others, to SRE investments under operational programmes.

Renewable energy deployment needs to be continuously supported by public funds. Their allocation must be evidence-based, and the continued top-down approach should enable flexible reacting to changing energy market conditions and laws and regulations. Programmes supporting solar renewable energy deployment should build up on already existing collaboration among local authorities and between local authorities and individual households, strengthening endogenous rural and urban potentials for renewable energy deployment.

The advantages of solar renewable energy investments for public facilities and for individual households should be promoted more, highlighting their positive practical aspects, to encourage other new urban and rural beneficiaries to take up such projects.

7. Limitations

A limitation to this study may be the fact that EU funds are a special kind of public funding. Their most unique and important characteristic is being non-refundable, which may result in different outcomes for solar renewable energy investments than those supported by other types of public funding. Thus, the findings and conclusions of this research should be attributed to EU funds only, until a comparative study with other public funding outcomes confirms or rejects this limitation.

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