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PHOTOVOLTAIC MICROGENERATION (RES) IN SELECTED MAJOR CITIES IN SILESIAN VOIVODESHIP

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ABSTRACT: The impact of climate change on the economy and environment humans live in has increased, leading to a relatively quick intensification of the effort to reduce the environmental footprint of the civilisation. The push to establish a sustainable energy economy has become one of the primary challenges today. A sustainable energy economy should ensure energy security, reduce energy poverty, and contribute to lower greenhouse gas emissions. Poland is facing considerable challenges relevant to the objectives of EU policy, particularly the Fit for 55 package, which cannot be achieved without renewable energy sources. The most popular renewable energy source in Poland is solar energy. Apart from its obvious advantages, the use of distributed photovoltaic generation (including microgeneration) entails the need for transmission grid upgrades. The paper's objective was to assess the RES potential of Poland through an analysis of the steps the state took and the progress of its targets. The empirical part focuses on the assessment of the use of the solar energy potential (in photovoltaic microgeneration) in cities with district rights in Silesian Voivodeship, Poland, from 2014 to 2020. The study employs selected cartographic representation, comparative analysis, in-depth case study, and spatial analysis methods. The calculations involved data from Tauron Dystrybucja SA on the number of microgeneration systems in the cities, Database of Topographic Objects, Local Data Bank of the Central Statistical Office of Poland and Eurostat.

KEYWORDS: renewable energy sources, global warming, sustainable development, photovoltaic microgeneration

Introduction

A competitive, safe, and sustainable energy economy that helps curb greenhouse gas (GHG) emissions is the primary climate and energy challenge for the European Union and Poland as its member state. Sustainable energy economy is the seventh of the Sustainable Development Goals listed by the United Nations (2022).

Intensified use of renewable energy sources (RES) is an important component of a sustainable energy economy and a method for controlling climate change. RES means not only reduced CO_2 emissions but also lower emissions of air pollutants and alleviation of low emission ramifications, although to a lesser extent.

In the past, Poland signed documents obliging it to reduce greenhouse gas emissions (such as the Kyoto Protocol or Paris Agreement). The country's agreement is currently bound by is the European Green Deal and the Fit for 55 package aiming at a 55% reduction in greenhouse gas emissions and European Union climate neutrality by 2050.

Among the different types of settlement units, urban areas account for the largest share of GHG emissions. (Seto et al., 2014) presents several estimates that indicate the significant contribution of cities to GHG emissions. Cities also have higher building density compared to rural areas hence solar energy, unlike wind or water energy, is one of the main renewable energy sources used in dense suburban spaces.

The paper's objective was to assess the RES potential of Poland through an analysis of the steps the state took and the progress of its targets. The empirical part focuses on the assessment of the use of the solar energy potential (in photovoltaic microgeneration) in cities with district rights in Silesian Voivodeship, Poland, from 2014 to 2020. The study employs selected cartographic representation, comparative analysis, in-depth case study, and spatial analysis methods. The calculations involved data from Tauron Dystrybucja SA on the number of microgeneration systems in the cities, Database of Topographic Objects, Local Data Bank of the Central Statistical Office of Poland and Eurostat.

The origins and conditions of RES use

Consequences of climate change were noted and addressed in the early 1990s in the United Nations Framework Convention on Climate Change (UNFCCC). The main objective of the Convention was a debate on climate change and proposals to limit anthropogenic greenhouse gas emissions. Since then, the international community started to pay more attention to the

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potential adverse consequences of climate change, leading to further international agreements and agendas.

The impact of energy on sustainable development has also been increasingly recognised. One of the goals of the 2030 Agenda for Sustainable Development is goal no. 7 – to ensure that everyone has access to stable, sustainable and modern energy at an affordable price (Graczyk, 2017, http://www.un.org.pl/cel7 2015). As you can read in the Agenda: *Overcoming challenges and taking advantage of the many opportunities in today's world is associated with access to energy. It is essential for work, ensuring security, combating climate change, producing food and increasing national incomes*. It also sets out in more detail the 2030 targets (included in the 2030 Agenda for Sustainable Development) under Objective 7 and is (Sustainable Development Goals, 2022) including:

- 7.1 Ensuring universal access to affordable, reliable and modern energy services.
- 7.2 Significantly increasing the share of renewables in the global energy mix.
- 7.3 Doubling the growth rate of global energy efficiency.

In 1998, Poland signed the Kyoto Protocol, setting more detailed goals under the Framework Convention. In 2004, Poland was obliged to comply with EU obligations as it joined the European Union. Still, more importantly, it started to co-create the climate and energy policy of the EU, which grew more ambitious over time. The most current obligations include the Paris Agreement signed by Poland in 2018 and the climate neutrality by 2050 agreement signed in 2020. These targets would be met through the reduction in emissions of 'European' greenhouse gases by 55%, which will require a number of interdisciplinary activities in virtually all sectors of the economy, such as (European Commision, 2021):

- investments in environmentally-friendly technologies,
- introduction of cleaner private transport means,
- reduction in the emissions from the energy sector,
- increased energy performance of buildings.

These ambitious goals were set for a long horizon of 2050. It is vitally important to draft programmes to place reduction targets for each year and monitor progress. By 2020, one of the key national documents directing the pursuit of consecutive obligations regarding the promotion of renewable energy sources for the period 2010-2020 was the National Action Plan for Renewable Energy Sources. It set the national target for 2020 and annual thresholds for renewable energy consumption in heating and refrigerating, electricity generation (Figure 1) transport, and final consumption (Figure 2) (Ministerstwo Gospodarki, 2021). Using publicly available statistical data, the target RES proportions were compared to the reached values (Eurostat)

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and energy consumption (Central Statistical Office, 2021). Regrettably, the targets were more or less achieved only until 2015. After 2015, the actual proportion of RES both in electricity generation and total generated energy grew slower and failed to reach the milestones. The planned RES proportion in energy generated is unlikely to be met. An even greater difference of 2.5% was found for targets of RES proportion in electricity generation (Figure 2).

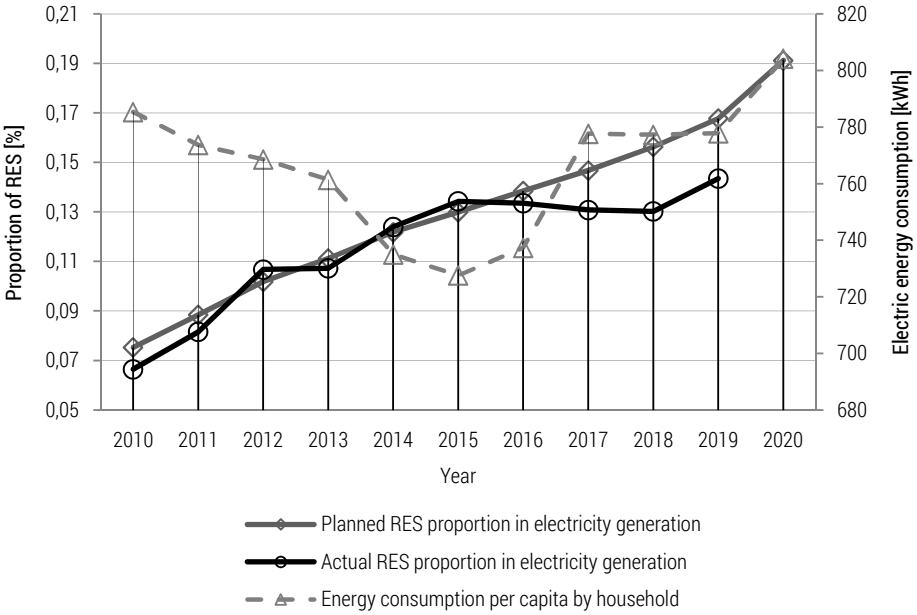

Figure 1. RES proportion in electricity generation

Source: Ministerstwo Gospodarki, 2021; Central Statistical Office, 2021; Eurostat.

Despite the actions taken and gradual reduction of CO_2 emissions, it was clear back in 2013 that the effort so far had been insufficient. Therefore, it was necessary to prepare for inevitable, adverse consequences of climate change in parallel to the reductions. Such adaptation plans for Poland were provided in the 2020 Strategic Adaptation Plan for Climate Change-Sensitive Sectors and Areas with 2030 Horizon (SPA) (Ministerstwo Środowiska, 2013).

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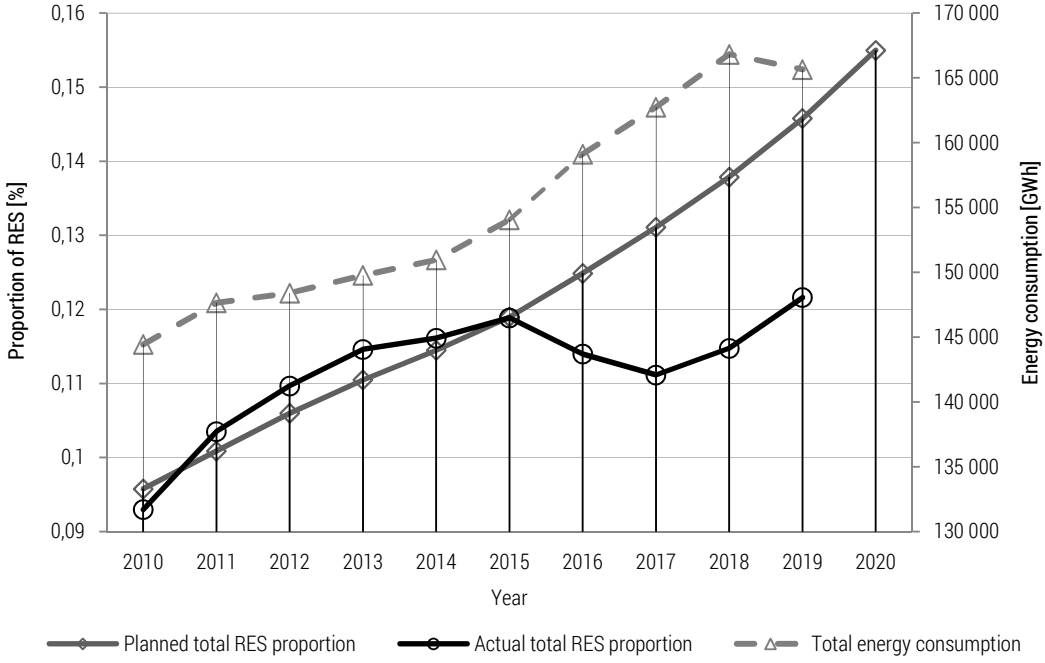

Figure 2. RES proportion in consumed energy

Source: Ministerstwo Gospodarki, 2021; Central Statistical Office, 2021; Eurostat.

The SPA presents threats and provides adaptive actions to ensure the effective functioning of the economy and society and sustainable development.

Regarding the energy sector, the authors noted (Ministerstwo Środowiska, 2013, p. 26):

- the susceptibility to damages of the overhead transmission grid, which is the dominant type in Poland,
- the potentially reduced performance of conventional power stations that need substantial amounts of water for cooling,
- the potential reduced biomass volume,
- the increased unpredictability and general worse wind conditions, which would mean increased failure or destruction risk for wind turbine generation,
- the potential improvement of photovoltaic generation conditions, which should be more effective with longer sunny weather spells and shorter winters.

The adaptive measures in the energy industry are summarised in Table 1.

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Table 1. Selected directions under activities 1.3 – the adaptation of the energy sector to climate changes

Item	Designation of adaptive activities as per the SAP	Selected development strategy areas with the adaptive activities
13.1	Development of alternative energy production potential at the local level, particularly for heating and air conditioning in low population density areas	1.3.5 Diversification of sources, effective use of energy, and natural threat responding 5.5. Increase in renewable energy sources use in rural areas 2.6. Increase in the importance of distributed renewable energy generation
1.3.5	Support for RES growth, in particular, microgeneration in agriculture	1.3.5 Diversification of sources, effective use of energy, and natural threat responding 2.7. Energy development of suburban areas

Source: Ministerstwo Środowiska, 2013, p. 38.

SPA was yet another document that emphasised the need for more significant RES employment. It further noted the potential improvement of photovoltaic (PV) generation use.

On RES and technical conditions

The problems of reaching the targets of RES proportion in generated energy as discussed earlier and the inevitability of adverse climate change consequences in a way leaves no choice but to use the available RES. In addition, fossil fuels, which are non-renewable resources, are gradually depleted.

Urban areas account for the largest share of GHG emissions. The IPPC report (Seto et al., 2014) presents several estimates of the percentage of cities in GHG emissions. According to IEA (2008), urban emissions accounted for 71% of total emissions in 2006. Final energy consumption in cities is estimated at 56-78% of global final energy consumption, which in terms of CO_2 emissions accounts for 53-87% of global emissions from final energy consumption (2005 data), (Grubler et al., 2012).

Combustion of fossil fuels, particularly low-class ones, in low, uncontrolled emission causes significant air pollution. It entails smog and several adverse health effects. Cities are responsible for high GHG emissions but are also seen as key areas where appropriate reduction measures can be implemented (Croci et al., 2021). The size of cities allows for a comprehensive, integrated policy covering the development of infrastructure, and mobility, as well as energy demand management (Brautigam & Knack, 2004; Rodrik et al., 2004).

Renewable resources/energy sources cannot be depleted. Still, 'large' RES systems (such as wind farms, PV farms, or large water reservoirs) can have multiple adverse effects on the environment and are frowned upon by environmentalist organisations. Microgeneration and small units generally

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do not have a negative environmental footprint. Note the issue of PV panel disposal. Humanity has fifteen years to resolve it. Wind turbine blade disposal poses problems as well.

The most popular type of energy used in microgeneration and small systems is solar energy. Hydropower generation requires a suitable location (on a river) and relatively significant upfront expenses, while the so-called 'wind turbine Act' (Ustawa, 2016) directly halted wind turbine investments in Poland in 2016.

Solar radiation offers a significantly large 'energy potential' value because it is on average 1000 kW/m^2, equivalent to 100 l of heating oil or 100 m^3 of natural gas (Szpryngiel, 2012, p. 81). Solar energy can be converted into:

- electricity with PV panels,
- heat with thermal panels to heat tap water or aid house heating (less popular).

The use of PV as RES comes at a price of economic and technical conditions. PV systems are relatively expensive (the unit cost decreases historically) but still much cheaper than heat pumps of similar power, and the payback period often exceeds ten years. PV microgeneration systems are installed chiefly on single-family houses due to legal and economic factors. One obligatory precondition is the so-called smart meter to measure consumed and generated energy. Installation of PV systems in multi-family buildings can entail significant infrastructural modifications. The impact of such systems on the transfer grid is not immaterial, either. According to the Polish Power Transmission and Distribution Association (PTPiREE, 2021), the following factors could contribute to an increase in the risk of problems:

- a large number and high output of microgeneration systems in an area with a single substation,
- systems located far from substations,
- small conductor sizes, uninsulated network,
- small energy consumption during the sunniest periods.

These problems can intensify in discontinuous urban fabric (urban sprawl) and for old, excessively elongated and underperforming power grids.

Formal, legal, and financial conditions for RES use

Today, PV microgeneration is supported through legal and financial means in Poland. Basic principles for shaping the energy policy and regulations and conditions for fuel and energy supply and use in Poland are provided in the Energy Law Act (Ustawa, 1997) aimed at providing energy security and rational energy and fuel use. The Act also contains regulations for energy transfer, connecting RES systems, and licensing requirements. In addition, detailed conditions and principles for generating electricity from

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RES, mechanisms and tools to support electricity generation from RES, biogas, and heat are regulated by the Renewable Energy Sources Act (Ustawa, 2015).

A microgeneration system is a RES system of a total installed electric power not exceeding 50 kW connected to an electric grid where the voltage does not exceed 110 kV (Ustawa, 2015., p. 7). RES system with a greater installed capacity between 50 and 500 kW are considered small systems (Ustawa, 2015, p. 7). Generating energy from microgeneration, small, or agricultural biogas systems does not require a licence or formal economic activity. Several more requirements apply (mainly technical ones, such as notifications or opinions) that will not be discussed here due to the length limitations. Small systems have to be registered with the Energy Regulatory Office (ERO) according to Article 17 (Ustawa, 2015).

PV panels can be installed virtually anywhere. The most significant challenge is installations in multi-family buildings as the approval of the housing community (and often technical opinion) is required in addition to a significant modification of the premises wiring. It often leads to prolonged duration and greater costs at the preparation stage, so such systems are rarely installed.

The most important financial instruments that support the growth of RES in Poland at the national level include:

- 'My Power' (*Mój Prąd*) scheme, which supports prosumer generation. Currently discontinued due to depleted funds. The subsidy in the previous year was PLN 5 thousand per system,
- 'thermal upgrade' tax deduction only for owners or co-owners of single-family residential buildings who improved building thermal performance or installed PV panels.

At the local levels, some Regional Operational Programmes offer subsidies. Therefore, there are several financial incentives to promote RES investments in Poland, both at the local, regional, and national levels.

RES performance and use, a case study

Study area

The selected group of objects was chosen purposefully. The cities are comparable (all of them are cities with district rights situated in Silesian Voivodeship), and their data are available. (Figure 3) presents the geographical location of the cities (19) within the limits of Silesian Voivodeship. Its central part has the greatest abundance of urban areas. It is the Upper Silesian conurbation of 14 cities with district rights. In 2017, nearly all cities in the conurbation (except Jaworzno) created the first metropolitan area in

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Poland. The Metropolitan Association of Upper Silesia and Dąbrowa Basin started in 2018. The area covers adjacent municipalities (41 municipalities in total) situated in historical Silesia and west Lesser Poland. Despite parts of the metropolitan area belonging to different regions, they are brought together by their industry-focused history cemented by local government initiatives and the local identity. A much smaller cluster of cities with district rights is located in the southwestern part of the voivodeship and covers Rybnik, Żory, and Jastrzębie-Zdrój.

Apart from the two conurbations, Silesian Voivodeship has two separate urban areas of broad impact zones and regional significance. Częstochowa in the northern part of the voivodeship has a colourful history and is essential for the local identity of the whole north part of the voivodeship, referred to as the Jurassic Upland. On the other hand, Bielsko-Biała is the most southern city with district rights in the voivodeship and the main urban area for the mountainous southern municipalities.

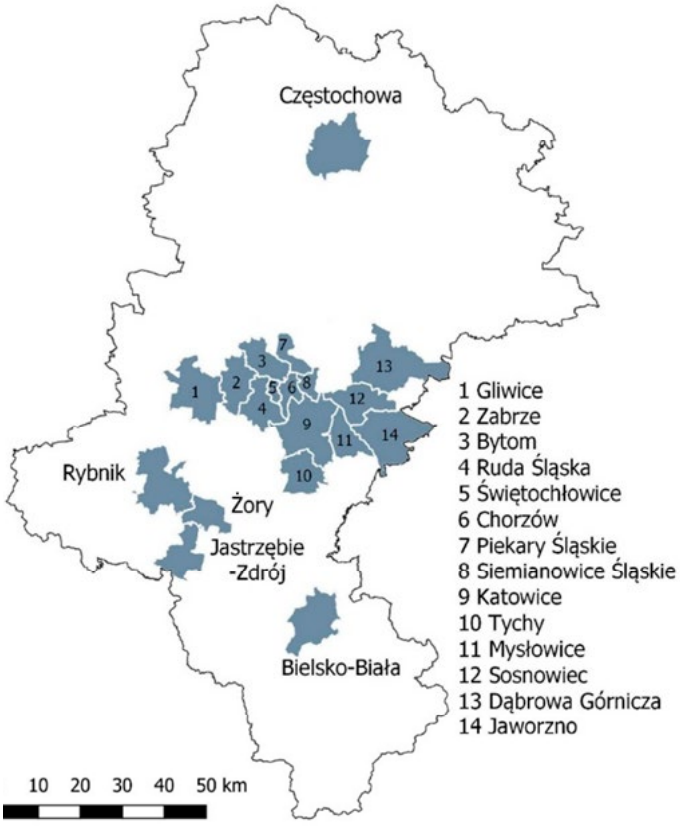

Figure 3. The investigated cities in Silesian Voivodeship

Source: author's work.

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Silesian Voivodeship has a significant RES potential, mainly from solar energy (PAN, 2005, 130-139). The analysis of the RES potential of the cities with district rights excluded biogas, which is used mainly in rural areas, and hydropower, which depends on hydrographical conditions. Solar energy was analysed as the most easily available RES in Silesian Voivodeship. The present paper investigates RES investments, the support measures used, and the growth potential of RES, particularly PV microgeneration. Therefore, the fundamental component of the profiles of the cities is the housing structure, focusing on single-family buildings (Figure 4).

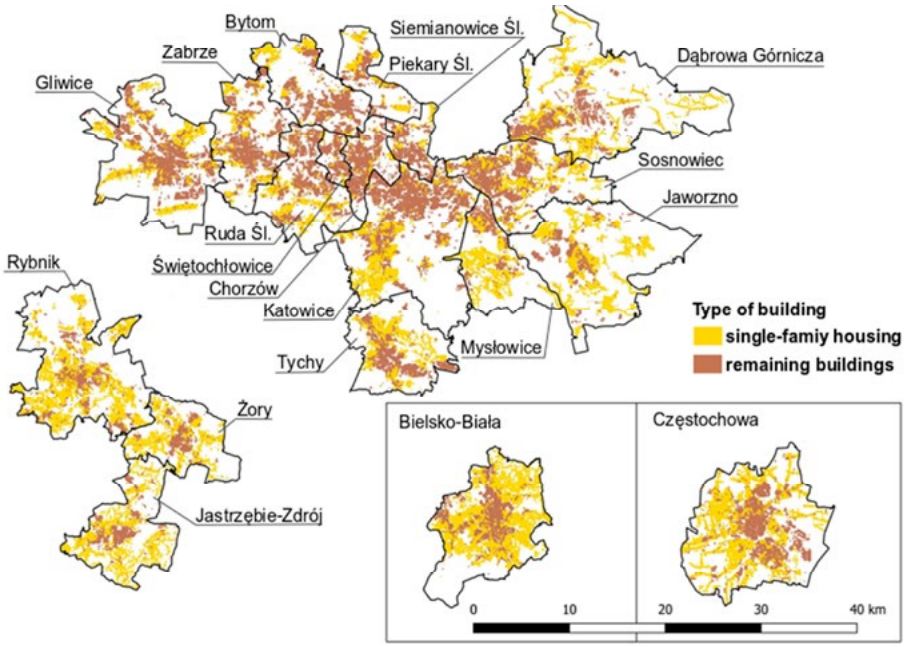

Figure 4. Types of buildings in the investigated cities

Source: author's work based on the database of topographic objects data (DTO).

Single-family housing dominates the conurbation of Rybnik, Żory, and Jastrzębie-Zdrój, covering almost entire areas of these cities up to their cores. In Bielsko-Biała and Częstochowa, the area of other buildings is greater, but single-family housing still dominates the city area. The Upper Silesian conurbation looks much different. Compact development stretches west to east and is the centre of gravity for single-family buildings that also sparsely dot other developments. Exceptions can be found in Tychy, where numerous multi-family blocks apparently stand out. Jaworzno and Dąbrowa Górnicza also feature individual clusters of compact developments. This image clearly depicts the agglomeration as a functional whole. Situated in its centre,

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Chorzów and Świętochłowice are dominated by close stories, while Jaworzno, Dąbrowa Górnicza, Mysłowice, and even southwestern part of Katowice are dominated by single-family housing.

The investigated cities vary significantly in terms of RES potential, area, population, population density, income, and development structure (Table 2).

Table 2. Profiles of the cities (as in 2020)

No.	City/district	Population density (people/1 km^2)	District income per capita (PLN)	Single-family housing vs. total district area (%)	Proportion of single-family housing*) in all buildings in district	Planning permissions for single-family houses
1	Bielsko-Biała	1364	8,151.40	**22.09**	89.60	236
2	Bytom	2350	6,345.64	5.63	46.06	107
3	Chorzów	3207	6,904.34	3.57	38.90	52
4	Częstochowa	1362	6,756.78	**16.06**	88.25	353
5	Dąbrowa Górnicza	**627**	7,788.75	6.85	91.44	**388**
6	Gliwice	1322	8,896.50	8.25	65.80	160
7	Jastrzębie-Zdrój	1032	6,655.52	13.46	**93.48**	139
8	Jaworzno	**593**	7,033.31	8.60	**92.53**	256
9	Katowice	1764	8,176.27	8.59	66.18	146
10	Mysłowice	1136	6,559.97	13.38	87.96	200
11	Piekary Śląskie	1372	6,118.58	9.15	82.49	73
12	Ruda Śląska	1757	6,501.52	8.12	73.08	309
13	Rybnik	925	7,302.49	**15.24**	**91.03**	300
14	Siemianowice Śląskie	2597	6,694.68	6.28	56.70	103
15	Sosnowiec	2167	6,324.86	10.24	79.78	194
16	Świętochłowice	3691	6,323.71	5.73	52.11	1
17	Tychy	1551	7,739.92	9.97	88.24	207
18	Zabrze	2125	6,295.62	7.58	59.36	121
19	Żory	972	6,696.16	12.55	**95.39**	**363**

*) Single-family and two-unit buildings (class BUBD01 and BUBD02) compared to class (BUBD) according to the DTO.

Source: author's work based on DTO and LDB data.

Some substantial differences can be found even in the Upper Silesian conurbation: the smallest and most densely populated city in the voivodeship is Świętochłowice (more than 3 thousand people per 1 km^2), while Jaworzno and Dąbrowa Górnicza have the smallest population densities (593 and 627

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people per 1 km^2, respectively). The largest income per capita is in Gliwice, Katowice, and Bielsko-Biała (over PLN 8 thousand), while the lowest, in Piekary Śląskie, Zabrze, Świętochłowice, Sosnowiec, and Bytom (less than PLN 6.5 thousand).

Compared to the other cities, Bielsko-Biała has the largest percentage of single-family housing (over 22%), while Chorzów has the smallest. Single-family houses dominate the majority of the urban areas compared to other buildings in terms of numbers. The largest value of the indicator was found in Żory, Jastrzębie-Zdrój, Jaworzno, Dąbrowa Górnicza, and Rybnik (over 90%), while the smallest, in Chorzów (less than 39%) and Bytom (about 46%). At the same time, the cities with the largest numbers of planning approvals for single-family houses were Dąbrowa Górnicza and Żory.

In light of the above, the cities with the largest solar energy use potential were Żory, Dąbrowa Górnicza, Jastrzębie-Zdrój, Rybnik, and also Częstochowa and Bielsko-Biała.

Use of RES from 2014 to 2020

The period from 2014 to 2020 can be divided into two stages. The subperiod of 2014–2018 was a time of microscopic interest and investments in PV microgeneration. Then, they grew massively in the other half of the period, from 2019 to 2020 (Figure 5).

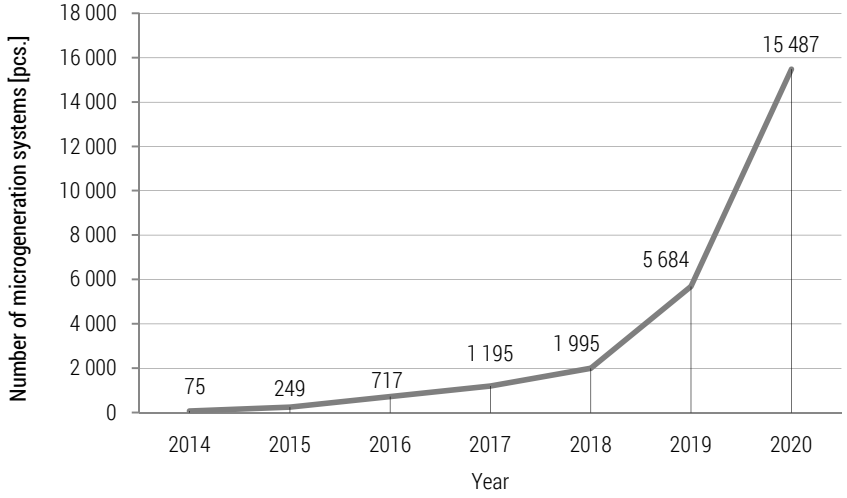

Figure 5. The total number of microgeneration systems in the cities from 2014 to 2020

Source: author's work based on data from Tauron Dystrybucja SA.

The conditions for RES investment changed substantially over the investigated period. New financial support instruments were offered. The My

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Power scheme was launched, and the 'thermal upgrade' tax deduction for RES projects was offered in late 2019. Some municipalities offered subsidies to RES (mostly PV systems and heat pumps) under the Regional Operational Programme of Silesian Voivodeship. The number of systems installed with local donations is shown in Table 3.

Table 3. The number of microgeneration systems and PV subsidies

No.	City/district	Number of microgeneration systems (2020)	Number of microgeneration systems vs. units in single-family buildings (%)	Microgeneration subsidies in 2021	Number of subsidised PV systems	Number of not subsidised microgeneration systems (2020)
1	Bielsko-Biała	1148	4.72	No	-	1148
2	Bytom	431	9.48	No	-	431
3	Chorzów	202	9.43	No	-	202
4	Częstochowa	**1613**	6.11	Yes	124	**1489**
5	Dąbrowa Górnicza	704	4.98	Yes	327	377
6	Gliwice	1028	8.10	No	-	1028
7	Jastrzębie-Zdrój	928	**11.12**	Yes	102	826
8	Jaworzno	1148	8.14	No	-	1148
9	Katowice	1243	7.58	No	-	1243
10	Mysłowice	676	7.64	No	-	676
11	Piekary Śląskie	352	6.66	Yes	69	283
12	Ruda Śląska	668	8.99	Yes	165	503
13	Rybnik	**1990**	8.76	Yes	154	**1836**
14	Siemianowice Śląskie	235	9.09	Yes	92	143
15	Sosnowiec	486	4.44	No	-	486
16	Świętochłowice	107	7.54	No	-	107
17	Tychy	793	**10.37**	Yes	647	146
18	Zabrze	889	**11.23**	No	-	889
19	Żory	846	**10.68**	Yes	91	755

*) Single-family and two-unit buildings (class BUBD01 and BUBD02) compared to class (BUBD) according to the DTO.

Source: author's work based on data from Tauron Dystrybucja SA and DTO.

The total number of systems in the cities is shown in (Figure 4). The undisputed leader in Rybnik with 1990 PV systems followed by Częstochowa (1613 systems). Note further that in Częstochowa, only 6.11% of units that

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could install PV systems did it, while in Rybnik, it was 8.76%. Cities that exceeded the 10% threshold of microgeneration system proportion in single-family buildings were Zabrze, Jastrzębie-Zdrój, Żory, and Tychy. This means that the leaders in microgeneration still have a significant capacity for such systems. Interestingly, both Rybnik and Częstochowa had PV subsidy schemes, but Zabrze achieved the best result (11.23%) without extra financial incentives.

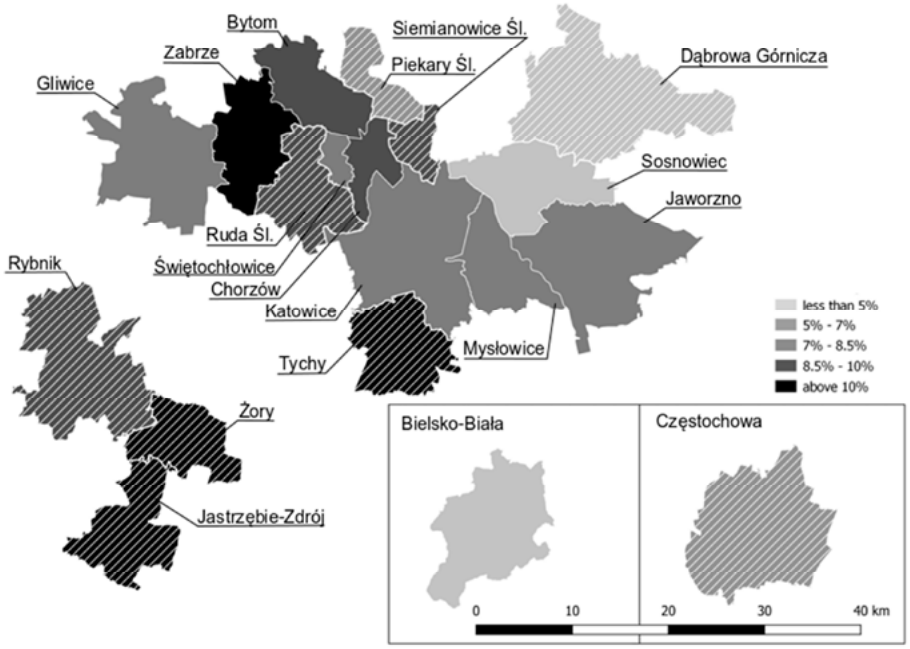

Figure 6. Microgeneration systems vs residential units in single- or two-family houses (%). Cities with PV subsidies are hatched

Source: author's work based on data from TAURON Dystrybucja SA and DTO.

Conclusions

The proportion of renewable energy failed to reach Poland's obligatory, planned level in 2019. The increase in PV microgeneration and small generation was one of the relatively more straightforward and faster methods for improving power generation statistics. Regrettably, there were virtually no investments in such systems from 2010 to 2016, which was undoubtedly due to unfavourable regulations (the wind farm Act) and lack of compelling financial incentives.

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The public grew more interested in PV generation in 2018 when the number of installed systems grew significantly, only to boom in 2019 and 2020. It was the period of the My Power scheme and subsidies in selected cities under the Regional Operational Programme of Silesian Voivodeship 2014-2020. Legal procedures for microgeneration connections were simplified significantly.

The subsidies fuelled public interest in PV systems. Still, they were not the decisive factor because subsidised projects usually vary from 10 to 20% of the total number of new systems. The only exception is Tychy. Other financial factors that could stimulate PV investments could have been low-interest rates and forecasts of high electricity prices.

The investigated cities have a significant, unfulfilled RES potential. The proportion of single-family houses with PV systems usually does not exceed 10% of the total number of single-family buildings. Of course, not all roofs are suitable for PV systems for various reasons (be it technical or situational). Still, the RES potential of large cities in Silesian Voivodeship remains largely untapped.

Financial incentives at various levels and seemingly attractive regulations for RES investments are not enough to drive a clear and dynamic increase in such investments. A high planning risk is not insignificant here. One-time subsidies provide support for the installation of a system, but what is needed is long-term legal and financial stability. Policies for calculating and purchasing energy from RES have been changing relatively frequently. First, it is vital to minimise the risk of investments in alternative energy sources.

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