

Article

Determinants of Decarbonization—How to Realize Sustainable and Low Carbon Cities?

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Abstract: The objective of this paper is to identify the determinants of decarbonization processes in Poland by urban and rural areas. It also presents directions for knowledge diffusion on decarbonization to develop a sustainable energy strategy for Poland, particularly for local governments and cities. Despite extensive research on the determinants of decarbonization and sustainable energy development, there is a lack of specific solutions in this area. The authors of this paper investigated which determinants, according to the respondents, would lead to better decarbonization solutions in cities and villages in terms of sustainability. The studied sample was purposefully selected and an online questionnaire was used with the use of the “snowball” method. The authors conducted surveys that allowed the concerned parties themselves (respondents) to indicate which factors they believe best influence decarbonization. Such measures are helpful in terms of the understanding public acceptance of decarbonization in terms of the energy transition. This is of particular importance in terms of green governance globally and in Europe. The results of the authors’ research indicate that despite the reduction in the share of coal in residential and domestic heating, coal remains the main source of electricity generation and that the potential for low-carbon policy to have an impact on solving urban challenges is underestimated. From the findings, it can be concluded that more in-depth research is needed on public acceptance of decarbonization in its broadest sense and its implications.

Keywords: decarbonization; energy transition in the cities; low carbon policy; climate changes; energy efficiency in the cities



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1. Introduction

One of the most essential sources of decarbonization processes is the concept of sustainable development [1,2]. Thanks to the concept of sustainable development, a number of international, national and local economic solutions have been implemented [3,4]. The development of this concept and its growing importance has led to, among others: United Nations General Assembly Resolution of 21 October 2015 (hereinafter: Resolution), which provides the impetus for many processes, including those closely related to decarbonization and its determinants [5,6].

Under the Resolution, 17 objectives of sustainable development were adopted. Of these, the authors of this study have identified four whose assumptions are implemented through the instruments of analysis in this study. Among the selected goals are Goal 7—renewable energy; Goal 9—innovation and infrastructure; Goal 11—sustainable cities and communities; and Goal 13—climate change mitigation. Decarbonization and the correct definition of its determinants are particularly important in the case of Poland. According to statistics compiled annually by the Energy Regulatory Office (hereinafter: ERO), in 2019 the primary source of electricity in Poland was fossil fuels, including hard coal and lignite, which together accounted for 75% of all existing sources [7,8].

The above statistics should be expanded with data collected by the Central Statistical Office (hereinafter: GUS) in the report: “Electricity Consumption in Households in 2018” issued on 21 January 2020 (hereinafter: Report). According to the collected information, GUS indicated in the Report that households in Poland, representing 6.5% of all households in the European Union countries, are heated by solid fuels in 43% of the cases. This figure consists of the following: 19% are dual-function boilers, 17% single-function boilers, 5% indoor stoves and 2% fireplaces [9,10].

The above data indicate Poland’s situation, where solid fuels are the primary source of electricity. Therefore, the need to take corrective actions, which include numerous international, national or local programs aimed at decarbonization [11,12].

An example of international action is, among others, the creation of a legal framework for the allocation of funds from the European Union Cohesion Fund, thanks to which Poland received about 80 billion euros between 2014 and 2020 [13]. These funds have been allocated primarily for the development, renovation and creation of new renewable energy sources and the improvement of energy efficiency in the public and residential sectors [14,15].

The challenges and threats identified in the literature lead to one assumption, their most tremendous significance are as an impetus to push for change, both internationally and locally. One example of international action is the Paris Agreement, signed in 2015. According to the Agreement, signatories cooperate at the international level by exchanging information and preparing relevant funds, which are updated every five years [16].

The literature on decarbonization processes, especially in terms of social understanding, lacks broad theoretical explanations pointing to the key determinants supporting these processes [17,18]. The authors of this paper, utilizing this study, aim to fill these gaps by showing not only the urban but also the rural perspective, considering the Polish example. The main objective of the paper was to reveal the determinants influencing the process of decarbonization in Polish cities. Cost-effective, carbon-neutral and sustainable cities need to be supported by changing political, technological and market conditions. The most important thing is to actively involve citizens and increase the social acceptance of highly profitable buildings and new technologies in cities. Therefore, the question is what kind of determinants are recognized and accepted by citizens.

The purpose of this study is to identify the determinants of decarbonization processes in Polish cities and rural areas. This study also shows the directions enabling the diffusion of knowledge regarding decarbonization with the aim of developing a sustainable strategy for Polish towns. Preferences were studied among the inhabitants of cities and villages [19].

2. Literature Review

2.1. Urban Decarbonization and Renewable Energy Perspective

In addition to international activities, we can also talk about the activity of the states or even cities themselves, which are becoming more and more visible in the sphere of proclimate actions [20]. Particular activity in this area can be seen on the example of large metropolises and organizations created by them, such as the C40 Cities Climate Leadership Group [21] or the Cities in the Climate Protection Program, which brings together more than 1000 cities in 30 different countries that are responsible for 15% of CO₂ emissions [22].

The move towards sustainable and low-carbon cities is one of the responses to climate change. It fits, through several concrete actions, into the concept of smart cities. This concept is given a lot of importance, pointing out that smart cities are becoming the center of innovative solutions and thus of economic growth, and therefore require proper analysis and consideration [23]. The discussion and research conducted within the smart cities concept framework gain its justification, especially since the idea involves some risks. An example of the risk of adverse consequences of the implementation of some innovations is the achievement of too high energy efficiency of buildings, which in turn would increase the price of energy distribution in the network [24].

Particularly developed smart city concepts are implemented in Masdar (Abu Dhabi), Stockholm (Sweden), Amsterdam (The Netherlands) or Yokohama (Japan) [25]. Among the many solutions, the implementation of which fits into the assumptions of smart cities, the literature mainly indicates innovations in energy technologies [26], transport [27], construction or creation of green building standards [28,29]. Examples of innovations that are analyzed in terms of efficiency, cost-effectiveness or functionality are passive house heating and lighting systems [30,31], national integration of renewable energy system in cities [32] or optimization of road lighting to improve energy efficiency [33]. Besides, also noteworthy is the concept of using urban greenery to create a microclimate suitable for residents, which results not only in lowering the temperature but also has an impact on air purification [34]. From the point of view of the research conducted in this paper, it is also important to point out the measures discussed in the literature in the field of home heating systems using heat pumps and underground ventilation systems [35].

As indicated above, the literature does not explicitly address the social determinants of decarbonization processes. However, other discussed criteria, such as economic or technological criteria, can be identified [36,37].

Comparative analyses to compare the cost-effectiveness of specific mechanisms, as seen in the example of the installation of light-emitting diode (LED) lighting in cities [23]. The value of economic determinant is also visible in literature as a condition of implementing or expanding new renewable energy sources such as hydropower [38]. In addition, it should be noted that the economic determinant is the potential creation of business opportunities [39,40] associated with applied measures aimed at decarbonization or smart cities [41,42].

The technological criterion is related to the development of modern technologies, including information technologies, aimed at supporting the automation of smart city creation processes [43,44]. The number of types of smart cities concepts depends on the number and type of existing technologies [36,45]. The described criterion has a unique character because its application is related to the specific technological development of the city where it is to be applied; however, in case of insufficient development, some activities cannot be applied [46–48]. Examples of measures can be the implementation of intelligent transport or intelligent traffic management. The aspect of new technologies is particularly evident in the implementation of intelligent traffic management, which in its assumptions uses a number of devices, such as roadside sensors or active signaling, to improve traffic flow or reduce the arrival time for traffic participants [49,50]. It is worth noting that the technical criteria also propose solutions that are based on advanced planning and do not require advanced technologies at the time of implementation. An example of such measures is the natural cooling of urban environments, which increasingly becomes the focus of planners and designers [51,52].

The economic criterion is considered in the form of sustainable and low-carbon cities, are a frequent subject of scientific analysis. One of the possible reasons for this phenomenon is the distribution of the population in urban areas. Using the example of the European Union, it can be pointed out that as many as 68% of the people resident in the Member States live in urban areas [43]. In addition, these areas are responsible for 70% of the primary energy consumption, which translates into 75% of the total greenhouse gas emissions in the European Union [53,54]. Globally, 3% of the land area is urbanized, and more than

half of the population lives in urbanized areas. These areas are responsible for 70% of CO₂ emissions [55].

A concept that can not only support the decarbonization process but also complement it by supporting the smart cities idea is the notion of the energy prosumer. The first attempts at defining this concept assumed that consumers [56,57] produce more goods and services for their own consumption [58]. Today, the literature assumes that an energy prosumer is a person who both produces and consumes energy [59] or a person who actively manages the production of their own energy and their own consumption of that energy [60]. Prosumers not only increase opportunities to generate clean energy but also support the technological development they need to meet their needs. Additionally, they can take an active role in regulating energy demand, thereby influencing the energy market [61,62].

Adding the aspect of society to the decarbonization process directly or indirectly by supporting other methods that implement decarbonization processes will allow the creation of a model of citizen energy [63].

Increasing the role of prosumers and their participation in the decarbonization process is associated with the development of energy justice theory. According to this theory, we can talk about principles that should form the basis for decision-making processes. These include good governance, easy availability and sustainability [64]. States, guided by the theory of energy justice, can support the development of prosumers by, for example: supporting less wealthy consumers and enabling them to become prosumers or by supporting renewable energy initiatives by influencing its availability [61].

Importantly, the statistics indicated above may change due to the increasing rate of urbanization in the 21st century, which is rooted in the rising world population and the migration of people to urban centers [24]. According to World Bank projections, the urban population will double by 2030, assuming current economic growth [65,66]. These figures alone should be enough incentive for urban centers to take a greater interest in ways to address the challenges of a growing population, which include adequate living resources and air pollution, among others. These global challenges require drastic measures; in other words, the most critical actions of the 21st century [24].

2.2. Climate Change Perspective

According to the authors of the paper, in addition to the growing population of cities, attention should be paid to the issue of climate change and its impact on cities. Among the frequently cited effects of climate warming on cities are rising urban temperatures and rising sea levels [24]. According to one study, there is a risk that more than 1.5 billion people living in cities will be exposed to temperatures above 35 °C for three months by 2100, compared to 5.6 million today, which is a real threat to urban populations [67]. Regarding sea and ocean level rise, it is essential to note that more than 146 million people live in areas 1 m above sea level. In contrast, 397 million people live between 1 m and 10 m above sea level [68]. The currently predicted sea-level rise oscillates between 0.5 m and 1 m by the year 2100. There is a risk that if certain events occur, such as the melting of the Greenland ice sheet or West Antarctica, the water level could rise by up to 7 m [69]. The effects of rising sea and ocean levels could significantly affect the functioning of major metropolises such as New York, Mumbai, Dhaka, Tokyo, Lagos, Cairo or Rio de Janeiro. Moreover, these effects are already visible and manifested in the form of storms, floods, and heavy rains, which were almost four times more frequent between 2003 and 2013 than between 1901 and 1910 [70].

In addition to the determinants [71–73], the decarbonization process itself is also associated with concerns arising from its implementation. These concerns range from efforts to shut down some existing fossil fuel-based industries [74,75] to concerns about renewable energy sources and their intermittent supply [76–78].

3. Methods

This study addresses the scientific problem of decarbonization and changes in diffusion in the practice of that process and attempts to find a solution to it. Schmidt and Weight go on to note that within the broader energy sciences, interdisciplinary work remains rare: “despite the predominately socioeconomic nature of energy demand, such interdisciplinary viewpoints—albeit on the rise—are still the minority within energy-related research” [79]. Therefore, the authors made an attempt to conduct such research.

In the literature on decarbonization processes, particularly regarding their social understanding, there are no broad theoretical explanations indicating the crucial determinants supporting such processes [36,79]. Furthermore, even though decarbonization has been discussed in both European Union and international literature, there is no reference to knowledge diffusion processes as the causative factors for those changes precisely in the scope of rural and urban areas [80].

To determine the current state of knowledge and to identify specific existing research gaps, the authors have compiled the literature on the subject, taking into account the compilation and integration of existing studies. This evidence is conducted as a systematic literature review.

The structured questionnaire was performed with a sample of respondents from a relevant target population. The design of the research tool was based on already standardized and verified tools. The research was based on a survey by the Tyndall Centre for Climate Research [81]. The survey asked two questions with responses based on the Likert scale. The questions concern fundamental issues on the determinants supporting decarbonization processes in Poland—urban and rural areas and the model of decarbonization (centralism vs. localism).

The authors used the questionnaire as a method widely used in the practice of survey research. The studied sample was purposefully selected and an online questionnaire was used with the use of the “snowball” method.

The research was conducted between December 2019 and April 2020. This research included 444 respondents who filled in the questionnaire online, of which 46% were men and 54% were women. This brings the minimum sample size to 384, for the whole population of 38 million people in Poland. The following assumptions were made for statistical research.

The individual activities indicated in the survey are assigned one of the following grades:

1. No impact;
2. Very little/negligible impact;
3. Neutral;
4. Visible impact; and
5. Significant impact.

The survey also asked two open questions on the most effective solutions to support decarbonization processes in rural and urban areas. Question—“What do you think the EU should introduce solutions, regulations regarding decarbonization?”—concerns what solutions the EU should introduce in decarbonization. The respondent could give a free, subjective answer or several answers. Our intention when asking open questions was to obtain as many attitudes and opinions as possible to analyze the studied phenomenon, including decarbonization. The second open question: “What do you think should be the main factor in the decarbonization process in Poland?”

The research was exploratory, conducted to determine the nature of the problem, and was not intended to provide conclusive evidence but to obtain a better understanding of the problem [82].

The sampling was focused on respondents dealing with the problem of decarbonization.

Among the respondents, the majority were people living in the cities. Table 1 presents the structure of the sample. The research was conducted on a representative sample.

Table 1. Sample characteristics.

Place of Residence	No.
City	317
Village	127

Source: Own research based on the results of an online survey, $n = 444$ (444 respondents who filled in the questionnaire online, of which 205 were men and 239 were women).

4. Research

The research yields answers for the following research question: “Which of the following do you think has the most impact on decarbonization?”

1. Subsidies for mining.
2. Subsidies for local governments (e.g., decommissioning of boilers).
3. Prosumer solar photovoltaics development programs.
4. Capacity market.
5. Opening the EU energy market.

Additionally, the second question: “Which of the following activities should be transferred from central to local?”

1. Subsidies for the residents
2. Prosumers’ photovoltaics development program
3. Compensation for electricity, energy storage, production
4. Funds for environmental protection
5. Support of development of modern power sources—cities.

The answers to the questions are based on Figures 1 and 2.

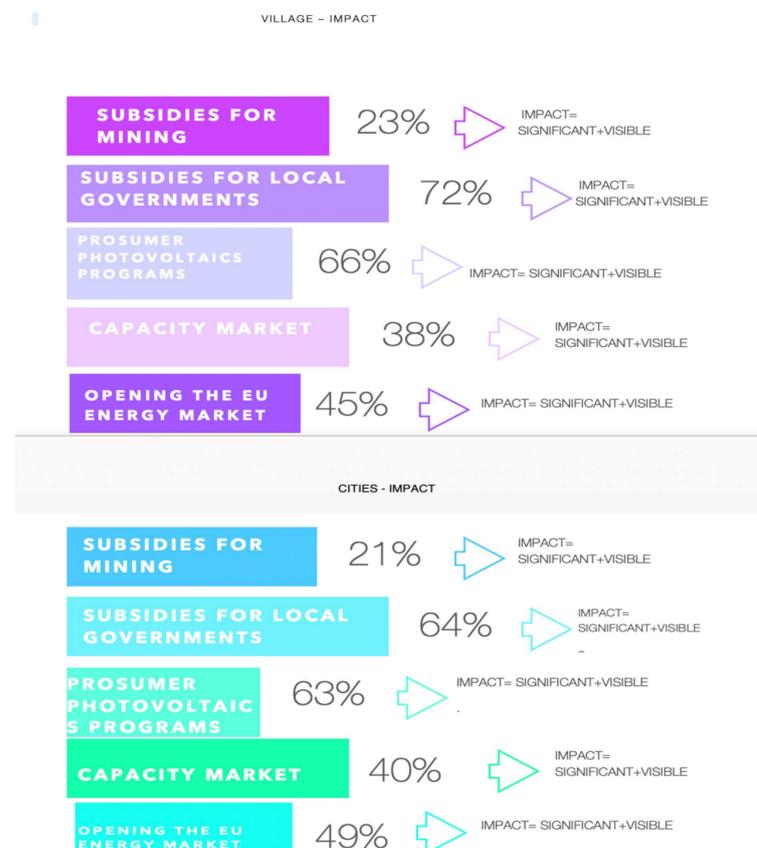


Figure 1. Respondents’ opinions on the activities determining decarbonization processes—village. Source: Own research based on the results of an online survey, $n = 444$ (444 respondents who filled in the questionnaire online, of which 205 were men and 239 were women).

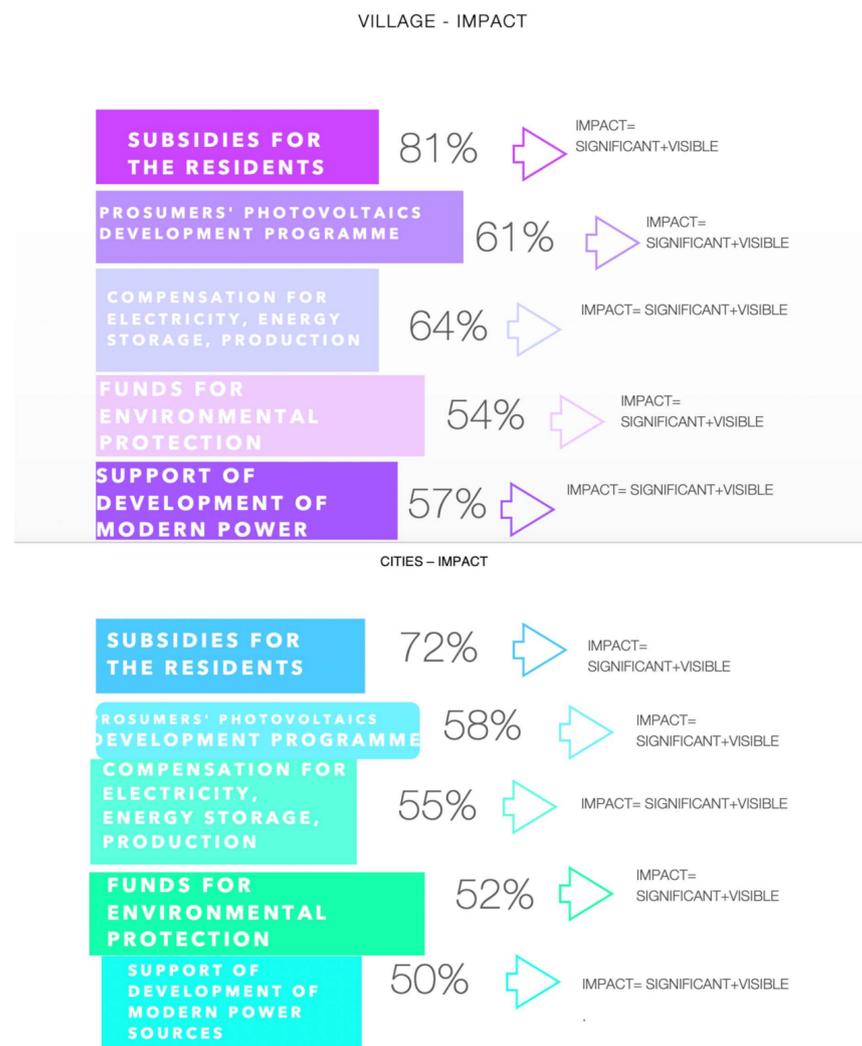


Figure 2. Respondents' opinions on the activities transferred from central to local (Question 2: (Which of the following activities should be transferred from central to local)). Source: Own research based on the results of an online survey, $n = 444$ (444 respondents who filled in the questionnaire online, of which 205 were men and 239 were women).

The answers provided by the respondents show that they care most about local programs aimed directly at interested residents. Both town and village residents agree that direct support programs can best and most effectively lead to an effective decarbonization process. Photovoltaic support programs were also assessed as effective at an equally high level. These programs also provide direct support [79]. Thus, the inhabitants of villages and cities choose direct support programs that will reach recipients and, therefore, will be an incentive to replace stoves or install photovoltaics. To a small extent, rural residents are much more concerned with these programs, but this is natural. Rural residents can benefit more from these programs as this is only possible in the suburbs in the main program [81]. On the other hand, city dwellers also strongly believe in the effectiveness and efficiency of these direct programs. There are also solutions on the market that can meet their expectations. Housing cooperatives and communities cooperate with energy and photovoltaic suppliers to install group installations in cities, securing multifamily buildings' needs.

The data from Table 2 are presented in Figure 3. They are the means of all responses obtained in the studies.

Table 2. Respondents' opinions on the average importance of impact on decarbonization.

Place of Residence	A	B	C	D	E
City	2.26	3.87	3.79	3.14	3.40
Village	2.45	3.99	3.82	3.20	3.30
Total average	2.31	3.91	3.80	3.16	3.37

Source: Own research based on the results of an online survey, $n = 444$ (444 respondents who filled in the questionnaire online, of which 205 were men and 239 were women). (A—Average of Importance of impact on decarbonization: subsidies for mining; B—Average of Importance of impact on decarbonization: subsidies for local governments (i.e., boilers' replacement program); C—Average of Importance of impact on decarbonization: prosumers' photovoltaics development program; D—Average of Importance of impact on decarbonization: capacity market; E—Average of Importance of impact on decarbonization: the opening of the EU energy market).

- Average of Importance of impact on decarbonisation: subsidies for mining
- Average of Importance of impact on decarbonisation: subsidies for local governments (i.e. boilers' replacement programme)
- Average of Importance of impact on decarbonisation: prosumers' photovoltaics development programme
- Average of Importance of impact on decarbonisation: capacity market

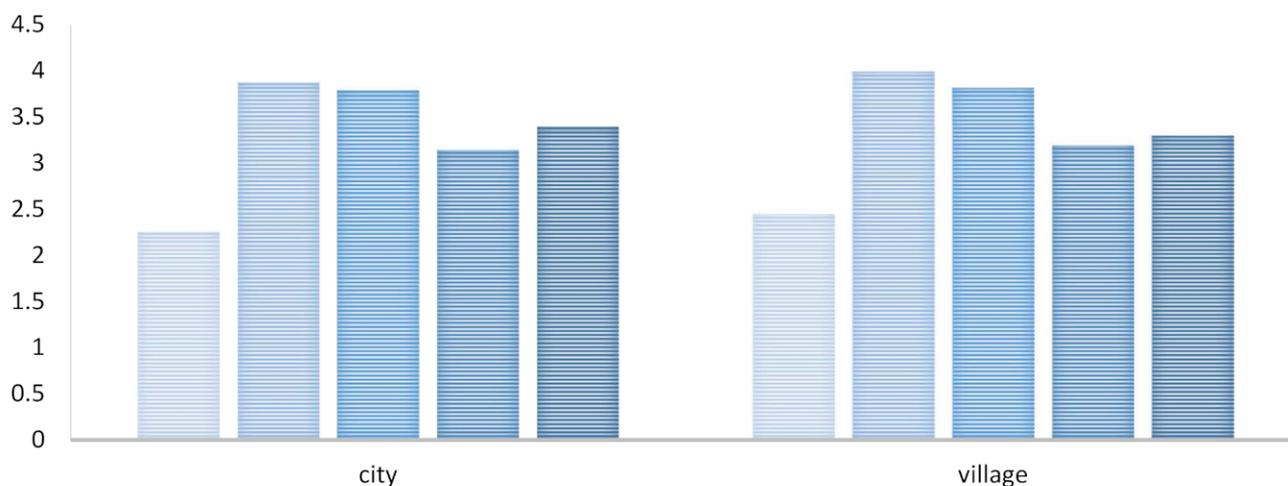


Figure 3. Average importance of impact on decarbonization. Source: Own research based on the results of an online survey, $n = 444$ (444 respondents who filled in the questionnaire online, of which 205 were men and 239 were women).

The next question and the answers to it confirm that local support is much more appreciated and much better perceived as effective and efficient in the decarbonization process. Here, as well, to a small extent, rural residents are much more concerned with these programs, but this is natural. It is worth noting that villagers can benefit to a greater extent from these programs, especially local ones, which have independent housing and often burn solid fuels. The responses given by city dwellers show slightly lower response scores, as this is only possible in the suburbs of cities. In both question one and question two, city dwellers also firmly believe in the effectiveness and efficiency of these direct programs. In the second question, again, photovoltaics takes a key place. It should be noted here that solutions that can meet the expectations of city dwellers are also more and more distressed. There are still no specific legal regulations, but housing cooperatives and communities cooperate with energy and photovoltaic suppliers to install group installations in cities, also securing the needs of multifamily buildings, precisely speaking of the needs of shared spaces in buildings, but also already providing green energy to individual residents or lighting (presented at Table 3 and Figure 4).

Table 3. Respondents' opinions on Average of Necessity to transfer actions from the central to the local level.

Place of Residence	A	B	C	D	E
City	3.99	3.61	3.49	3.41	3.37
Village	4.28	3.85	3.77	3.51	3.70
Total of average	4.07	3.68	3.57	3.44	3.46

Source: Own research based on the results of an online survey, $n = 444$ (444 respondents who filled in the questionnaire online, of which 205 were men and 239 were women). (A—Average of Necessity to transfer actions from the central to the local level: subsidies for the residents/end users (i.e., boilers' replacement program); B—Average of Necessity to transfer actions from the central to the local level: prosumers' photovoltaics development program; C—Average of Necessity to transfer actions from the central to the local level: compensation for electricity, energy storage, production during the daytime and consumption at night; D—Average of Necessity to transfer actions from the central to the local level: funds for environmental protection; E—Average of Necessity to transfer actions from the central to the local level: support of development of modern power sources (CHP bonus, renewable energy sources)).

- Average of Necessity to transfer actions from the central to the local level: subsidies for the residents/end users (i.e., boiler's replacement programme)
- Average of Necessity to transfer actions from the central to the local level: prosumer's photovoltaics development programme
- Average of Necessity to transfer actions from the central to the local level: compensation for electricity, energy storage, production during the daytime and consumption at night
- Average of Necessity to transfer actions from the central to the local level: Funds for environmental protection
- Average of Necessity to transfer actions from the central to the local level: support of development of modern power sources (CHP bonus, renewable energy sources)

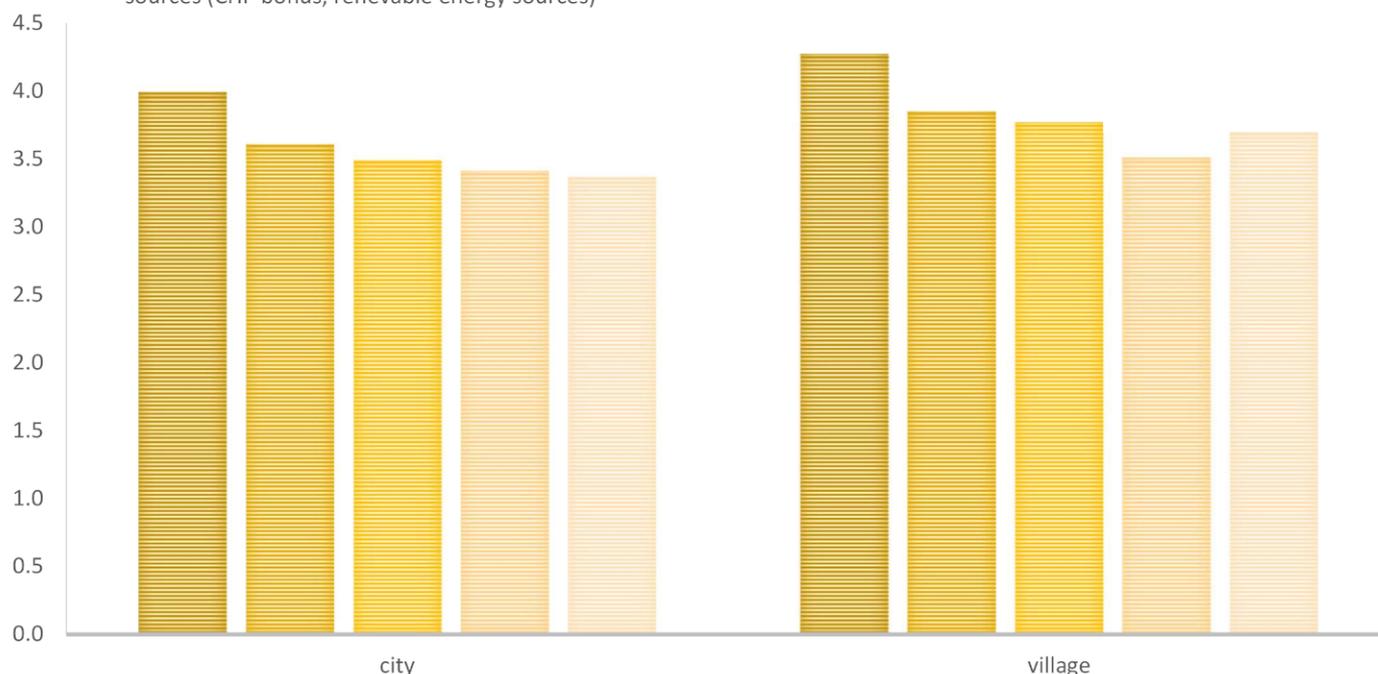


Figure 4. Average of Necessity to transfer actions from the central to the local level. Source: Own research based on the results of an online survey, $n = 444$ (444 respondents who filled in the questionnaire online, of which 205 were men and 239 were women).

Figure 5 presents the means obtained from the answers about the importance of impact on decarbonization and standard deviations. They clearly show that all standard deviations are in the range from 1.5 to 2.6. The most unambiguous answers of cities respondents concern the installation of photovoltaics.

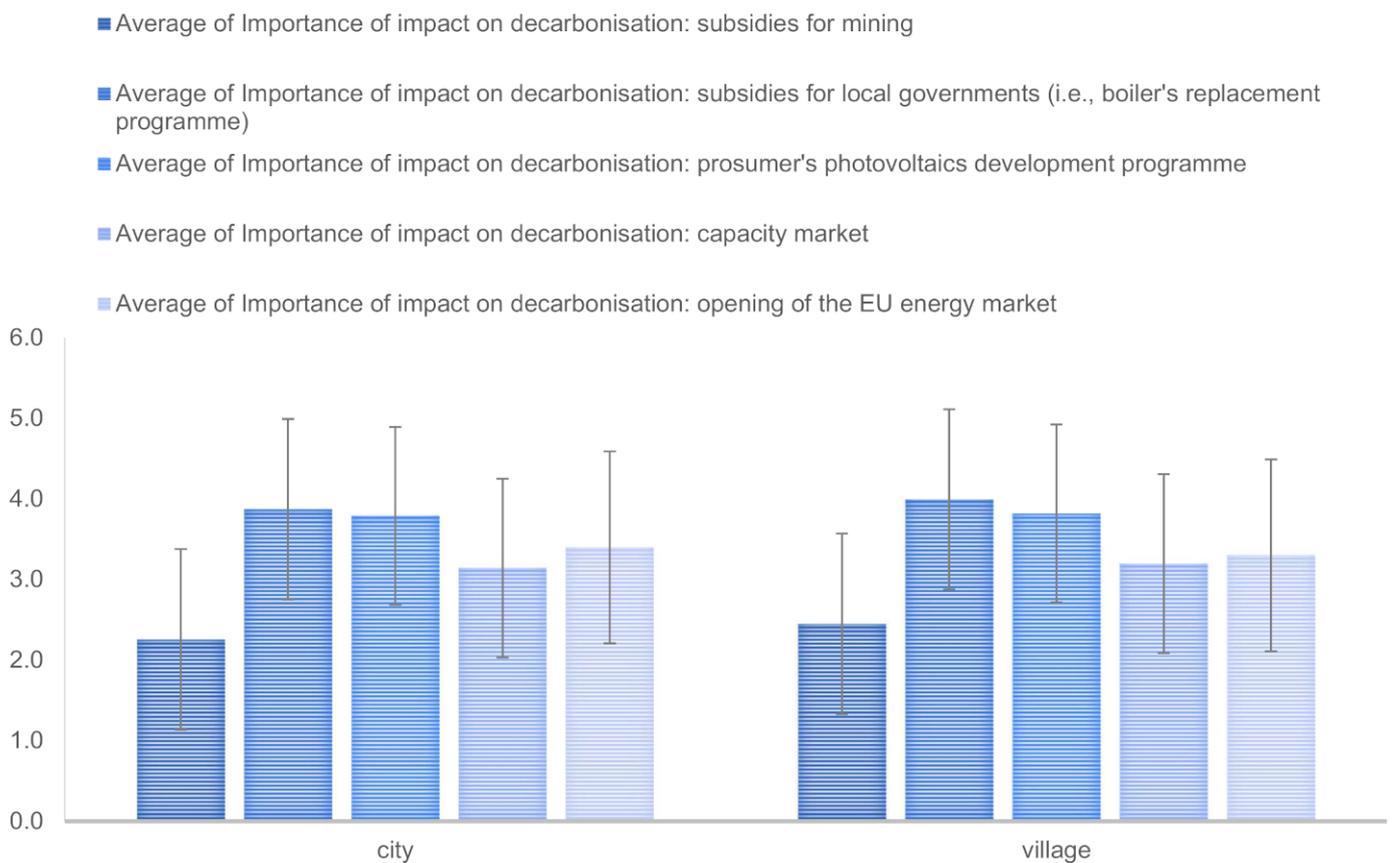


Figure 5. Average importance of impact on decarbonization with marked standard deviations. Source: Own research based on the results of an online survey, $n = 444$ (444 respondents who filled in the questionnaire online, of which 205 were men and 239 were women).

Both the inhabitants of villages and cities gave the highest answers (according to the average) to the answer n1, i.e., “Necessity to transfer actions from the central to the local level: subsidies for the residents/end users (i.e., boilers’ replacement program)”. The data from Table 4 are presented in Figure 6.

Figure 6 shows the average levels of answers to the question necessary to transfer actions from the central to the local level and the standard deviations for it. Priority is given to local support programs in the field of boiler replacement and programs related to photovoltaics.

Table 4. Mean values in responses to the question “Necessity 1 to 5”, sorted by place of residence.

Place of Residence	A	B	C	D	E
City	3.99	3.61	3.49	3.41	3.37
Village	4.28	3.85	3.77	3.51	3.70
Total of average	4.07	3.68	3.57	3.44	3.46

Source: Own research based on the results of an online survey, $n = 444$ (444 respondents who filled in the questionnaire online, of which 205 were men and 239 were women) (A—Average of Necessity to transfer actions from the central to the local level: subsidies for the residents/end users (i.e., boilers’ replacement program), B—Average of Necessity to transfer actions from the central to the local level: prosumers’ photovoltaics development program, C—Average of Necessity to transfer actions from the central to the local level: compensation for electricity, energy storage, production during the daytime and consumption at night, D—Average of Necessity to transfer actions from the central to the local level: Funds for environmental protection, E—Average of Necessity to transfer actions from the central to the local level: support of development of modern power sources (CHP bonus, renewable energy sources)).

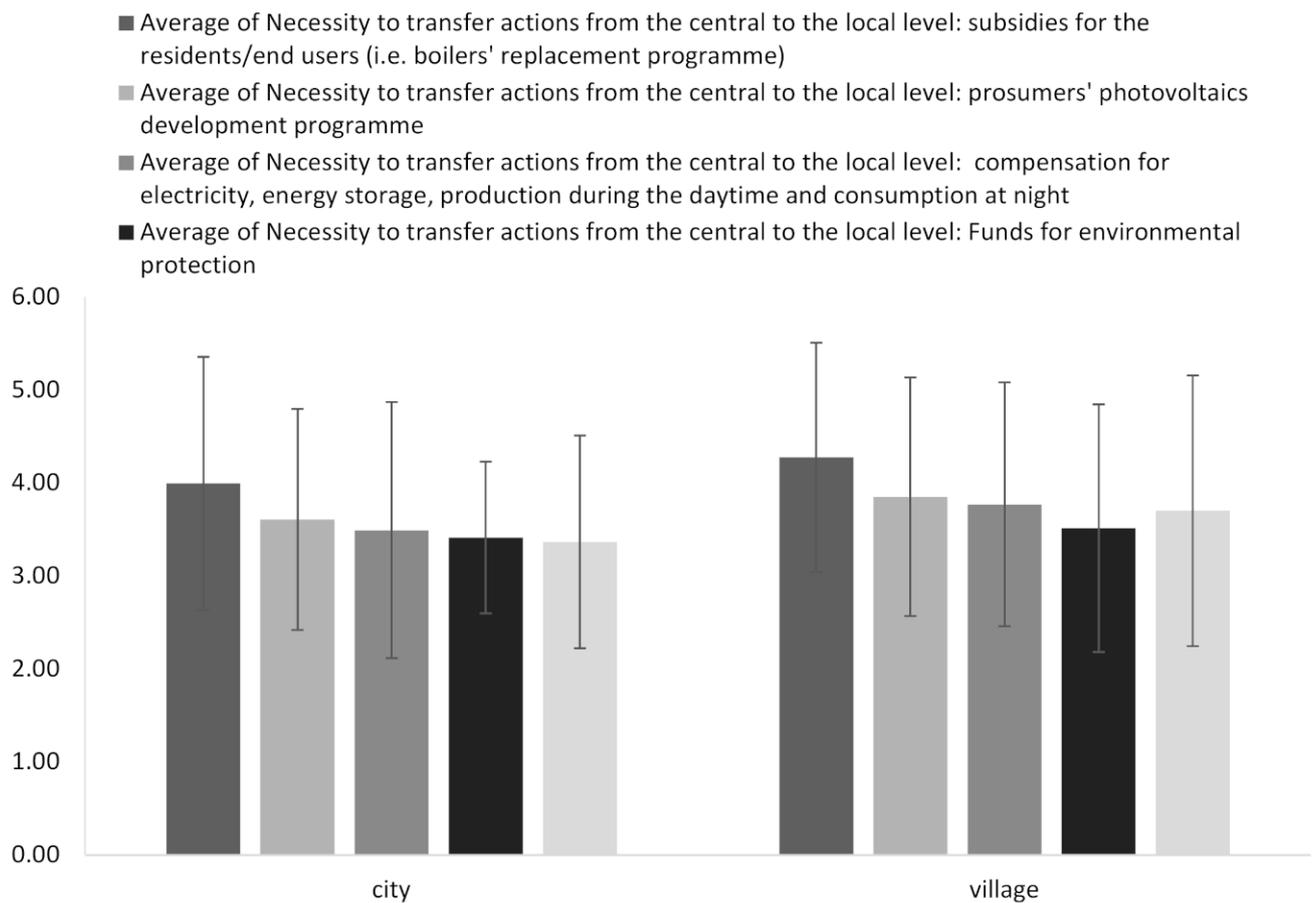


Figure 6. Average of necessity to transfer actions from the central to the local level. Source: Own research based on the results of an online survey, $n = 444$ (444 respondents who filled in the questionnaire online, of which 205 were men and 239 were women).

The chi-squared tests for cities and villages are presented Table 5.

Table 5. The chi-squared test for cities and village e (results).

		Village					
	A	B	C	D	E	Row Totals	
1	44	4	4	8	11	71	
2	24	8	10	23	18	83	
3	29	23	20	48	41	170	
4	18	42	46	16	21	143	
5	12	50	38	32	36	169	
Column Totals	127	127	127	127	127	635 (Grand Total)	
		Cities					
	A	B	C	D	E	Row Totals	
1	142	10	10	25	28	215	
2	54	32	36	69	40	231	
3	54	73	72	95	93	387	
4	32	76	92	36	66	302	
5	35	126	107	92	90	450	
Column Totals	317	317	317	317	317	1585 (Grand Total)	

Source: Own research based on the results of an online survey, $n = 444$ (444 respondents who filled in the questionnaire online, of which 205 were men and 239 were women, and 127 from villages and 217 from cities).

The results of the importance of impact on decarbonization survey were tested with the chi-squared test, which showed that there is a strong dependency between all the responses. For the “city” category the calculated chi-squared result is 421.8, whereas for the “village” category, the chi-squared result is 156.9. The p -value in both these cases is <0.000001 , and the result is significant at $p < 0.05$. The chi-test for necessity to transfer actions from the central to local level shows similar results.

The survey also asked two open questions on the most effective solutions to support decarbonization processes in rural and urban areas. Question—“What do you think the EU should introduce solutions, regulations regarding decarbonization?”—and the second open question: “What do you think should be the main factor in the decarbonization process in Poland?”.

Both questions are open questions to which the respondent could give a free, subjective answer or several answers simultaneously. The authors’ intention when asking open questions was to obtain as many consumer opinions as possible, which will shed a new, different light on the examined phenomenon of the decarbonization process—how to realize sustainable and low carbon cities. It should be stressed that decarbonization is still a phenomenon that is poorly recognized in society, as is expressed:

- (1) Among the 444 respondents, 238 respondents answered question 11 (nearly 54%) and 249 answered question 12 (which constituted 56%).
- (2) In both open questions, only 80% of the respondents who answered the abovementioned open questions proposed interesting suggestions, while nearly 20% of the survey participants indicated that: “has no opinion”; “cannot evaluate”; “does not know”; “difficult to evaluate”.
- (3) From this sample, the authors chose only those answers that are consistent with the decarbonization process and the implementation of a sustainable and low-carbon city, as the local perspective (of the cities) is closer to the surveyed sample of respondents.

Respondents’ answers to the question “What do you think the EU should introduce solutions, decarbonization regulations” have been categorized into five basic groups (categories) and presented in Tables 6 and 7 refers to the Sustainable Development Goals (SDGs) and indicates which respondents carried out this activity (living in a village or city). This table (Table 6) presents the responses of individual survey participants, treating them as a determinant of sustainable development objectives in the context of the division into town and village, namely: Action Items:

Table 6. List of answers for two questions.

N.B.	Question:	Village (Number of Respondents)	City (Number of Respondents)
1	What do you think the EU should introduce solutions, regulations regarding decarbonization?	50/127	143/317
2	What do you think should be the main factor in the decarbonization process in Poland?	57/127	160/317

Source: Own research based on the results of an online survey, $n = 444$ (444 respondents who filled in the questionnaire online, of which 205 were men and 239 were women; both questions are open questions) and The 2030 Agenda for Sustainable Development [83].

Table 7. EU solutions for decarbonization determinants from the SDG perspective (sustainable and low carbon cities)—implementation proposals.

N.B.	Title of the Action	Target Name According to SDG (GOALs 1–17)	City (C) or Village (V) or City and Village (C&V)
1.	RES technologies	Sustainable cities and communities (GOAL 11) Innovation and infrastructure (GOAL 9) Renewable Energy (GOAL 7)	C&V

Table 7. Cont.

N.B.	Title of the Action	Target Name According to SDG (GOAL's 1–17)	City (C) or Village (V) or City and Village (C&V)
2.	Nuclear energy	Climate action (GOAL 13) Sustainable cities and communities (GOAL 11) Innovation and infrastructure (GOAL 9)	C&V
3.	Coal management	Renewable Energy (GOAL 7) Renewable Energy (GOAL 7)	C&V
4.	Taxes	Sustainable cities and communities (GOAL 11) Climate action (GOAL 13)	C
5.	Grants	Renewable Energy (GOAL 7) Innovation and infrastructure (GOAL 9) Climate action (GOAL 13) Renewable Energy (GOAL 7)	C

Source: Own study based on the results of the online survey, $n = 238$ for question 11 and 249 for question 12 (both questions are open questions) and The 2030 Agenda for Sustainable Development [83].

Table 7 presents the EU solutions for decarbonization determinants from the SDG perspective (sustainable and low carbon cities) for implementation proposals.

Respondents also drew attention to issues related to the low carbonization of cities in the context of the decarbonization process, such as

- Introducing emission limits for households;
- Minimization of formalities in the process of replacing heating devices;
- Mandatory decommissioning of solid fuel boilers (coal);
- Increasing public and consumer awareness of the positive impact of RES on the natural environment and human health;
- The elimination of own contribution to EU subsidies;
- Introduction of CO₂ certificates.

To sum up, although the decarbonization process assessments were based on the respondents' subjective opinions, it should be noted that the views and attitudes of the external environment, in this case consumers, are fundamental. This is true in a situation where the most appropriate solutions related to climate change and zero-emissions are being sought in the international arena, due to their harmfulness to the environment.

Considering the results of the assessment of the main factors influencing the decarbonization process in Poland, the respondents were asked in the next open question: "What do you think should be the main factor in the decarbonization process in Poland?" The possible answers were categorized according to four basic groups (categories) and shown in Figure 7, which refers to Sustainable Development Goals (SDG). This figure shows the answers to individual survey participants, treating them as a determinant of sustainable development goals for cities and villages. In the respondents' answers, the main factors in the decarbonization process are subsidies and nuclear energy (approx. 50% of the respondents), followed by the conversion of coal-fired power plants to nuclear and decommissioning of old solid fuel boilers. The most frequently indicated decarbonization determinants—how to realize sustainable and low carbon cities—are presented in Figure 7.

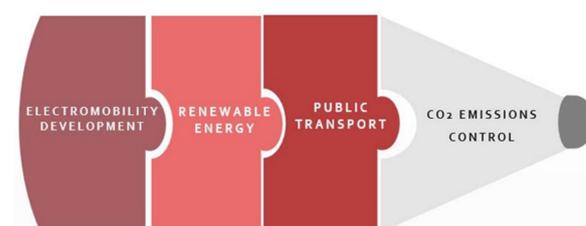


Figure 7. Main determinants of decarbonization according to the respondents with sustainability goals (SDG). Source: Own research based on the results of an online survey, $n = 249$.

In the opinion of the respondents, there were statements which put forward specific conclusions about the key determinants in the decarbonization process in Poland, that is, above all, education, knowledge and awareness of the society and enterprises for the sake of the future, clean air, and health. These are also factors such as the use of RES, subsidies for RES, replacement of boilers, development of new technologies (including transmission infrastructure) and change of deep-rooted “people’s beliefs”.

The group of respondents surveyed is aware that the issue of reducing fossil fuel combustion and carbon dioxide emissions does not have a single, simple solution. The largest sources of carbon dioxide emissions are the burning of fossil fuels in power stations, car and aircraft transport, processes related to the production of industrial goods and deforestation.

5. Result Discussion

Decarbonization is influenced by the following conditions: subsidies for mining, subsidies for local governments (e.g., decommissioning of boilers), prosumer solar photovoltaic development programs, the power market, and the opening of the European Union energy market. The authors were interested in social support for these conditions. The research showed that subsidies for the mining industry did not affect the decarbonization process. The respondents stated that development programs for prosumer solar photovoltaics had a significant or reasonably large impact on the elimination of CO₂ emissions due to their harmfulness to the environment. Regarding the most important local programs for urban residents, both urban and rural residents agree that direct support programs can best and most effectively lead to an effective decarbonization process. Photovoltaic support programs have also been assessed as useful at an equally high level. These programs also provide direct support. Therefore, rural and urban residents choose direct support programs that will reach their recipients and thus encourage the replacement of boilers or photovoltaic installations. The authors also examined the social assessment of the level at which support should be provided. It is undisputed that local programs are more effective than state programs, and they are seen as more effective. It is necessary to point out that the respondents themselves pointed out that such deterrents as the introduction of emission limits for households, the lack of administrative formalities and the introduction of additional charges for “polluters”, which play an ongoing role in the decarbonization process. Given that urban emissions are responsible for approximately 70% of greenhouse gas emissions, it is reasonable to assume that the pursuit of carbon neutrality, and any actions related to and aimed at it, without the participation of the urban sector, is doomed to failure. However, it should be pointed out that the amount of costs associated with going green, is significant.

The importance of the role of the urban sector can be seen in the analysis of the EU Green Deal, which aims to achieve climate neutrality by 2050, superimposing the essential elements of this agenda on a pyramid scheme. At the top of the pyramid is the goal of climate neutrality, going downwards, the next step is its approval by the executive of the Member States, and then, the result of the work is passed on to the state bodies of each Member State, ending with the municipalities, which thus form the basis of the whole program.

To quote an excerpt from a speech by Katarzyna Szumlewicz, Programme Manager at the European Commission’s Directorate-General for Regional and Urban Policies, in a discussion on ways by which cities can reduce their carbon footprint: “Cities face all kinds of challenges. They are seen as opportunities but they are also seen as those who have to take the responsibility for driving climate neutrality”.

The cost for cities globally to achieve climate neutrality is estimated to be in the range of USD 1.8 trillion annually, according to a report by the Coalition for Urban Transition. The report indicates, however, that these costs can be considered a form of investment with a return calculated at USD 2.8 trillion by 2030, and up to USD 7 trillion by 2050. The indicated increase is due only to cost savings. It is estimated that by 2050 more than 70% of

the world's population will live in cities. Already today, cities account for three quarters of carbon emissions worldwide [84].

Based on the research results, their analyses lead to similar or even the same specific conclusions about the critical conditions of the decarbonization process in Poland; that is, above all, education, knowledge and awareness of society and business. This is particularly important in light of global climate change. The challenges facing cities require a fundamentally different approach to the tools best suited to ensure a stable homeostatic relationship with nature and, at the same time, sustainable development of human life in the future [85,86].

6. Conclusions

Currently, the largest Polish and European cities support decarbonization activities. In the case of Poland, the share of coal used to heat flats and houses is decreasing. However, coal remains the most important fuel for electricity production. Local governments and local authorities must implement environmentally friendly, cost effective and socially acceptable policies. It is not only a fashion, but also a necessity.

The conducted research is a solid basis for the following considerations. In future, researchers should look for economic confirmation of whether the government is implementing a decarbonization policy in accordance with the needs of cities' and regions' and social expectations. It is important to carry out a detailed study in the future whether Poland will implement a coherent, long-term vision of the transformation of the economy into a zero-emission economy by 2050. In the future, the authors should focus their research on areas related to social acceptability: energy efficiency in buildings, low-carbon transport in cities, and sustainable waste management. The role of low-carbon policies in addressing broader urban challenges has been greatly underestimated. The positive impacts resulting from effective mitigation can be uncertain in scale and global in nature. It should also be pointed out that the vast majority of them will be felt in the medium to long term, and the question to be asked is whether people will be aware of them and accept them. A practical perspective indicates that a bottom-up approach examines these issues in specific cities, before considering the problems of aggregating or extrapolating results at the national, regional or city level. Accordingly, policymakers with a political focus should develop a more precise, consistent, and compelling language/narrative about the co-benefits of urban partnerships. After all, people may not only see solar PV but also, for example, green hydrogen.

Cities are the largest social clusters, concentrated, well-functioning organisms, it is important that they receive proper support from the government in the area of decarbonization policy.

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