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Landscape Online
open access peer reviewed

RESEARCH ARTICLE

Landscape Online | Volume 100 | 2025 | Article 1132

Submitted: 19 June 2024 | Accepted in revised version: 26 January 2025| Published: 24 February 2025

Implementing agrivoltaics in Poland: Policy and impact of photovoltaic farms on rural landscapes

Agnieszka Faustyna Szuta[1*], Kamil Makowski[2], Jakub Szczepański[1], Szczepańska Agnieszka[2]

1) Gdańsk University of Technology, Department of History, Theory of Architecture and Conservation of Monuments, Gdańsk, Poland

2) University of Warmia and Mazury in Olsztyn, Department of Socio-Economic Geography, Olsztyn, Poland

*Corresponding Author Email: agnieszka.szuta@pg.edu.pl

Agnieszka Faustyna Szuta
https://orcid.org/0000-0003-2158-110X

Abstract

As the global transition to renewable energy accelerates, integrating renewable energy sources (RES) into existing landscapes presents both challenges and opportunities for sustainable development. This article investigates the implementation of RES solutions in Poland, with a specific focus on agrivoltaics, and analyzes the impact of the development of RES technologies, particularly photovoltaic (PV) cells, on rural landscapes. The research examines Local Spatial Development Plans (LSDPs) in 40 municipalities in the Pomeranian Voivodeship to assess the role of photovoltaic farms in the urbanizing rural landscape. The findings reveal that while photovoltaic farms offer significant potential to meet energy goals, they also create visual, spatial, and land-use conflicts that require careful management. To address these issues, the paper explores alternative design solutions aligned with European Union sustainability goals and provides an analysis of the advantages, disadvantages, and potential application of these proposals in Poland. The research is based on literature studies, comparative analyses, and logical argumentation. The study concludes that adopting a multi-faceted approach could be crucial for integrating urban, landscape, technical, and legal actions. This approach aims to balance the benefits of RES development with the preservation of rural character and provides actionable recommendations for advancing Poland's agrivoltaic strategy.

Keywords:
photovoltaic farms, renewable energy sources (RES), rural landscape, architecture, energy, agrivoltaics, sustainable development, spatial planning

https://doi.org/10.3097/LO.2025.1132

1 Introduction

In recent years, significant technological advancements in photovoltaic cells (PV cells) have been observed. New models and simulations illustrating the use of solar energy are constantly emerging (Lazdins et al. 2021). The conducted research is reflected in reality, with the efficiency of PV cells steadily increasing, reaching 44.5% according to data from 2021. The widespread promotion and adoption of alternative energy sources, along with technological progress, including higher efficiency and easier access, have resulted in a dramatic drop in their prices (Matasci 2022). Additionally, the European Union's efforts to achieve climate neutrality and increase the share of renewable energy sources (RES) in total energy production stimulate investments in photovoltaic technologies. 'In September 2022, in its position on the revision of the Renewable Energy Directive, Parliament proposed a renewable energy target of 45% by 2030. In October 2023, Parliament and the Council raised the 2030 renewable energy target to 42.5%, with the aim of achieving 45%, almost doubling the existing share of renewable energy in the EU.' (Ciucci 2024).

The above-mentioned goals have led to a growing interest in electricity derived from solar radiation among both consumers and developers. The increasing interest in alternative energy sources is also driven by government subsidies (Chomać-Pierzecka et al. 2022; Szałata et al. 2016; Hilarowicz et al. 2013). This heightened interest is directly reflected in numerical statistics. 'At the end of 2021, the capacity of photovoltaics in the European Union countries amounted to 198 GW, representing an annual increase of 36 GW. EU countries achieved a 22% growth in installed PV capacity compared to 2021, which is almost three times less than that in Poland. In 2022, Poland once again ranked second, after Germany, in terms of growth in installed PV capacity in the European Union. At the same time, as the only country in Central and Eastern Europe, it ranked in the top six EU countries in terms of total installed capacity (Institute of Renewable Energy 2023) (author's translation). It is worth highlighting that Poland plays a significant role in the European photovoltaic market, confirming its important position in the context of developing the potential of RES in Central and Eastern Europe.

It is worth noting that photovoltaics, evolving in line with current technological and market trends, holds significant potential to improve environmental conditions, enhance energy security, and mitigate energy crises. According to the Institute for Renewable Energy (IEO), photovoltaics ranks as the second most important RES technology in Poland in terms of installed capacity. In rural areas, there is a growing interest in investments in RES based on photovoltaics, leading to increased production and energy acquisition from this renewable source (Institute of Renewable Energy 2019; Bukowski et al. 2013).

Although research is being conducted on the potential for renewable energy production in cities, and ideas for the placement and use of photovoltaic panels are becoming increasingly advanced, they still have weak points. For instance, studies on the potential for locating wind turbines on the roofs of buildings in cities (Aydin et al. 2022) do not take into account the constantly developing air traffic (Szuta and Szczepański 2018). At the same time, other concepts for the location of photovoltaic panels in cities are being explored, such as roofs of halls, service buildings, parking lot canopies (SARP 2020) (Figure 1), or the use of transparent panels on building facades, such as skyscrapers (Lai and Hokoi 2015; Radhi 2010; Zou et al. 2024). Research on these methods of using panels is dynamically evolving, as confirmed by a literature review from 2010-2022 (Lai and Hokoi 2015; Radhi 2010; Yu et al. 2021; Gorjian et. al 2022). Nevertheless, these concepts remain challenging for investors to access, particularly the implementation of photovoltaic facades on multifamily or office buildings, resulting in a scarcity of properties utilizing these solutions. As a result, despite the growing interest in photovoltaic technology, the available area for installing photovoltaic panels in cities remains insufficient compared to the increasing demand resulting from the energy sector's transformation. In response to this challenge, a greater number of photovoltaic installations are being observed in rural areas, which is also related to the increased willingness to invest in RES among rural residents compared to city dwellers (Cichowska 2021). This trend is due to the advantages offered by

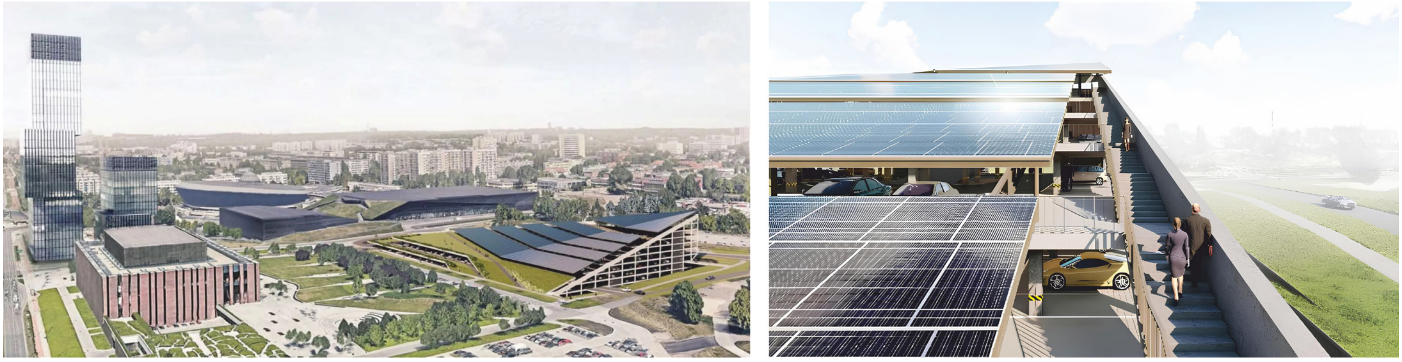

Figure 1. Visualizations from the project awarded third place in the competition: Competition for the development of the urban-architectural concept of a multi-level parking garage in the Cultural Zone in Katowice. Source: Bralczyk 2020.

rural areas, allowing for greater opportunities in the construction of both prosumer micro-installations and photovoltaic farms (in non-forested and undeveloped areas) (Foks 2019), thus more effectively harnessing solar energy.

Nevertheless, the location of photovoltaic farms among rural residents entails far-reaching landscape consequences, with a potentially negative aesthetic impact on the existing environment. To ensure visual compatibility, equipment should ideally be installed in inconspicuous locations. Photovoltaic modules, along with all components facilitating the installation and operation of the system, should be concealed from landscape views, streetscapes, and public spaces to avoid visual clutter (Lucchi et al. 2023).

Western European countries within the European Union, such as Spain, the Netherlands, France, Germany, and Poland, are addressing the challenge of integrating solar systems into the landscape. Among these, several nations are specifically focused on refining this system and implementing it as effectively as possible into their economies while preserving landscape and historical values (Lucchi et al. 2023; Kempenaar et al. 2020; Codemo et al. 2023). The response to the need for simultaneously increasing the acquisition of energy from renewable sources while maintaining control over the resulting landscape transformations is agrivoltaics. Agrivoltaics, an innovative approach to effective land development combining photovoltaics and agriculture, is gaining increasing popularity internationally (Dinesh and Pearce 2016; Dupraz et al. 2011). Its dynamic development underscores its versatility and potential. Agrivoltaics offers a promising solution to the preservation of the rural landscape by avoiding the need to sacrifice agricultural land solely for photovoltaic installations. By integrating photovoltaic panels with agricultural activities, agrivoltaics proposes multifunctional solutions that address the challenge of balancing land use between photovoltaic farms and agriculture (Dupraz et al. 2011; Gallo and Sossio de Simone 2023). This approach presents an opportunity to harmonize renewable energy production with agricultural productivity, potentially resolving the tension between these two land uses.

At this juncture, given the dynamically evolving situation regarding the placement of photovoltaic farms in rural areas, pertinent questions arise: **Is the Polish policy of rural municipalities adequately prepared for these ongoing changes? Are there measures in place to achieve the goals associated with obtaining energy from renewable sources without compromising the aesthetic values of the rural landscape?**

2 Methods and research context

2.1 The study timeframe and area

To address the questions posed in the introduction, an analysis was conducted on the factors contributing to the decrease in agricultural land area, as well as the fate of former arable fields. The growing number of photovoltaic farm developers prompted an examination of existing regulations governing their location. To achieve this, Local Spatial Development Plans (LSDP, or MPZP in Polish) in the Pomeranian Voivodeship, specifically in the Kashubian region (Figure 2), were scrutinized. This region encompasses 40 municipalities, each potentially having multi-

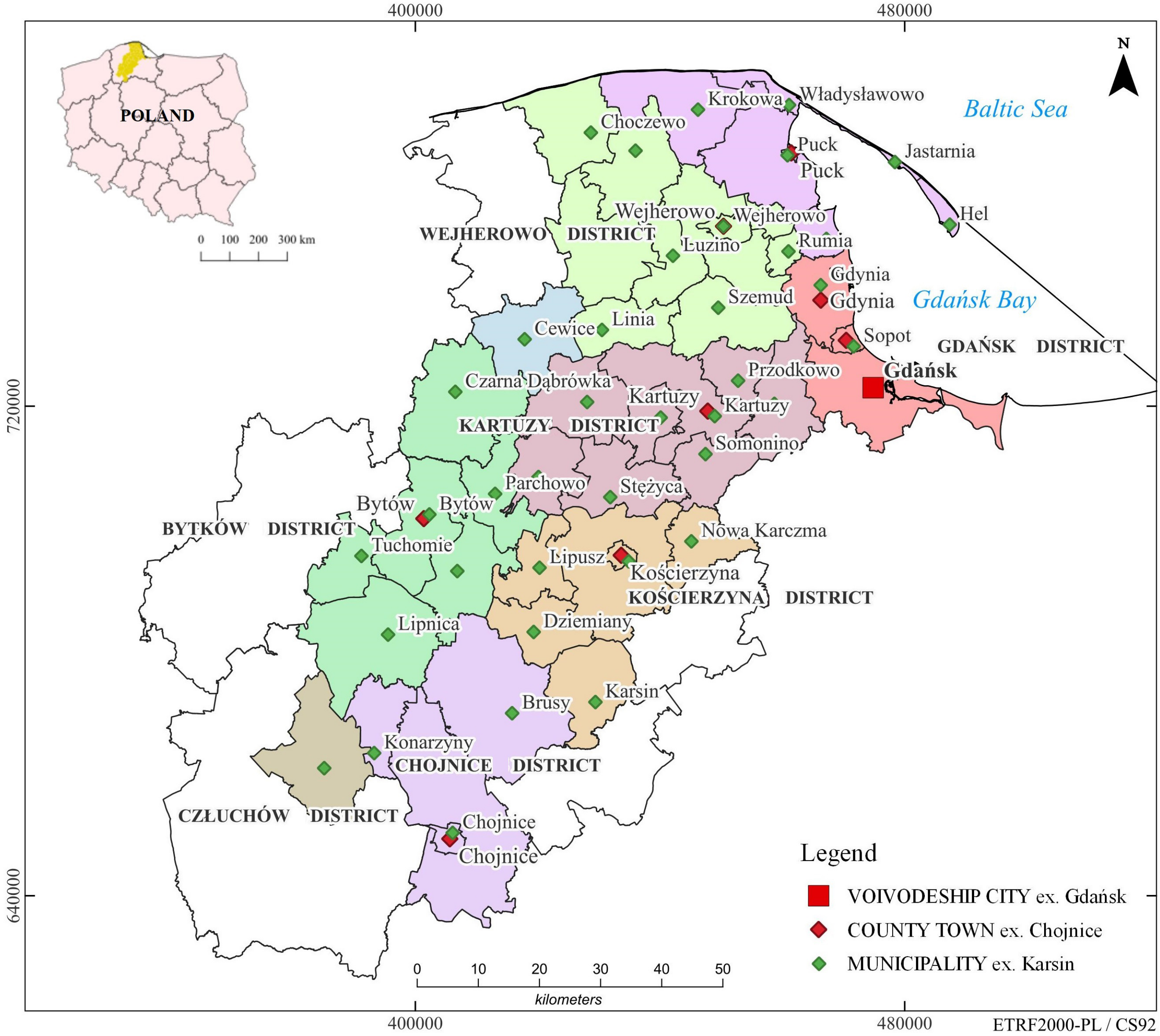

Figure 2. Municipalities comprising the Kashubian region. Created using GIS tools for the article's purposes. Author: Marcin Puczyłowski.

ple LSDPs depending on its size and the number of localities it covers. The research focused exclusively on the Kashubian region. This region was selected due to its unique landscape, cultural values, and its appeal to tourism, which largely relies on the natural environment as a key attraction. Additionally, the region faces significant risks of losing these attributes due to intensive spatial transformations and development projects (Kurkowska 2015; Prószyńska-Bordas 2008).

The study's timeframe spans from the establishment of the first photovoltaic farm in Poland in 2011 to the article's submission date in February 2024, as the issue remains relevant.

2.2 Methods

The first stage of this research involved acquainting with existing publications on the development and utilization of RES in architecture. This preparatory phase encompassed a comprehensive review of literature (Lazdins et al. 2021; Matasci 2022; Ciucci 2024; Chomać-Pierzecka et al. 2022; Szałata et al. 2016; Hilarowicz et al. 2013; Institute of Renewable Energy 2023; Lai and Hokoi 2015; Radhi 2010; Narod-

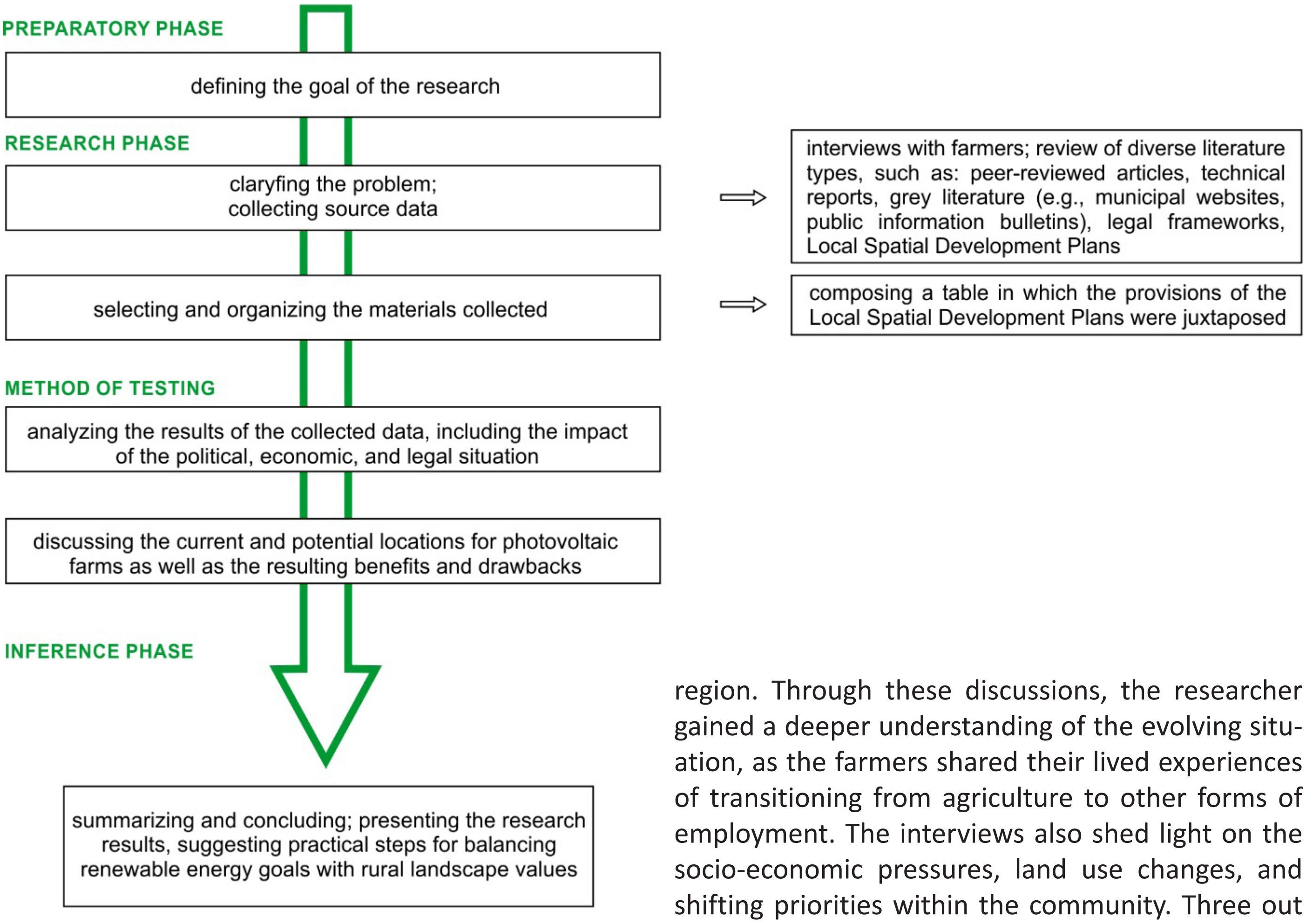

Figure 3. Research Procedure Outline. Source: A. F. Szuta own work.

zonek 2021; Ciok 2014; Oskwarek 2020; Przesmycka 2012; Szultka 2023). To collect the widest range of available resources, the review considers bibliometric databases (e.g., ScienceDirect, Google scholar, Taylor & Francis, MDPI, ResearchGate), and grey literature (e.g., websites of associations, municipal office websites, public information bulletins, laws and resolutions, LSDPs, technical manuals, and reports). Furthermore, conversations with former farmers were conducted to supplement the research.

The author of the text conducted interviews with several former farmers. The conversations with former farmers provided a broader perspective on the challenges faced by farmers in the Kashubian region. These interviews, which were conducted rather than using formal surveys or questionnaires, allowed for a more personal and in-depth exploration of the challenges faced by farmers in the Kashubian region. Through these discussions, the researcher gained a deeper understanding of the evolving situation, as the farmers shared their lived experiences of transitioning from agriculture to other forms of employment. The interviews also shed light on the socio-economic pressures, land use changes, and shifting priorities within the community. Three out of four farmers owning land of up to 8 hectares relied on farming for their livelihood until the year 2000. After that, they gradually sold their livestock. For the past 15 years, each of them has been working a full-time job. These conversations helped contextualize the findings from literature and official documents, offering a more nuanced perspective on how rural communities are facing with these changes.

The subsequent step entailed analyzing the LSDP across 40 municipalities in the Kashubian region. The collected data was then verified and organized into a table (Table 1). Following this, a summary was compiled, and conclusions were drawn, which were subsequently compared with the development objectives outlined by the European Union and Polish law. The shifts occurring in the development and formulation of RES policy directions were substantiated with quotations within the text.

After comparing the existing legal regulations and summarizing all the analyses and compilations performed (Table 1), complemented by photographs (Figures 3, 4, 5), a discussion was conducted based on literary sources as well. This discussion highlighted the functioning of municipal spatial policies and the degree of their preparedness for ongoing changes. It allowed for determining the current state of awareness among officials and specialists regarding the present direction of land reclassification (from agricultural to land for development) and its landscape consequences, as well as the involvement of municipal policy in improving the situation. Additionally, the analysis also examined how similar issues are addressed in other countries, particularly within the European Union and Western Europe, focusing on their approaches and policies regarding land reclassification and renewable energy integration.

This approach also provided an answer to whether there are measures that allow achieving the goals related to obtaining energy from RES while preserving the aesthetic values of the rural landscape. Additionally, possible directions for improving planning policies and maintaining the identity of the place were presented.

The outlined process (Figure 3) enabled drawing conclusions and identifying measures that can facilitate the harmonious coexistence of agriculture and energy production while preserving the place's identity. In the final part of the article, conclusions were drawn, along with directions for further steps essential to achieving a balance between energy and climate goals and the policy, aesthetic, and cultural values of rural landscapes.

The research was grounded in literature and iconographic studies, encompassing laws, regulations, and plans, alongside in-situ investigations and interviews with former farmers. Employing a comparative approach alongside logical reasoning methods, the studies drew from statistical analyses and in-situ observations.

3 Conceptual background: A New Dimension of the Rural Landscape

The rapid agrarian transformations are influenced by several factors, particularly farmers leaving agriculture for other professions. The decline in the profitability of agricultural activities in recent years has led to the leasing and selling of arable land. This situation is also influenced by the broad marginalization of agriculture, and family reasons — such as converting capital into cash and providing alternative sources of income (Narodzonek, 2021).

To a large extent, the elimination of suburban agricultural activities is only a matter of time. This situation is prevalent, among others, in the Kashubian region, where the average farm size does not exceed 15 hectares. In Kartuzy County, the average farm size is 7.84 hectares (Załącznik do Uchwały Nr 180/702/2022 Zarządu Powiatu Kartuskiego z dnia 28 kwietnia 2022 r., 2022), in Sierakowice Municipality it is 13.3 hectares (Urząd Gminy w Sierakowicach - Biuletyn Informacji Publicznej Sierakowice 2024), and in Przodkowo Municipality, a large proportion of farms—48.07%—are up to 5 hectares, and their owners are 'dual-career' individuals working simultaneously outside agriculture (Urząd Gminy w Przodkowie - Biuletyn Informacji Publicznej Przodkowo 2024). This significantly reduces the profitability of this type of work. Moreover, according literature and interviews (section 2.2 *Methods*; Narodzonek 2021), it is becoming more and more visible that farmers seeking solutions to improve their quality of life, stop raising animals and take up full-time jobs in other sectors. Another common solution is subdividing the land and selling it as building plots. In-situ observations indicate that in the Kashubian region, it is rare for farmers with larger farms to buy out smaller ones to increase their land area (as is the case in other regions of Poland), which affects the overall decline of agriculture.

As a result of suburbanization and restrained spatial planning, previously open spaces are beginning to shrink, agricultural functions are giving way, and the rural landscape is disappearing (Ciok 2014). Former farmland, now suburban and subdivided areas, becomes attractive to developers (Oskwarek 2020) and private individuals, often leading to landscape chaos (Figure 3) caused by a lack of coordination and planning of forms and materials, stemming from municipal policies (Przesmycka 2012). Rapid and spontaneous construction has resulted in poorly thought-out projects in terms of architectural quality, aesthetics, and execution. Developers simply aim to erect and put into use as many housing units

Figure 4. On the left: Example of residential development in Dąbrowa near Banino, Pomeranian Voivodeship, Poland. In the foreground farmhouse and tractor are being visible, and behind it the expanding residential development is being visible. Source: photo by A. F. Szuta, 02.02.2024. On the right: Photovoltaic farm located in a rural landscape. Source: Wikimedia Commons CC BY.

as possible, as quickly as possible. Additionally, the choice of location often results in unfavorable extensive urban/rural development, where buildings are often erected randomly, without clear purpose or functionality (Oskwarek 2020). Nevertheless, from the perspective of farmers, for whom small farms are no longer profitable to maintain, landscape aspects play a secondary role, and the sale or lease of fields becomes a favorable investment for them. Thus, there is supply and demand, and former rural areas become extremely attractive for investment, albeit not for agricultural purposes.

New investors have emerged as a result of the development of photovoltaic technologies (section 1 *Introduction*) and their increasing attractiveness in terms of long-term economic benefits. After years of intensive activity by developers who built residential buildings on land often acquired from farmers, a groundbreaking shift is now noticeable. Instead of continuing the trend of constructing more houses, developers are now focusing their attention on a new area of investment. Rather than seeking sites for new homes, they are once again turning to land from farmers, but this time their aim is to build photovoltaic farms (Gręda et al. 2020; Wiśniewski and Krzyżanowska 2023). Locating a photovoltaic farm in rural areas (Figure 4) offers several benefits for investors, making this option particularly attractive. Firstly, rural areas often have available land, making it easier to find suitable space for the installation of

Figure 5. On the left: View of the photovoltaic installation from a distance of approximately 140 meters. Source: Klimek, J. 2021. On the right: View of a rural house in close proximity to a photovoltaic farm. The house in the rural landscape is 'surrounded' by a photovoltaic farm located on neighbouring plots. Aerial photo taken with a drone. Source: photo by A. F. Szuta.

photovoltaic panels. Additionally, rural areas typically have better access to natural resources such as sunlight, which enhances the efficiency of the photovoltaic farm. Furthermore, cooperation with farmers could be more direct and efficient, positively impacting the negotiation and contracting process. Therefore, this procedure is significantly easier than in cities, where, although it would be advantageous to find and connect installations to the Medium Voltage (MV) lines, the search would involve finding space on building facades or roofs of halls and communicating with building managers or companies.

Locating photovoltaic farms in rural areas has become a significantly more advantageous solution compared to placing photovoltaic panels in urban areas. This is influenced by several factors, including easier exposure to sunlight and larger expanses of land (Foks 2019; Szultka 2023). Only such locations allow for the generation of energy for rural areas, as generating it in the city and transferring it to the countryside is not cost-effective. The location of farms in rural areas, with their large processing capacities for example, the photovoltaic farm in Zwartowo, Poland, reaches up to 204 MWh, which can power approximately 150,000 households (HydroEnergy 2024), brings us closer to meeting the European Union's targets for the share of RES in the economy (Ciucci 2024).

Poland is a significant case study due to its high carbon emissions intensity in electricity generation in Europe, which makes the transition to renewable energy particularly urgent. Over the past four years, the country has witnessed a remarkable increase in photovoltaic capacity, now accounting for approximately 18% of the total installed capacity (Benalcazar 2024). However, despite the numerous benefits of investing in photovoltaic panels, there are several negative aspects; including visual disturbances (refer to Figure 4 and Figure 5). If actions to regulate the legal framework concerning the location of farms are not taken, they can become highly invasive to the rural landscape. Another issue affecting Poland's planning policy and agricultural sector is the absence of provisions for "agrivoltaics" in the Polish system of legal regulations, with only "photovoltaics" being recognized.

4 Analysis of data from local development plans and decisions of the energy operator

The following table (Table 1) presents data on Local Spatial Development Plans (LSDP) for 40 municipalities in the Kaszuby region. It analyzes the LSDPs adopted from 2011 to the present, along with any changes. The starting date is defined by the time of the establishment of the first photovoltaic farm in Poland in 2011.

Municipalities that have LSDP in a given category are marked with a '+' symbol in the corresponding column. This symbol remains consistent regardless of the number of documents in a given category. For example, in one municipality, there may be 2 LSDPs allowing for the location of a photovoltaic farm, but the '+' symbol is included only once.

In the LSDP applicable in the territory of 21 out of the 40 analyzed communes, references to various photovoltaic installations have emerged, including prohibitions on their use. The total number of LSDPs referring to this type of installation amounts to 96. Nineteen communes did not address this issue at all. The LSDP containing references can be categorized into four groups:

I. LSDPs addressing the issue of allowing photovoltaic installations for personal use;
II. LSDPs concerning photovoltaic farms;
III. LSDPs prohibiting all photovoltaic installations;
IV. Others, which includes LSDP where references to photovoltaic installations are indirect. For example, they may indicate how to calculate the height of a building on whose roof photovoltaic panels are installed, or indicate the probable location of a photovoltaic farm in the future, going beyond the scope of the plan's development in which it is mentioned. Another example is indicating how to calculate the built-up area when panels are located on the ground near a single-family residential building, although without a direct provision enabling their location, as in the first group.

The summary of Table 01 is reflected in Figure 6. Among all plans addressing photovoltaic installations (96), 70 LSDPs relate to the installation of photovoltaic panels for personal use, most commonly

Table 1. Table presenting data from the LSDP for municipalities in the Kashubian region.

No..	County	Community	LSDP - reference to photovoltaic installations	LSDP - no reference to photovoltaic installations	LSDP- prohibition on photovoltaic installations	LSDP- reference to photovoltaic farms	LSDP- other references to photovoltaics
1.	PUCKI	Hel		+			
2.		Jastarnia		+			
3.		Puck			+		
4.		Władysławowo		+			
5.		Kosakowo	+		+		+
6.		Krokowa	+		+	+	
7.	WEJHEROWSKI	Reda		+			
8.		Rumia		+			
9.		Wejherowo	+				
10.		part of Choczewo	+				
11.		Gniewino	+				
12.		Linia				+	
13.		Luzino		+			
14.		Łęczyce	+			+	+
15.		Szemud	+		+		
16.	LĘBORSKI	part of Cewice	+				
17.		Lębork		+			
18.	BYTOWSKI	Bytów	+				
19.		Czarna Dąbrówka	+				
20.		Lipnica	+				
21.		Parchowo	+				
22.		Studzienice		+			
23.		Tuchomie		+			
24.	KARTUSKI	Kartuzy		+			
25.		Żukowo	+				
26.		Chmielno	+			+	
27.		Przodkowo		+			
28.		Sulęczyno		+			
29.		Sierakowice			+		+
30.		Somonino		+			
31.		Stężyca	+			+	+
32.	KOŚCIERSKI	Kościerzyna				+	
33.		Dziemiany		+			
34.		part of Krasin			+		
35.		Lipusz		+			
36.		part of Nowa Karczma	+				
37.	CHOJNICKI	Brusy		+			
38.		part of Chojnice	+				
39.		Konarzyny		+			
40.	CZŁUCHOWSKI	part of Przechlewo		+			

domestic, accounting for 72.9%. References to the location of photovoltaic farms can be found in 13 LSDPs, representing 13,5%. Prohibition of photovoltaic-related devices appears in 7 LSDPs, amounting to 7,3%. The last category, IV 'Other,' is assigned to 6 plans, representing a share of 6,3%.

13.5% of plans solely address photovoltaic farms. It is noteworthy that in the surveyed area, the Energa operator issued 177 connection conditions to the MV grid from 2008 until September 2023 for areas within the Kaszuby region. A significant portion of photovoltaic farms connected to the Energa operator's grid are investments realized based on Decisions on Development Conditions because the LSDP did not designate locations for photovoltaic farm installations. Consequently, farms that could have been established through LSDP account for approximately 7.3% of all those connected to the Energa Operator grid. Thus, photovoltaic farm projects based on Decisions on Development Conditions constitute 92.7% of all farm projects in this region.

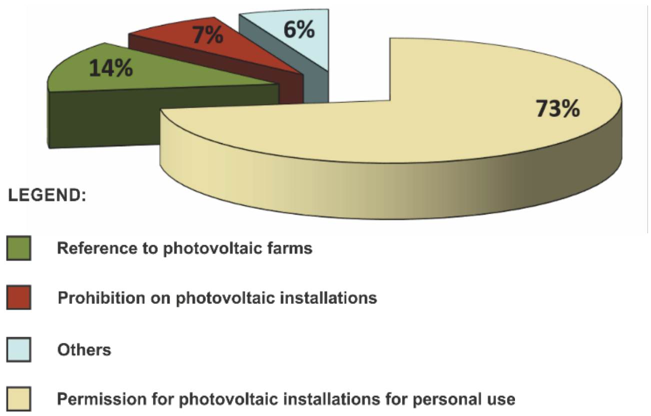

Figure 6. Percentage distribution of the four categories of provisions appearing in LSDPs relating to the acquisition of energy from PV cells. Source: Author's own work.

5 Discussion – The Role of Collaborative Partnerships as a Key Tool in Shaping Spatial Policies for Renewable Energy

The spatial policy of a municipality is shaped by three key documents: the Study of Conditions and Directions of Spatial Development (which is not a local law act), the LSDP, and the Decision on Development Conditions. The LSDP, as a legal act, serves as a significant tool for spatial planning, facilitating the sustainable development of urban and rural areas and ensuring order in spatial development (Dz. U. z 2016 r. poz. 778, Art. 14). Ongoing discussions focus on how local governments formulate functional-spatial policies, particularly concerning concerns about the weakness of spatial policy, which have gained traction since the emergence of mixed-use construction on the outskirts of cities and continue to this day (Kocur-Bera and Pszenny 2020). The effects of spatial decisions are evident, as former agricultural land has transformed into areas of urbanized landscape, losing their original character—they are neither urban nor rural (Fig. 3). These transformations are influenced by various factors mentioned earlier (section 3 - Conceptual background), ranging from the decline in the profitability of agriculture to the rise of volumetric developers, now being displaced by photovoltaic farm developers. A pertinent question arises: must the pursuit of energy efficiency and climate neutrality result in the loss of landscapes and the identity of rural areas, akin to what has occurred with residential areas?

Z. Zibrowski, already at a conference in 2009 concerning the relationship and dependencies between the Studies of Conditions and Directions of Spatial Development and the Local Spatial Development Plans, noted the lack of real impact of these documents on the municipality's role (Konferencja 2009). The observed weaknesses in spatial policy over the past 14 years (Przesmycka 2012; Nowak 2015; Rogatka et al. 2023) indicate the need for a fundamental change in the approach to planning urban and rural areas. Contemporary challenges, such as the pursuit of energy efficiency and climate neutrality, require strategic actions that consider landscape protection and the preservation of the identity of rural areas, thus raising the bar even higher than in previous years. It is noteworthy to observe the direction of the municipality's development, where former agricultural fields are giving way to modern photovoltaic farms. This paradigm shift underscores the need for an integrated approach to spatial planning that considers ecological, social, and economic aspects. The situation is urgent, as indicated by the conducted analyses (Table 1) — only 13 LSDP have addressed the location of photovoltaic farms, although many more have been established. Furthermore, the information contained in the LSDP is usually not correlated with the technical conditions enabling the full utilization of energy produced by photovoltaic farms.

The selection of a photovoltaic farm's location is a crucial strategic decision, impacting electricity producers, network enterprises, and authorities alike, with implications for both economic perspectives and the sustainable development of the region (Sindau et al. 2017). While significant efforts are being made to reduce production costs and achieve higher efficiency, choosing the right location for photovoltaic farms is a multifaceted challenge. Numerous factors come into play, including environmental considerations such as terrain coverage and shape, climatic conditions (especially sunlight exposure), the presence of protected areas, and settlement patterns. Economic factors, such as proximity to power lines, road networks, and other infrastructure, also play a significant role (Foks 2019). Recent data, such as average annual rainfall and the area and shape of the plot, further contribute to the decision-making process (Kowalczyk 2022). Recent research suggests that proximity to MV stations may not be as crucial as locating farms where there is potential for high power intake. Proper planning of connection points in the MV grid has been shown to enhance the connective capabilities of RES. Additionally, the number of farms does not necessarily correlate with energy generation, as poorly chosen locations may result in decreased efficiency. Inefficiently placed farms can generate less power, even if their number is greater (Szultka 2023). Therefore, coordination between spatial planning authorities and electricity industry specialists is essential to optimize efficiency. Collaboration with local authorities is paramount, as relationships must be complementary rather than competitive to meet all needs—agricultural, energy-related, and industry-specific. The success of photovoltaic farm projects hinges on strategic location decisions and effective cooperation between stakeholders (Pascaris et al. 2021; Gottwald 2022).

Lack of cooperation between specialists and local governments during the design of the local development plan is an aspect negatively impacting planning policy and the agricultural situation in Poland: in the Polish system of legal regulations is an absence of provisions for “agrivoltaics”. The Polish approach differs from that of Germany, a neighboring country also part of the European Union. The German government supports agrivoltaics through the EEG (German Renewable Energy Sources Act) and the Building Act, aiming to offset the additional costs of agrivoltaic systems and integrate them into small-scale farming operations. Additionally, studies in Germany have assessed the spatial potential for land use by agrivoltaics. These studies indicate that greater financial support and further research are necessary to identify barriers and gain a better understanding of stakeholders’ perspectives on agrivoltaics and its integration into the landscape. Importantly, agrivoltaics is viewed positively in the political arena, as well as among farmers and the general public. The study’s findings regarding Germany suggest that a deeper contextualization of the policy regulations surrounding agrivoltaics could enhance the effective utilization of the technology’s benefits (Rösch and Fakharizadehshirazi 2024).

Recent studies on agrivoltaics in general (Al Mamun et al. 2022) as well as its implementation in specific Western European countries such as Spain, the Netherlands, and Germany (Codemo et al. 2023; Kempenaar 2020; Rösch and Fakharizadehshirazi 2024; Wagner et al. 2024) indicate that the role of government policy in promoting agrivoltaics remains crucial yet often overlooked. Public support is essential for the growth of this emerging technology, as it encourages acceptance among farmers, thereby stimulating production. It has been observed in Spain that while the landscape has been extensively discussed in the context of wind energy, hydropower, and high-voltage power lines, significantly less attention has been given to the relationship between landscape and solar energy. Most studies assessing potential locations for solar installations focus on environmental and economic criteria, often overlooking landscape considerations. Local energy plans are rarely adopted, and spatial plans frequently neglect landscape issues and fail to engage stakeholders, hindering the translation of energy objectives into collaborative scenarios. According to this, researchers in Spain are developing an integrated approach to spatial planning that incorporates qualitative criteria, landscape integration, and principles of sustainable development in the context of solar energy production. As a result, planning frameworks are emerging that combine spatial requirements with quality criteria for solar power plants, enabling the projection of future development. This method is being tested in Arcos de la Frontera, considering both on-ground and on-roof energy systems (Codemo et al. 2023).

In the Netherlands, it has been observed that the direction of the energy transition goes beyond the ‘simple’ allocation of new spatial investments. This task requires changes in policy and institutional solutions, as well as intelligent integration with other forms of land use. To address this, regional design ateliers were organized with the aim of facilitating interaction and collaboration among stakeholders. Considerable time was dedicated to leveling the knowledge base of workshop participants. Stakeholders involved in the design ateliers primarily came from organizations related to the energy sector or spatial planning, and had limited knowledge of other areas. Conversely, energy sector stakeholders had to familiarize themselves with an integrative perspective and methods of working common to the spatial planning domain. During the ateliers, numerous 'learning' sessions were conducted, which enabled a constructive discussion on the main issue: the spatial implications of the energy transition in the region (Kempenaar 2020).

A well-designed agrivoltaic installation can address issues related to land-use competition while simultaneously providing income and employment opportunities in rural areas. An integrated system of crop cultivation and energy production does not require significant changes to farmers' business models (Pascaris et al. 2020; Al Mamun et al. 2022; Codemo et al. 2023; Kempenaar 2020; Rösch and Fakharizadehshirazi 2024). Furthermore, combining agricultural production with electricity generation in an agrivoltaic system can financially increase land productivity by up to 70% (Weselek et al. 2019).

Selecting sites for new investments, including photovoltaic systems, requires detailed data on solar exposure, meteorological conditions, and a comprehensive assessment of land availability and land cover characteristics within a given region or specific location. The growing demand for spatial data has led to the development of integrated mapping tools, commonly referred as Geographic Information Systems (GIS) (Benalcazar et al. 2024). GIS systems, in addition to providing information on the location of spatial phenomena and processes, enable the cross-referencing, overlaying, organizing, and analysis of data, allowing for a wide range of spatial analyses. Through a broad set of methods and techniques, GIS provides a scientific and professional foundation for evaluating potential locations for specific human activities (Josimović 2023), highlighting the versatility and utility of these tools.

GIS tools also facilitate interdisciplinary collaboration and integrate knowledge across diverse fields. GIS-based multi-criteria analyses significantly support the identification of potential sites for photovoltaic farms, thereby aiding the decision-making process (Foks 2019). An effective and automated tool in this regard is the development of a matrix, which assists in determining the optimal location for a photovoltaic farm. This matrix facilitates the creation of decision-making maps, clearly delineating areas that are unsuitable for development and those with the potential for hosting a solar farm (Kowalczyk 2022). By providing a visual representation of decision alternatives, the matrix serves as a valuable basis for investment planning activities. Effective cooperation among specialists from various industries is essential at this stage, as it can yield tangible benefits for the development of rural areas in terms of ecology, economy, and landscape preservation. Leveraging the combined expertise of urban planners and power engineers allows for the identification of optimal locations that maximize the efficiency of the photovoltaic farm while preserving landscape values (Kowalczyk 2022). Further supporting this approach, recent research (Rösch and Fakharizadehshirazi 2024) shows that a socio-technical GIS model can aid decision-making processes related to land-based solar energy in Germany and contribute to achieving the country's climate neutrality goal by 2045, while maintaining stakeholder and public acceptance.

In recent years, numerous experiments have explored the integration of agricultural production with photovoltaics, yielding promising results. One such experiment focused on maize crops, where better yields were achieved under conditions of water scarcity. This was attributed to the mitigation of direct radiation effects by reducing soil evaporation and increasing water savings (Amaducci et al. 2018). Similarly, studies on tomato crops, known for their sensitivity to light variation, revealed a reduction in tomato yield compared to conventional greenhouses. However, this was compensated by significant revenues generated from photovoltaic energy. Analysis of solar radiation distribution provided valuable insights for selecting suitable crops, especially when 50% of the roof area is covered with photovoltaic panels (Cossau et al. 2014). Research on lettuce also demonstrated the feasibility of combining it with photovoltaics. Initial findings from this research marked the first step in analyzing crop production under shade conditions created by the PV panels. It was observed that certain plants, such as lettuce, could adapt to reduced light availability, partly or completely compensating through higher light-gathering capacity. This adaptive behavior was linked to observed morphological changes in leaf development and morphology (Marrou et al. 2013). Such approaches to crop production in an agrivoltaic system showcase the potential for effectively combining energy and food production while enabling plants to grow under optimal conditions. While the results demonstrate the feasibility of this combination, further refinement is necessary, particularly for crops like tomatoes (Cossau et al. 2014). Model analyses suggest that production can be optimized in an agrivoltaic system by modifying panel architecture and adjusting inclination during the crop cycle. A significant advancement is the installation of movable photovoltaic panels capable of maximizing energy and food production by adjusting their position (Amaducci et al. 2018). Furthermore, research is ongoing on the use of transparent photovoltaic panels. As an additional solution, it has been suggested to implement photovoltaic modules with self-cleaning glass surfaces in highly dusty environments, which help maintain the cleanliness of the modules. However, these proposals require further technical and economic studies to assess the feasibility of their application. Alongside technological research, it is equally important to continue investigating plant responses to various technologies, both in terms of photomorphogenic and photosynthetic effects (Gorjian et. al 2022).

Agrivoltaic solutions, increasingly popular abroad and promoted by the European Union, are encouraged by the European Commission for their potential to combine solar energy generation with crop protection (Komisja Europejska 2022). Despite this endorsement and its evident benefits, agrivoltaics faces certain challenges in Poland, even though it holds the same potential as in other parts of Europe, such as neighboring Germany, with a similar climate, as mentioned above. In Poland, agrivoltaics could be particularly beneficial for blueberry plantations, as blueberries require shade, and photovoltaic panels can provide protection from hail while generating solar energy. This dual-purpose approach could offer farmers an additional source of income. However, legal hurdles pose significant obstacles. The absence of the term ‘agrivoltaic’ in Polish law means that agricultural land with photovoltaic installations would be excluded from agricultural production, disadvantaging farmers. This creates a conflict in the classification of the farmer’s activity — whether it should be considered agricultural or energy-related (Bukowski et al. 2013).

Farmers aspiring to engage in both agricultural activities and energy generation on their land encounter numerous challenges regarding regulatory compliance (Bukowski et al. 2013). The existing disparities in the taxation of agricultural and energy activities present an additional hurdle for the owners of agrivoltaic installations. It appears that if a farmer wishes to conduct both activities on their land, they risk losing their status as a farmer. Currently it is observed that solar farms on leased land are expanding due to new investors, even though many farmers would like to engage in energy production on their own agricultural land without changing its primary use, cultivation methods, and taxation. Agrivoltaics, which combines energy production with farmland preservation, offers a potential solution. However, regulatory gaps pose challenges. Efforts are underway to propose legal solutions that support continuous agricultural production and classify agrivoltaic systems as agricultural infrastructure, similar to irrigation systems (Skłodowska 2023).

In the near future, an increase in the number of installations and installed capacity is expected. Along with this trend, new concerns arise regarding issues related to landscape and urban transformation. The implementation of new systems must not focus solely on the efficiency of the photovoltaic system, while neglecting the proper synergy between energy production and food production (Toledo and Scognamiglio 2021). Confirmation of these forecasts can be found in Statistics in Poland (Institute of Renewable Energy 2023), which reveal a consistent upward trend in installed capacity over recent years, with further increases anticipated in alignment with the European Union’s energy strategy. However, the lack of appropriate legal regulations regarding agrivoltaics poses a significant obstacle to its development. Roman Karbowy, Chairman of the AgroPV Group operating within the Polish Photovoltaic Association, emphasizes the necessity of plans to provide recommendations and refine legal solutions. This is crucial to ensure the sustained development of agricultural production while treating agrivoltaic installations as infrastructure supporting agro-energy production (Skłodowska 2023).

6 Conclusions

As urbanization and urban sprawl continue, it is anticipated that the conversion of agricultural land for non-agricultural purposes, or its lease, will escalate, thereby increasingly impacting the rural landscape. The sale or lease of agricultural land presents farmers with opportunities to enhance their quality of life and financial well-being by diversifying into non-agricultural industries. This demand for land stems not only from residential developers but also, more recently, from photovoltaic developers. However, poorly planned decisions in the past have resulted in spatial chaos. Drawing lessons from these experiences and considering the dynamic growth of the photovoltaic farm industry in rural areas, it is essential to reflect on whether there are means to simultaneously achieve energy and climate protection goals without compromising the aesthetic values of the rural landscape. There may exist opportunities to harmoniously combine these two aspects, thus striking a balance between sustainable development and preserving the unique character of the rural landscape.

The observations regarding the limited impact of the Study of Conditions and Directions of Spatial Development and Local Spatial Development Plans on municipal roles prompt reflection on the efficacy of existing planning tools. Modern spatial planning should prioritize the creation of sustainable and functional communities, responsive to evolving social and environmental needs. Collaboration among energy specialists, urban planners, and local governments is crucial for this endeavor. Moreover, legal and tax frameworks should recognize the multifunctional potential of agricultural land, ensuring fairness for the farming community.

Local governments play a pivotal role in shaping functional and spatial policies. It is imperative for their planning documents to precisely delineate the directions and opportunities for the development of former agricultural lands, both functionally and spatially. This is essential for ensuring the sustainable growth of rural areas. However, professional practice reveals challenges such as difficulty in grasping the principles of balanced development, maintaining spatial order, and decision-making without considering long-term consequences, which are common pitfalls in local governance.

The current situation necessitates enhanced educational initiatives and open dialogues among local governments, specialists, and communities to ensure the effective management of rural development. It is crucial to consider both functional and aesthetic aspects, including the landscape, in decision-making processes. Government offices should prioritize thorough consideration of the potential consequences of their decisions. Urgent action is required as landscape alterations become increasingly prevalent, exacerbated by the unchecked expansion of photovoltaic developers' activities amid the rising demand for renewable energy.

A potential solution lies in fostering effective collaboration among specialists, which could yield tangible benefits for photovoltaic investors, the European Union, and local communities. Streamlining processes and involving architects and urban planners in the selection of locations could help preserve the rural landscape and its identity. Agrivoltaics offers a promising avenue by allowing electricity production on agriculturally utilized land, thus addressing spatial chaos. However, the implementation of agrivoltaics in Poland faces challenges due to the lack of recognition within Polish tax law. The absence of regulations hampers its development, necessitating collaboration across various sectors of society, including government, farmers, non-governmental organizations, and stakeholders. It is crucial to introduce plans that offer recommendations and thoroughly refine legal solutions to ensure the continued maintenance of agricultural production while treating agrivoltaic installations as infrastructure supporting both agricultural and energy production.

Another important issue addressed in this article concerns the location of photovoltaic farms. These installations in agricultural areas must first be properly located, while maximizing energy generation, and second, carefully adapted to specific local conditions to accommodate agricultural activities. An individual approach is necessary for each area that could become an agrivoltaic site — different solutions may be effective both in cornfields and blueberry plantations. Precisely defining the form and parameters of the photovoltaic installation is crucial to minimize negatively impacting agricultural activities and to contribute to better yields.

In light of all the issues discussed above, it is crucial to introduce appropriate regulations, incentives, and planning tools that will enable the harmonious coexistence of agriculture and energy production while preserving the identity of the rural landscape. Some potential solutions include:

- Collaboration among specialists: Foster collaboration with industry experts from the initial stages of determining development directions for a given village to the preparation of Local Spatial Development Plans, ensuring clear definition of goals and priorities for specific rural areas.
- Social dialogue: Promote dialogue among government institutions, farmers, and the local community to facilitate compromises and joint problem-solving.
- Clarification of regulations: Adapt laws to accommodate the specifics of agrivoltaics, particularly addressing taxation issues for farmers.
- Utilization of GIS tools: Harness GIS tools that offer extensive capabilities in utilizing public spatial data to unlock the economic potential of specific territorial units and expedite the location search process, potentially accelerating the planning process.
- Tax incentives: Establish tax incentives for farmers involved in agrivoltaics to mitigate differences in taxation between agricultural and energy sectors, discouraging farmers from seeking employment in other industries.
- Financial support: Provide farmers with access to funding and grants for investments related to agrivoltaics.
- Education: Support educational initiatives to enhance public understanding of the benefits of agrivoltaics and strategies to address potential challenges.
- Information dissemination: Promote information on techniques to enhance spatial planning quality, particularly through informed individual investment decisions, as a crucial component in improving spatial planning processes.

While agrivoltaics presents a promising solution to the challenges associated with balancing efficient land use and agricultural needs, and offers the potential to integrate energy production with the preservation of agricultural land, Poland lacks precise regulations enabling the realization of this potential. An innovative approach to simultaneously addressing energy and agricultural requirements could significantly contribute to the sustainable development of rural areas. However, in the current landscape characterized by haphazard building permit decisions and the absence of legal frameworks allowing for the multifunctional use of photovoltaic panels, achieving a harmonious balance between sustainable development, improving farmers' livelihoods, and safeguarding the rural landscape's distinct character poses significant challenges. It is crucial to prioritize achieving this balance. Therefore, promoting alternative solutions, albeit potentially more costly, that offer greater benefits and long-term returns, including the preservation of the rural landscape and local identity, is imperative. Otherwise, there is a risk of burdening future generations with the legacy of improperly planned spaces that become entrenched within the rural landscape, complicating subsequent modifications. Hence, it is essential for authorities to prioritize managing the chaotic planning processes and changes in the rural landscape.

Acknowledgements and funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sector.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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