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The Analysis of Geospatial Factors Necessary for the Planning, Design, and Construction of Agricultural Biogas Plants in the Context of Sustainable Development

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Abstract: This spatial analysis focuses on the relevant elements regarding the use of renewable energy sources, in particular, biogas, taking into account sustainability. The characteristics of the processes of biogas formation are presented, including the technological and biological aspects of its production. The issues of agricultural biogas plant profitability are discussed using examples from Poland, analyzing the economic and financial aspects of investing in this type of plant. Geospatial analysis supported by geographic information systems (GISs) looked at factors affecting the relief of the land and also the analysis of local plans or zoning decisions for the selected site. In addition, distance relationships and geological aspects taking into account terrain, landslides, and forestation, as well as hydrological aspects relating to flood and flooding hazards, were examined. It analyzed the availability of utility networks and proximity to road infrastructure. It was also examined that the proposed project will not have a negative impact on environmental protection. The analyzed site meets favorable conditions for the construction of the proposed project, and the conclusion drawn from this study is to emphasize the importance of integrating renewable energy sources with information systems to achieve sustainable development.

Keywords: renewable energy; sustainability; biogas; spatial information systems (GISs); environmental protection; economics of renewable energy

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1. Introduction

The European Union's long-term goal is to create a competitive low-carbon economy by 2050 and to achieve an 80 percent to 95 percent reduction in greenhouse gas emissions by 2050 (according to COM (2011) 112 final) [1]. The Energy Roadmap 2050 discussed the possible ways to reduce carbon emissions in the energy system, as well as related impacts, difficulties, and opportunities [2]. In this trend, a space opens up for installations from the renewable energy sector, such as biogas, among others.

The natural degradation of organic material results in the production of biogas by microorganisms under anaerobic conditions. In recent years, the anaerobic digestion (AD) [3] of waste and residues from agriculture and industry, municipal organic waste, and wastewater treatment plants has become one of the more attractive renewable energy sources [4].

Different types of processes are used to produce biogas, which can be classified into wet and dry fermentation systems. Wet systems are the most commonly used [5]. The general scheme of biogas plant construction is shown in Figure 1, where the inputs to the system are biomass, waste, and process water, and the outputs are emitted gasses, heat, and electricity. The center of the system is the acidogenic and methanogenic processes, which can be carried out jointly (in the digester tank) [6].

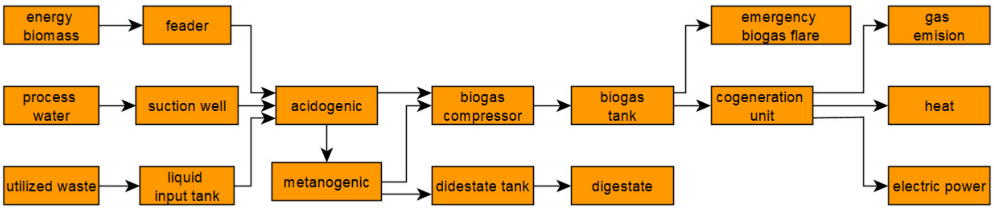

Figure 1. An example of a biogas plant system.

The main product of the plant's operation is biogas, the parameters of which determine the efficiency of the production equipment; the gaseous components are CO_2, CH_4, and H_2O. Their concentration can be monitored using systems based on photoacoustic spectroscopy [7]. The percentages of biogas components can vary significantly due to fluctuations in the composition of the feedstock and varying plant operating conditions. It is estimated that the shares of CO_2 range from 30 to 40% and CH_4 from 60 to 70%. The effect of oxygen on the biogas production process, on the one hand, is unfavorable due to the inhibition of bacterial growth [8]; on the other hand, studies show a beneficial effect of supplying small amounts of oxygen to stimulate the hydrolysis process [9–11]. Therefore, the O_2 content in biogas can vary depending on the technology variant and it is insignificant without additional aeration. Experimental results indicate the presence of H_2S in biogas at the level of 6000 ppm, and in the case of supplying oxygen to the digester, a reduction in this amount to the level of 50 ppm can be achieved. Nitrogen, on the other hand, appears in biogas in amounts ranging from 1 to 4%. Studies indicate optimal conditions for biogas production at a temperature of about 45 °C and a pH of 6.5 [12–15].

Agricultural biogas plants are a special type of plant. They allow for a process to be run systematically, fed with substrates in order to maintain a high efficiency of biogas production [16]. Both animal and plant substrates, as well as waste from the agri-food industry, can be used as a source of energy for an agricultural power plant [17].

Several technologies used in biogas plants can be distinguished. They perform the same basic function, but their designs can vary significantly, and this is influenced by local conditions, available raw materials, and climatic conditions [18]. Basic solutions of this type include covered lagoon digesters [19], garage-type digesters [20], the flow digester concept [21], and complete mixing digesters.

In practice, most facilities use biogas produced on-site to meet local energy needs for heating and electricity generation.

Purified biogas (H_2S < 100 ppm) is suitable for local applications such as cooking, combustion in boilers, or the generation of electricity and heat through cogeneration units [22]. Consequently, the need for storage under these conditions is temporary and is intended to bridge the gap between peak production and consumption. Biogas can be further upgraded by converting it to the form of biomethane (>97% CH_4) by removing impurities (CO_2, H_2S, and H_2O). The use of gas in this form includes injection into the natural gas grid (H_2S < 4 ppm) or conversion to transportation fuel (H_2S < 16 ppm) [23].

The system of financing environmental protection in Poland functions within the framework of the state financial system. It is a set of institutions and economic, legal, and organizational solutions that are designed to ensure the effective collection of financial resources and their rational use for environmental protection [24]. It is based on legally guaranteed sources of earmarked funds such as environmental fines and fees, as well as earmarked funds, foundations, funds from foreign sources including the European

Union, banking systems, and budget economies [25,26]. Expenditures on environmental protection relate to current tasks and the implementation of pro-environmental investments, such as those related to support for the development of renewable energy. The financial instruments used are subsidy systems, preferential loans and credits provided by banks, bank consortia, the project finance method, leasing, green bonds, equity, public–private partnerships, feed-in-tariffs (TiFs), feed-in premium (FiP), auction systems, and the tradable green certificates system [27].

The National Fund for Environmental Protection and Water Management (NFOŚiGW) has the largest budget for subsidizing such projects, offering various forms of project financing to local government units, as well as businesses, social organizations, or individuals. It cooperates with international financial institutions in administering foreign funds for environmental protection. The principles of financing by the NFOŚiGW are set forth in the Environmental Protection Law [28]. Energy security is a statutory goal of Poland's Energy Policy until 2040. Its specific goals include increasing the importance of biogas in the generation of electricity and heat and gaseous fuels [29].

The European Green Deal is the European Union's strategy, adopted in 2019, which aims to achieve climate neutrality in the Union by 2050. Achieving these goals obliges member states, among other things, to reduce net greenhouse gas emissions by at least 55% by 2030 compared to 1990. Meeting these requirements requires increasing the use of renewable energy sources (RESs) such as solar, wind, biomass, hydrothermal, and geothermal energy. According to data from the Energy Market Agency, energy capacity from renewable energy installations in Poland, in May 2024, increased by 20% compared to May 2023. In January–May 2024, RESs accounted for 30.35% of electricity generation, where in this period in 2023, it was 25.9% [30,31]. A summary of electric power from conventional and renewable sources in 2019–2023 is shown in Figure 2.

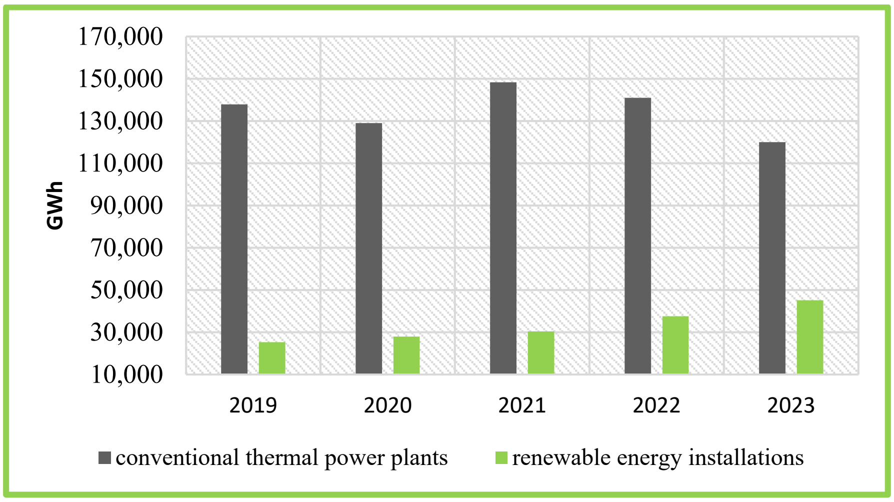

Figure 2. Electric power from conventional power plants and from renewable energy installations [30,31].

The development of energy production from renewable sources is crucial for sustainable development. Projections show that in 2050, the world's population will reach 9.6 billion, and three times the current natural resources will be required to meet their needs [32]. Limited by the depletion of fossil resources, rising global prices for fossil fuels, and the less negative environmental impacts of energy generation from renewable sources than non-renewable ones, economies are seeking to increase their share of energy production [33]. Sustainable energy will not run out, is widely available, does not harm the environment, and does not increase climate change. Its costs are not high, but setting up the system is capital-intensive [32]. Renewable energy sources are distributed and readily available, so it is possible to use them for energy production in different areas. Using them for energy production can positively affect local economic development. Increased financial resources from taxes and fees received by municipal governments can be used to improve the quality of life. Renewable energy shapes culture and pro-environmental attitudes. Unused rural land can be used, for example, to grow energy crops, thus affecting additional sources of income for residents.

The energy system in Poland is based on conventional energy sources and it is centralized. The public has little involvement in energy production. Thanks to renewable energy sources, a shift to prosumer energy, i.e., one in which the consumer is also the producer, is possible. Such a shift can affect lower energy prices and the development of renewable energy sources [34]. Investments in renewables and a decentralized energy system are important for sustainable economic and social development. Industry and the development of energy infrastructure affect the economy. One job in manufacturing plants creates 2.2 jobs in other sectors. The effect of economic growth is to improve, for example, healthcare or education [32].

The establishment of biogas plants has an impact on the life of the local community by generating additional jobs, and local construction and transportation companies can provide services for development. Biogas plants provide a market for agricultural products. The needed substrate can be obtained from local farmers, guaranteeing them a steady income and the development of the agricultural market [35]. Uncultivated land can be used to grow crops that are used in a biogas plant. Areas with difficult access to the electricity grid can obtain energy through agricultural biogas plants [36].

Despite the numerous benefits, the construction of biogas plants can raise many concerns among the local community. These are the result of a lack of knowledge about biogas technology, the operation of biogas plants, and how to use the digestate [37]. Residents are concerned about the nuisances that the operation of biogas plants may bring, such as odor emissions, increased transport traffic, substrates of unknown origin, decreased property values, leaks, or even explosions [38,39]. It is therefore important to educate the public about renewable energy sources, including biogas plants. These tasks are carried out by the National Center for Agricultural Support through information campaigns such as broadcasting spots, publishing articles, and materials in the trade press and on websites [40].

At the end of 2023, there were 388 biogas plants in Poland, mostly located in rural areas [41]. Unfortunately, Poland is lagging behind in the development of this way of obtaining energy. For example, in our country in 2022, 156 kWh of energy was produced in biogas per capita, while in the Czech Republic, there was 735 kWh and in Denmark, there was 1349 kWh [40]. At the same time, based on data from the Fraunhofer Institute, Poland became the largest European Union (EU) producer of electricity from coal in 2024 [42]. This situation is unfavorable in many respects, including economically. Biogas generated from agricultural production, municipal waste processing, or wastewater treatment plants is a so-called stable source of renewable energy, i.e., energy production does not depend on weather conditions, time of day, or year.

The production of agricultural biogas is increasing from year to year. However, the rate of change is low, although the estimated value of technical potential is high [43,44], as shown in Figure 3.

In 2023, the amount of agricultural biogas produced was only 33% of the technical potential.

It is also possible to use biomethane [45] in energy storage. The latter aspect is particularly important when constructing the so-called energy mix. One measure of the reliability of the power system is the probability that demand will exceed available energy production [46]. Many renewable energy sources are unstable in nature, meaning that there is an excess of produced energy on windy and sunny days and a shortage under unfavorable conditions. Biomethane can therefore act as a stabilizer of energy production, thus replacing energy from nuclear and fossil fuel power plants.

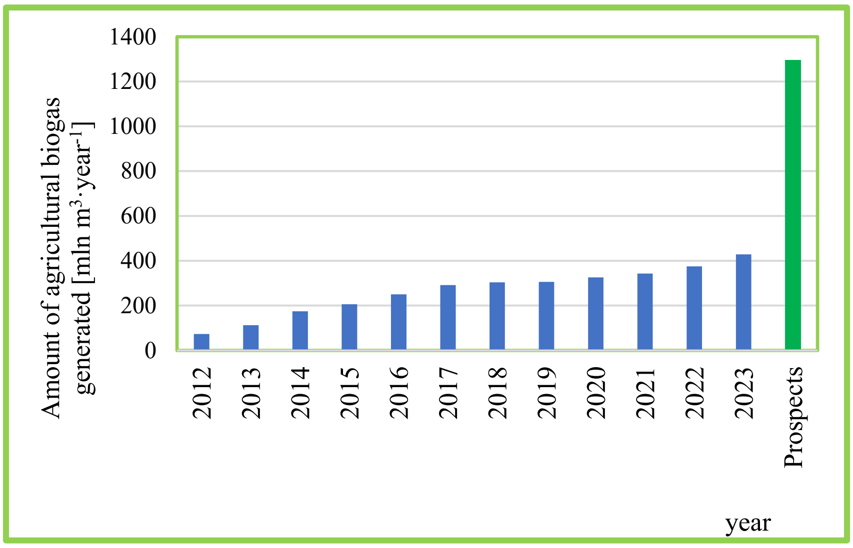

Figure 3. The amount of agricultural biogas produced in Poland in 2012–2023 [43] and its estimated technical potential (green bar) [44].

In summary, the creation of biogas plants and especially biomethane plants offers a number of benefits, which together have an additional synergistic effect. The methane extracted in biogas plants from environmentally burdensome waste becomes a valuable energy resource and by replacing fossil fuels, it reduces methane emissions from their extraction. Methane, whose greenhouse effect is 20–25 times stronger than that of carbon dioxide [47], contributes to the depletion of the ozone layer, so any action to reduce its emissions is by all means beneficial.

In addition to the above, the construction of a biogas plant brings a number of financial benefits to investors. These are revenues generated from the sale of generated electricity and heat, as well as fertilizer from digestate. The production of biogas reduces the amount of waste and thus, the cost of storage and transportation. The investor, who is an agricultural entrepreneur, gains an additional benefit—they can use the resulting digestate as fertilizer and the produced heat energy for drying wood or grain [48]. Some biogas plants provide heat to local consumers at lower prices compared to heat obtained from conventional sources [49].

Analyzing the above, there is a need to intensify efforts to improve the process of planning, design, and, consequently, the construction of an investment using renewable energy sources. This mainly concerns the selection of the location of a given project, its inconvenience to the environment, and the differentiation of construction work depending on the type and complexity of technological processes [50]. It is important to have access to the selected geospatial data for the selected location and the relationships between objects that occur between them [51,52] when planning and designing investments from renewable energy sources [53], especially for an agricultural biogas plant [44]. Spatial data are all objects that have a direct or indirect relationship to determining the location of one data point relative to another [54] and any information that is directly or indirectly related to a place or area defined in space [55,56].

A spatial information system is a set of data on the characteristics and use of land that is stored in various computer systems. These systems make it possible to efficiently collect, analyze, and present data, thereby supporting spatial planning processes and solving related problems. Their reliability and accuracy are ensured by relevant regulations.

According to Gaździcki, a spatial information system is a system that acquires, processes, and provides access to spatial data and accompanying descriptive information about objects located in the system's area of operation [57].

Spatial information systems are also computer programs that allow for the collection, organization, analysis, and visualization of geographic data. These systems combine spatial data with other types of information to create models and maps to support spatial management decisions [58].

Tomlinson's definition depicts that a spatial information system is a set of tools, techniques, and processes for collecting, managing, processing, and analyzing data that relate to specific locations on the Earth's surface [59].

The first geographic information system was developed in 1963, and its main application was the analysis of Canada's natural resources. By 1970, GIS 1 was already being used in the United States for the census [60]. In the mid-1990s, the first free GIS software appeared, which significantly affected the availability of these tools. In 2002, Gary Sherman created Quantum GIS, now known as Quantum GIS (QGIS), which is one of the most widely used GISs, available as open-source software on many platforms [61]. Its popularity is also due to a wide set of plug-ins, created in Python, which allow for the application's functionality to be extended [62].

A modern geographic information system [63] is a combination of advanced communication, information, or networking systems [64]. They run on high-performance platforms using external devices [65]. A GIS [66] is a complex organizational base using modern technology [67–69]. Technological developments have led to the development of GISs in different scientific fields, such as wireless and wired communication, mobile devices, computer graphics, or visualization techniques [70–72].

The literature on spatial information systems distinguishes the following two main types:

- Land information systems (LIS);
- Geographical information systems.

An LIS is a collection of terrain information, which includes raw data obtained directly from measurements. The information is area-specific and presented at high resolution, ensuring high accuracy.

A GIS, on the other hand, integrates geographical information, focusing on subdivisions and land uses. The data in a GIS is already processed and presented on smaller scale maps, resulting in lower precision compared to a LIS. A GIS includes both descriptive data, such as population, place, and street names, and spatial data, which describe the location, shape, size, and characteristics of objects, as well as the space between them. These data are visualized on maps, allowing them to be analyzed and interpreted in a geographical context [73].

GISs are widely used in a variety of fields, leading to a variety of terms to describe geographic information processing systems, such as geographic database information systems, geographic data systems, or spatial information systems. Each of these terms reflects the specific functions performed by the system in question. In practice, specialized systems focused on specific applications are the most common, although there are also multi-purpose GISs of a more general nature [74].

A spatial information system consists of several integrated software modules, each performing a distinct function. The main components of GISs include the following:

1. Modules responsible for inputting and verifying input data.
2. Modules managing and processing data within the database, often implemented in the form of a database management system (DBMS).
3. Modules for processing and analyzing geographic data.
4. Output modules, which include the presentation of data in graphical, cartographic, and textual form.
5. Modules providing interaction with geographic data.
6. Modules providing interaction and communication with the user.

This approach enables a comprehensive handling of geographic data at different stages of processing [75].

Geographic information systems are widely used in maintaining various types of records, including land, buildings, and other resources. Detailed data of this type are invaluable to urban planners, surveyors, and engineers. Thanks to the layered structure of the maps, a GIS allows selected elements to be easily updated without having to reconstruct the entire map. Computerized land ownership registration systems can effectively replace traditional methods, based on registers and geodetic or cadastral maps [76].

Another important group of GIS applications is the processing of information concerning the location of various phenomena, especially those characterized by high variability over time. A GIS is an effective tool for monitoring pollution emission levels, which is crucial in environmental protection [77]. Data for GISs can be acquired using remote sensors and computer-controlled measurement devices. The analysis and visualization of statistical data, such as crime risk, disease incidence, or land use patterns, also fall into this category of applications [78].

GISs are also extremely useful in the management of technical infrastructure, including water networks, aquatic ecosystems, gas, power, and communication lines [79]. Infrastructure data require frequent updates and high precision, which is possible with GISs [80]. This group of applications is closely related to a technology called automated mapping/facilities management (AM/FM), which enables the automated mapping and management of infrastructure [81].

In the course of a properly performed spatial analysis [82], the plot area and its dimensions can be determined. With the right technology for analyzing geospatial data [83], it is possible to detail aspects necessary for planning a new construction project [84] such as photovoltaic farms [53], wind farms [85], production halls, or residential buildings [86].

Geographic information systems play a key role in the planning, construction, and operation of agricultural biogas plants. A GIS enables efficient spatial analysis, which is essential when selecting the optimal location, taking into account environmental, economic, and social criteria [87]. Through the use of GIS tools, the distribution of potential sources of substrates, their availability, and transportation logistics can be accurately analyzed. This allows for minimizing costs and optimizing processes, such as the transportation of raw materials and the distribution of produced biogas [88]. Furthermore, a GIS assists in analyzing the environmental impact of an investment, including by assessing the distance from protected areas, watercourses, and human settlements, which is important from the point of view of public acceptance. In addition, potential risks, such as the possibility of leakage or contamination, can be predicted and analyzed using GISs, which enhances the safety of operating an agricultural biogas plant [89].

The issues in question will fill a gap in previous research presented in the literature. There is a need for research on spatial analysis in order to improve the process of planning, design and, consequently, the implementation of investments based on renewable energy sources, especially agricultural biogas plants. A GIS is a key tool to support the development and management of agricultural biogas plants, contributing to increasing the efficiency of these facilities and minimizing their negative impact on the environment. With this in mind, a thesis can be formulated as follows: spatial information systems support the decision-making process during the implementation of agricultural biogas plant investment.

2. Materials and Methods

The study used an analysis of spatial and terrain details made visible in various SIP applications. The research and conclusions were based on the data and knowledge available and visualized with the help of information systems.

The analysis of the entire construction process of an agricultural biogas plant, from the idea through planning, design, and construction to the obtainment of an operating permit, was carried out on the basis of the applicable legal regulations.

The entire process was based on the following legislation:

1. The Energy Law of 10 April 1997 [90].
2. The act of 20 February 2015 on renewable sources [91].
3. The act of 17 August 2023 amending the Renewable Energy Sources Act and certain other acts [92].

4. The act of 13 July 2023 on facilitating the preparation and implementation of investments in agricultural biogas plants and their operation [93].
5. The act of 27 April 2001; the Environmental Protection Law [94].
6. The act on the protection of agricultural and forest land [95].
7. The law of 14 December 2012 on waste [96].
8. The law on spatial planning and development [97].
9. The act on providing information on the environment and its protection, public participation in environmental protection, and environmental impact assessments [98].
10. The regulation of the Minister of the Environment of 27 August 2014 on the types of installations likely to cause significant pollution of individual natural elements or the environment as a whole [99].
11. The regulation of the Council of Ministers of 9 November 2004 on the determination of the types of projects likely to have a significant impact on the environment and the detailed conditions related to the qualification of a project to prepare a report on the environment [100].
12. The regulation of the Minister of Agriculture and Commune Council of 13 January 2023 on the technical conditions to be met by agricultural structures and their location [101].

The survey was carried out on a randomly selected area in the district of Nowy Sącz. Non-exhaustive functions and subject areas are available in the geoportal for each location. A qualitative analysis was made of digitally available IT datasets as follows:

- Data made available by the Kamionka Wielka Municipality Office on the website of the municipality where the analyzed agricultural biogas plant is located [102];
- Data from the geoportal for the municipality of Kamionka Wielka [103];
- Data from the spatial information system for the Municipality in Kamionka Wielka [104];
- Data from the Polish Geological Institute on landslide shielding [105];
- Data from the Informatic System of National Protection on hydrological data in the Hydroportal tab [106];
- Forest Data Bank data related to nature conservation using the Forests tab on maps [107].

The following tools, available as applications and software, were used to analyze the geospatial factors:

- Geoportals, such as Geoportal and Geoservices, which allow users to view spatial data stored in a database [108];
- QGIS computer software, current stable version: 3.34.9 'Prizren', which is used for various types of geographic data operations;
- eDrawings 2023 Service Pack 5.0 software,
- AutoCad 2020 software.

Based on the results of the study, the analysis of site selection was carried out as specified in the batch data, which was crucial to obtaining meaningful results. The decision-making process is not heavily constrained by geographic information systems (GISs) in other alternative locations because of the available information that can be obtained from geo-information systems.

At each stage of investment planning, access to geo-information data and its proper use increases the efficiency of operations, as well as the credibility of the results obtained, and a carefully conducted analysis was performed.

3. The Object of Research

The subject of this study involved a specific area and the technical and legal feasibility of conducting an analysis using information systems that use geospatial data. The analysis was aimed at assessing whether the area was suitable for investment for the construction of a power plant using biomass energy.

After studying the issues, it was determined that an agricultural biogas plant with typical parameters of up to 50 kW based on the Law on Renewable Energy [91] could be constructed.

The aim of this study was to carry out a detailed spatial analysis of a site with a total area of 13,767 m^2, necessary to design the construction of an agricultural biogas plant with a capacity of up to 50 kW, located on the following registered plots: 121005_2.0004.360/2 and 121005_2.0004.361.

4. Research Results and Discussion

4.1. Stages of the Investment Process—Construction of an Agricultural Biogas Plant

The planning, design, and construction of a planned investment project is a multi-stage and very complex process [109]. Analyzing the literature on the subject, there are many definitions of the construction process and its divisions into stages in which common features can be distinguished [110,111]. The construction process is a compilation of all the activities aimed at decision-making, the preparation of project documentation, the implementation of the project, and the commissioning of the project, which are presented in the diagram (Figure 4).

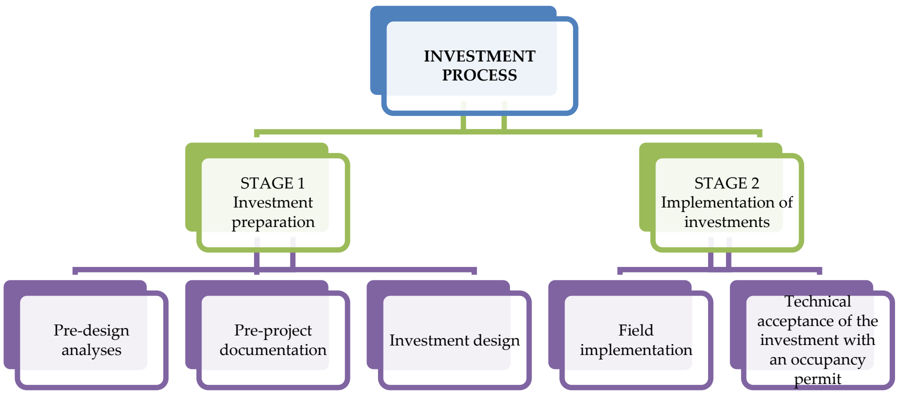

Figure 4. A distribution diagram of the investment process in the construction industry [109–111].

Following Siwkowska [112], the implementation of an investment from renewable energy sources depends on the type of project in question and its capacity, i.e., the amount of electricity the installation can produce. Therefore, the construction of a given type of installation will require going through a standard investment and construction procedure and obtaining the necessary administrative decisions on the basis of the acts regulating the given issues.

The construction of biogas plants in Poland is regulated by the Polish legal system. The norms regulating the production of agricultural biogas and electricity from it are contained in the Energy Law [90] and the Renewable Energy Sources Act [91]. The details of the construction of biogas plants are set out in the act on facilitating the preparation and realization of investments in agricultural biogas plants and their operation [111].

The construction of a biogas plant requires a number of decisions and permits, which vary depending on the type of activity and the location of the biogas plant. Licenses, permits, and approvals from local self-government organizations, environmental organizations, and other competent authorities are required [112]; in addition, each biogas plant must be entered in the register of agricultural biogas producers kept by the National Agricultural Support Centre.

In order to stimulate the biogas market, a biogas special law was introduced in 2023, facilitating the procedure for this type of investment by speeding up the process of issuing the required decisions.

In addition, biogas plants that will be entirely located on an area of no more than 1 ha have been exempted from the obligation to change land use. The act allows for the construction of an agricultural biogas plant on up to 1 ha of land belonging to an agri-food processing plant when the local spatial development plan includes the possibility of development relating to agriculture, production, or storage. Also, for an agricultural biogas plant with a capacity of more than 1 MW, the possibility of a special location mode is provided on the basis of a location resolution of the municipal council [113]. A prerequisite for a well-conducted construction project is concrete project management. Each project is characterized by conditions specific to its particularities. The individual stages of the process are shown in the diagram (Figure 5).

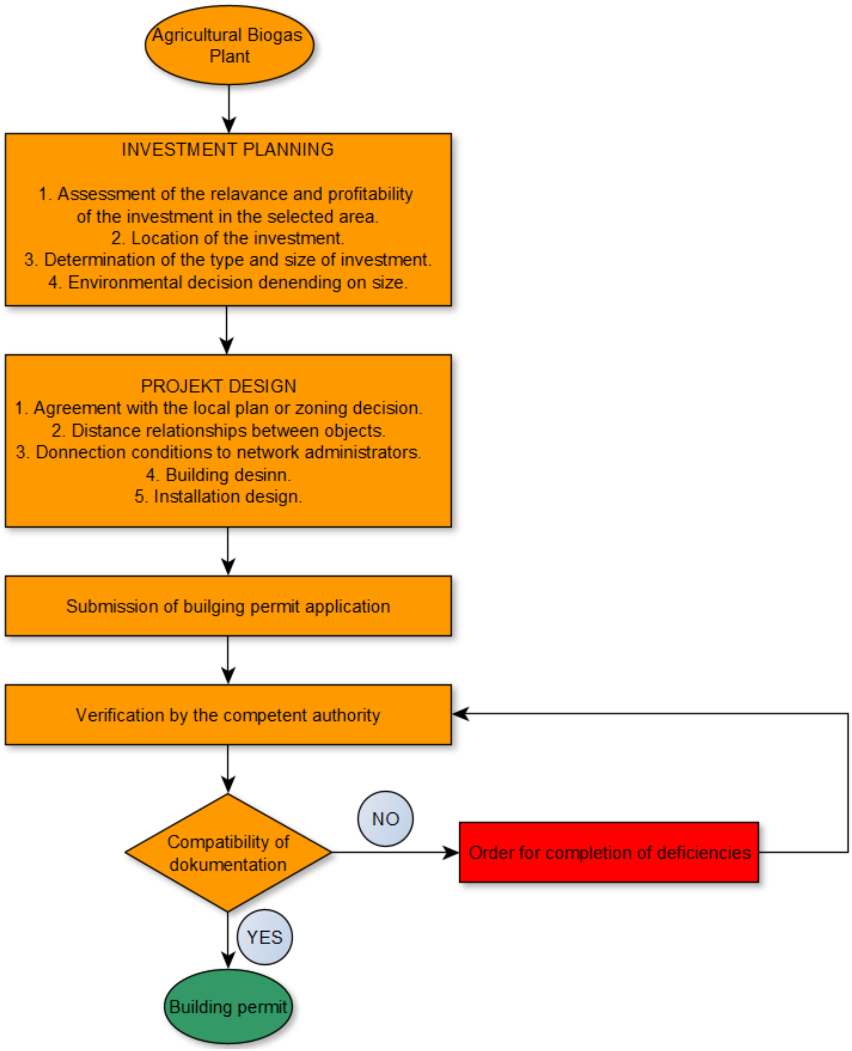

Figure 5. Schematic showing the process of developing project documentation for an agricultural biogas plant investment.

At the beginning of the process, the rationale and advisability of the investment at the location should be determined, taking into account its type and size. By correctly defining the biomass potential, the right technology for the planned biogas plant can be selected. Next, it is possible to proceed to the development of project documentation for the working biogas plant investment, which the investor will submit together with the application for a construction permit to the relevant state administration authority. After positive verification, the competent authority will issue a construction permit.

4.2. The Concept of the Construction of an Agricultural Biogas Plant

Pursuant to the act on facilitating the preparation and realization of investments in agricultural biogas plants, entities entitled to take advantage of the provisions will include natural or legal persons who run an agricultural holding; entities performing economic activity involving the production of electricity, heat, agricultural biogas, or biomethane from agricultural biogas; groups of agricultural producers; wine producers; and energy cooperatives. The issuance of such a legal act may result in an increase in demand for technologies for equipment and structures for the production of agricultural biogas and biomethane from agricultural biogas.

The first step in planning the construction of an agricultural biogas plant is a detailed assessment of the energy needs of the farm and the potential of the organic waste that will be used for biogas production. It is very important and necessary to determine precisely the amount of organic waste generated on the farm and what quantities will be generated, as well as to determine what substrates will be produced from this waste that can be used in the biogas plant, as different biogas plant process lines are used depending on the type of substrates.

With this in mind, in order to facilitate the conceptual processes related to the location and size of the project, future investors can be suggested that preciseley functioning and continuously developing spatial information systems (SIPs/GISs) are very helpful in such cases.

On the basis of [114], the plot numbers of the property earmarked for the construction of an agricultural biogas plant were determined, the total area of which, together with the accompanying infrastructure, will not exceed 1 ha.

The area on which the future investment will be located is shown in the fragment of the satellite map (Figure 6).

Figure 6. A fragment of a satellite map showing an example of an investment area for an agricultural biogas plant with marked boundaries [114].

The presented fragment of the map shows the area on which the future investment will be located, which at the planning stage allows for the selection of the biogas plant's size and type.

Another necessary element when planning the location for the construction of an agricultural biogas plant is the analysis of the local development plan (MPZP) and in the absence thereof, obtaining a decision on development conditions is necessary.

Figure 7 presents an extract from the MPZP based on resolution no. LXVIII/496/2023 Kamionka Wielka III of the Kamionka Wielka Commune Council [115].

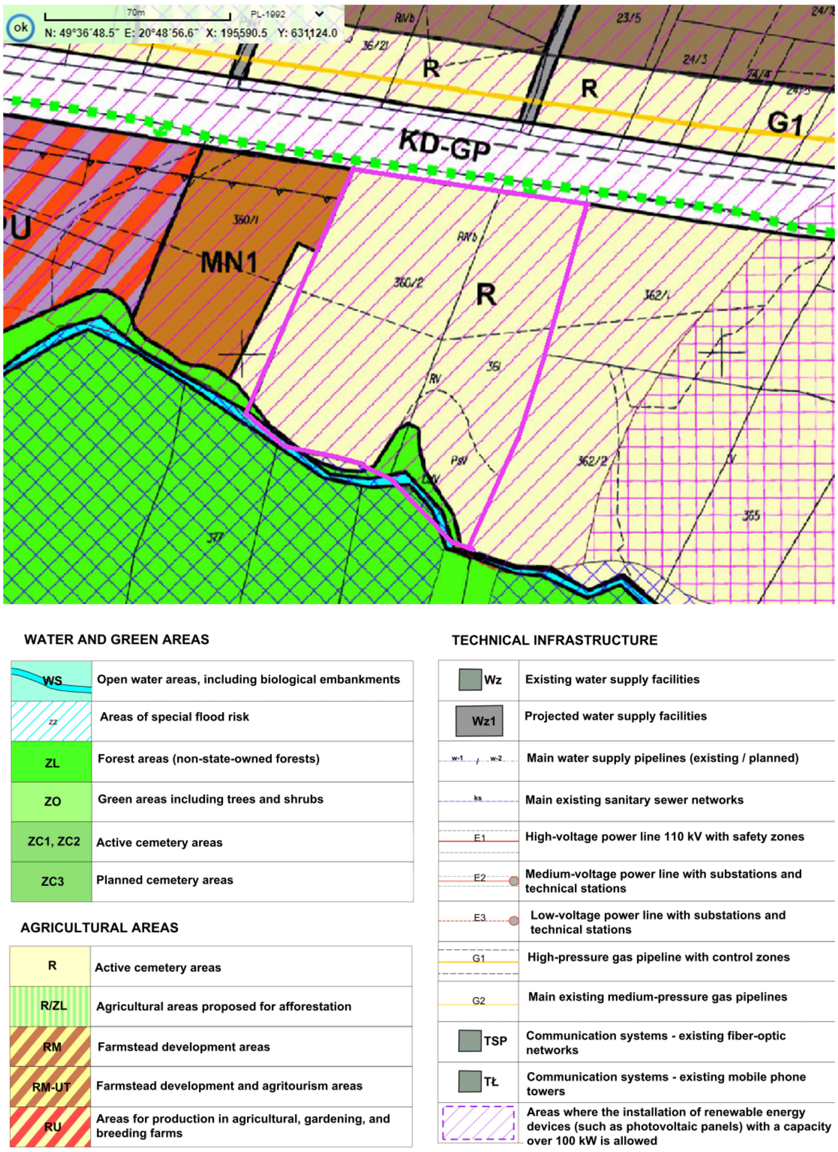

Figure 7. A fragment of a map with a legend showing the current MPZP of the planned investment [115].

Considering the information in the local development plan about the area designated for the planned investment (Figure 7), we see that the future agricultural biogas plant will be located in areas of agricultural designation. Using the distance measurement function in the Gison program, it is possible to analyze the distances between the planned investment and agricultural areas that are designated for afforestation, although they do not significantly affect the future investment. In the vicinity of the planned investment, we find areas of single-family residential development. A KD-GP road runs next to the investment plot. An important piece of information from the MPZP is that on plots 360/2 and 361, building and situating devices generating energy from renewable energy sources with a power exceeding 100 kW is allowed.

4.3. The Analysis of Geospatial Factors in the Design and Construction of the Project

When embarking on the design of an agricultural biogas plant, it is necessary to take into account a number of distance conditions contained in currently applicable legislation [101].

The excerpt from the satellite map shown illustrates one of the many distance buffers that must be maintained when designing a biogas plant (Figure 8).

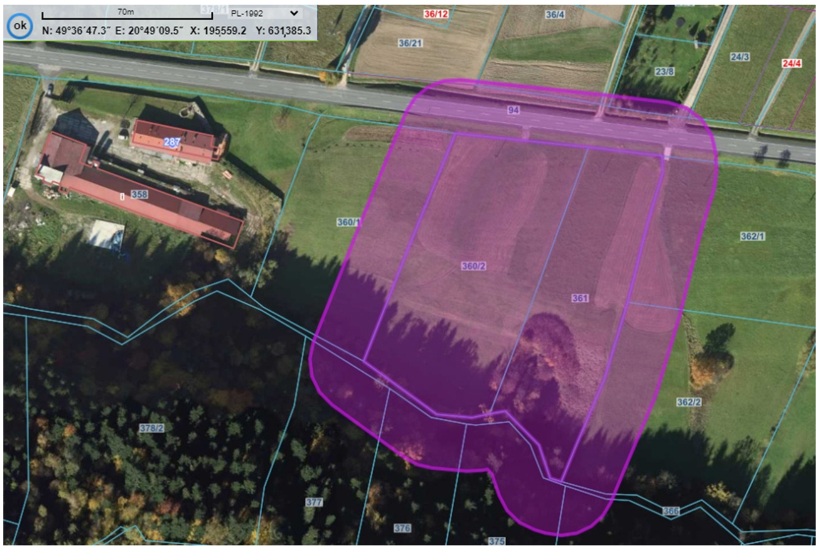

Figure 8. An extract from an orthophoto showing an example of a distance buffer (purple area) of 25 m imposed by law [101].

For example, the distance of the proposed development should be at least 25 m from premises intended for human habitation on neighboring g plots, but not less than 30 m from windows and doors in these premises. The designed buffer does not interfere with any existing facilities.

A very important element when planning this type of investment is to ensure its access to a public road. This is more precisely described in the decree of the Minister of Infrastructure [109]. In the absence of direct access to a public road, it is necessary to establish the necessary easements or purchase land providing an access road. It is important that the access road to such an investment is properly paved and that its width is not less than 5 m wide. The investment in question in the case under study is in close proximity to a national highway.

Another research factor is to check whether there are possible nature reserves and landscape park areas in the investment area or in its vicinity. In this case, the analyzed investment (Figure 9) is not located in the zone of the listed protected objects.

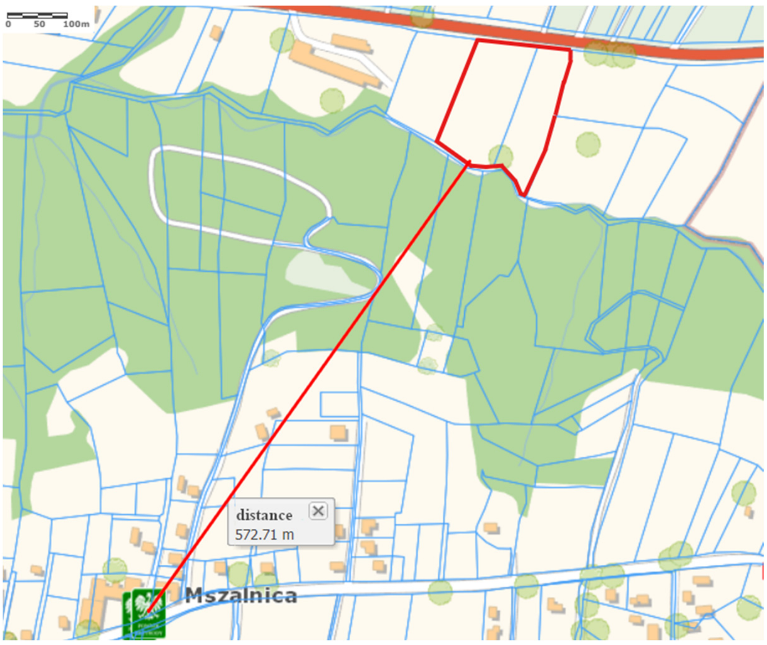

Figure 9. A fragment of a topographic map of nature conservation forms in the study area [116].

The nearest natural monument is located at a distance of 573 m [115]. There is no Natura 2000 protected area in the study area where the project is planned to be situated [116].

One of the important steps in the design of the structure is the analysis of the slope of the land on which the agricultural biogas plant will be built. The determination of the angle of the slope at which the land parcel intended for investment development is at is possible through the use of a numerical terrain model (NMT) analysis tool. An example of a numerical terrain model is generated in digital form. The satellite image (Figure 10) shows the land in 3D form, which was subjected to this analysis.

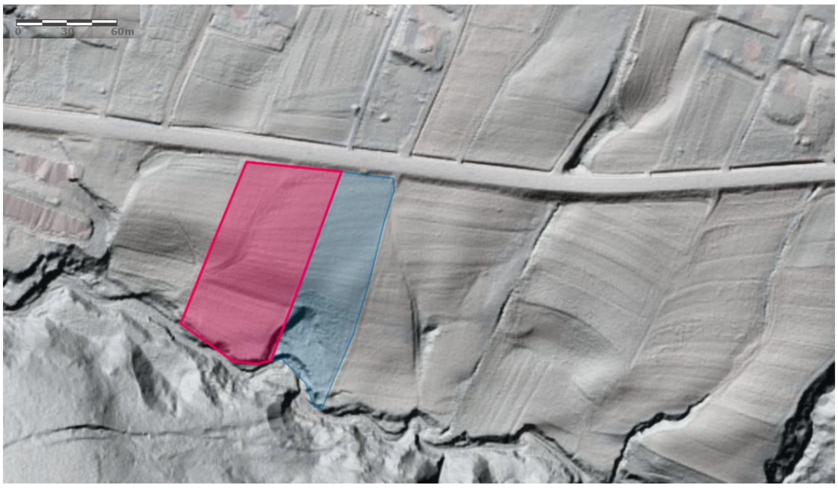

Figure 10. The visualization of the NMT in the form of shading an investment plot [103].

The next very important point in the geospatial analysis is to check the flood risk, which occurs in different areas of Poland, causing different types of flooding. The most common cause of floods and flooding is precipitation (59%).

There are publicly available flood hazard maps (MZP). To check whether the project site is in a flood risk zone, hazard maps are analyzed. Thanks to them, it is possible to determine the occurrence of disasters. In addition, it is possible to take rapid action to protect people and infrastructure (Figure 11).

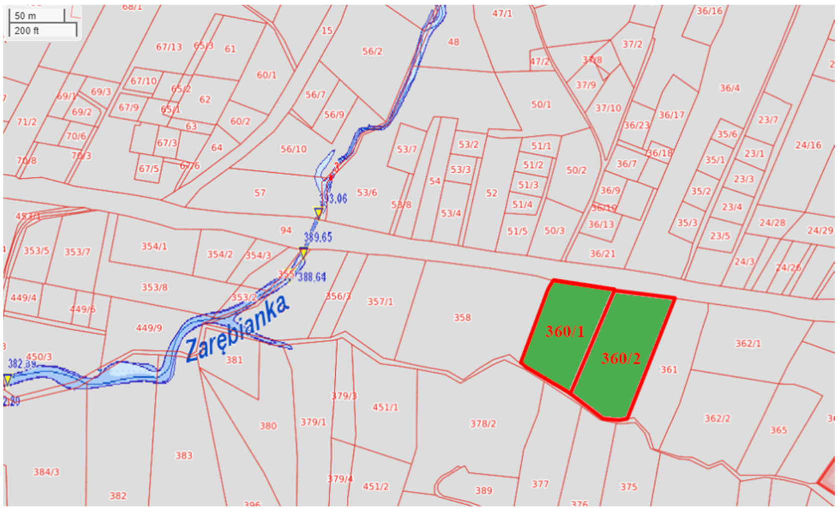

Figure 11. Simulation of Q1 and Q10 flood risk [106].

After simulation in both the Q1 and Q2 cases, the proposed development is not at risk of flooding.

The soil analysis consists of many elements such as the depth of the ground water, the study of the chemical composition of the soil, and also the measurement of the PH level in the soils. It is also very important to prepare an analysis for the occurrence of active landslides in Poland, i.e., translocations of earth and rock masses caused by human intervention or forces of nature. In order to minimize the potential risk of building a project in an area prone to landslides, maps of active landslides are used (Figure 12).

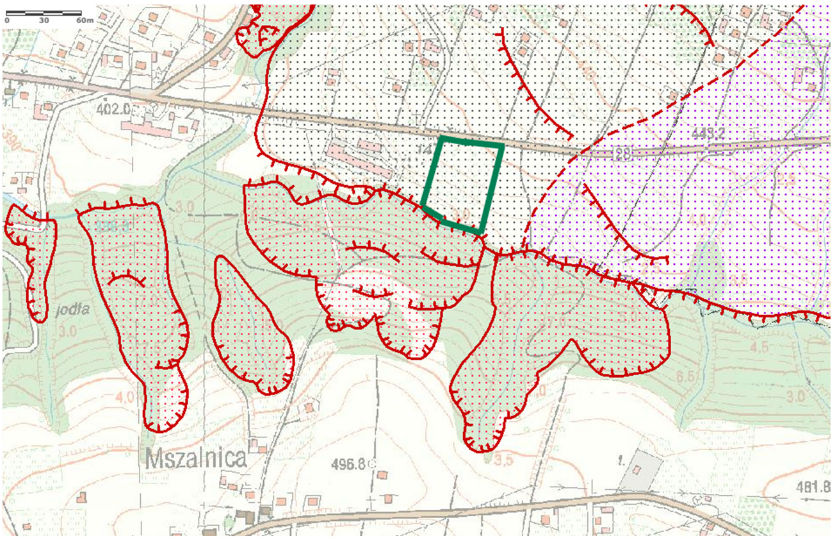

Figure 12. Map of active landslides with the investment plot marked [105].

An analysis of maps depicting landslide sites shows that the proposed project is not located in an active landslide area but is in the immediate vicinity of a continuous active landslide. Polish law does not prohibit building on inactive landslides, but the investor should be aware of possible consequences of building on such terrain, as inactive landslides may become active in the future.

In Figure 13, a profile of the site was drawn up and used to analyze active landslides showing the absolute heights.

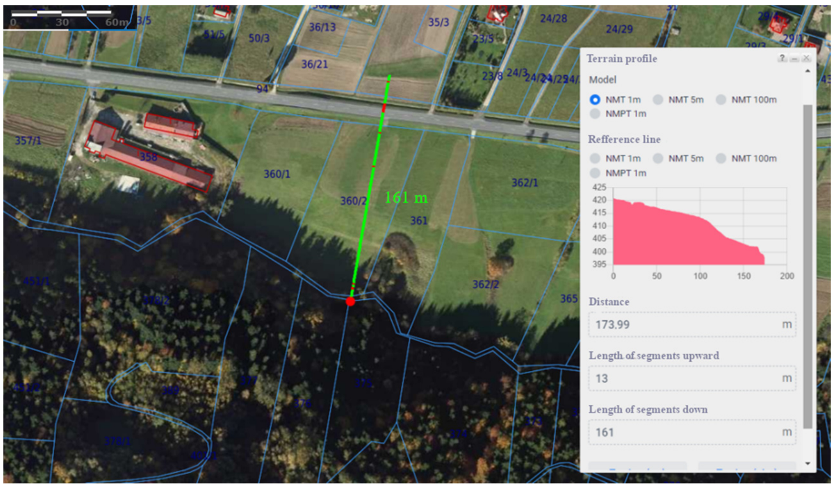

Figure 13. A map showing the profile of the site [103].

The analysis shows that the area of the site is not significantly different. The sum of the length of upward measurements was 13 m, while downward measurements were only 161 m. Based on this analysis, it is possible to search for a piece of land to be leveled.

Spatial information systems can be used to support the design and planning of infrastructure; with the help of web-based publicly accessible systems showing the course of above- and below-ground utilities, we can check the location of utility networks that may be necessary for the operation of the structure or that will be an obstacle and will have to be bypassed or rebuilt (Figure 14).

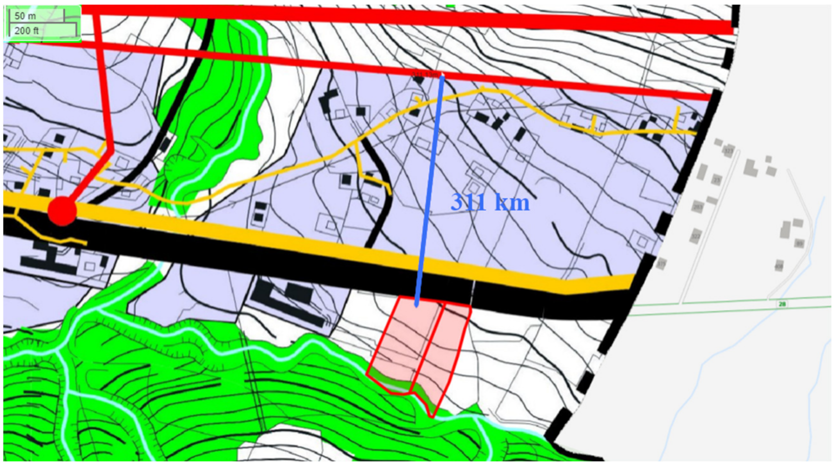

Figure 14. Map showing location of utility networks [104].

The proposed investment lies at a distance of 311 m from the 200 kV line. Placing the networks in the vicinity rather than directly on the plot allows for the statutory distance relationships to be maintained without taking away from the area of the project under consideration. When meeting fire requirements, GISs can be used to visualize designs and spatial analyses that facilitate cooperation and allow for faster and more accurate agreements.

When building this type of facility, fire safety measures such as the required maximum distance to the nearest hydrant are also essential. Here, using the system, we can find the nearest hydrant and measure the distance between it and the planned facility (Figure 15) [103].

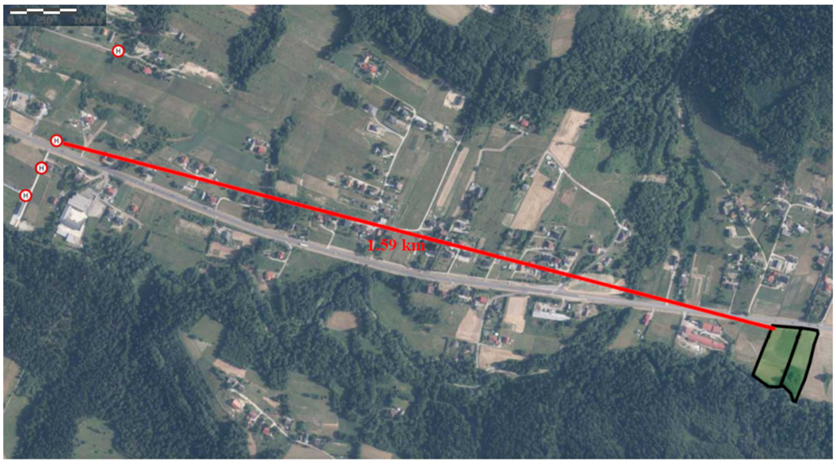

Figure 15. A map showing the location of hydrants (H) and the distance from the proposed development.

The nearest hydrant is located at a distance of 1.59 km, which provides fire protection for the proposed project.

Once the design process is complete, the developer can monitor whether the submitted application for a building permit has been granted. The map excerpt shows plots of land in close proximity to the proposed project that have an administrative decision number for the building permit, which can be helpful for project management and compliance with legal requirements such as building and occupancy permits (Figure 16).

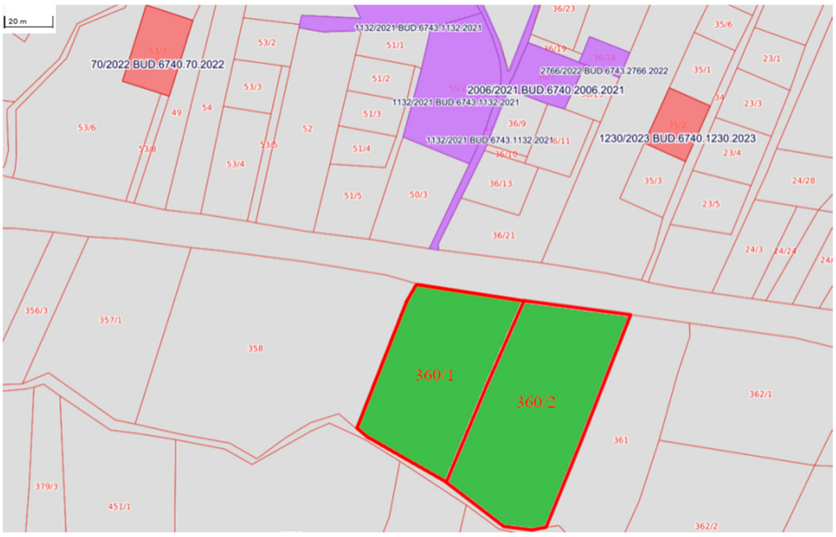

Figure 16. A fragment of a topographic map showing plots for which a building permit decision has been issued [113].

No decision has been issued for the planned investment; therefore, the studied area does not contain any elements.

4.4. Conclusion and Discussion

The main objective of the study was to analyze the land located in Nowy Sącz district in terms of the possibility of the planning, design, and construction of an agricultural biogas plant.

The agricultural biogas plant will be located on agricultural land, and the development of single-family dwellings will be at an appropriate distance from the planned investment. In addition, on selected plots of land, the implementation of equipment generating energy from renewable energy sources with a power of more than 100 kW is allowed.

The proposed agricultural biogas plant is located near a national road and is situated to provide a favorable impact on nature conservation and Natura 2000 areas.

In addition, the site does not occur in flood-prone areas but is located in an area of inactive landslides in the immediate vicinity of a continuous landslide. In Polish law, there is no prohibition of construction on inactive landslides, but the investor should be aware of the possible consequences of the foundation of structures in such an area. The profile of the terrain is not significantly different, and the proposed project lies at a distance of 311 m from the 200 kV line. The distribution of the network being in the vicinity, and not directly on the plot, allows it to maintain the statutory distance relationships. However, the nearest hydrant is situated at a distance of 1.59 km, which provides fire protection for the proposed project. In the final stage, it was checked whether the selected plots have a building permit.

By inference, when planning the investment, distance relationships from buildings, power grids, and the road should be taken into account. The second important aspect is to check the site in terms of environmental protection and flood and landslide hazards. Locating a biogas plant in floodplains and areas threatened by mass movements involves serious risks associated with the violation of the electrical and structural installation of the biogas plant.

The analysis performed above addressed spatial factors affecting the relief of the land and also the analysis of the LSDP or zoning decision for the selected site. Then, the issue of distance relations and geological aspects taking into account terrain, landslides, and forestation, as well as hydrological aspects directed at the possibility of flooding and watercourses, were examined. An analysis was performed on the access to the medium voltage grid and adequate access to a public road.

Taking into account the above, it is shown that the location in question is suitable for the construction of an agricultural biogas plant. The commencement of construction of such an investment, taking into account energy from biomass, will also not have a negative impact on environmental protection. The location of the site for the construction of an agricultural biogas plant was carried out by taking into account all the conditions that are necessary for the planning, development, and construction of such a project.

5. Summary

The conclusions of the analyses carried out unequivocally point to the fundamental importance of renewable energy, including biogas, as a fundamental pillar of sustainable development in Poland. Biogas, due to its properties and potential, not only allows for the reduction in greenhouse gas emissions but also plays a leading role in economic stabilization by reducing dependence on standard energy sources.

An analysis of the technological and biological aspects of biogas production has shown that the optimization of fermentation processes and innovations in production technology can significantly increase the energy and economic efficiency of agricultural biogas plants. The economic viability in agricultural biogas plants in Poland has shown that the success of such a solution depends on financial planning, taking into account specific market conditions and the availability of raw materials.

The analysis of geospatial factors proved to be an indispensable tool in the decision-making process regarding the construction of biogas plants. The use of GIS technology and the analysis of planning documents enabled a comprehensive assessment of sites for their suitability for a biogas plant location, taking into account geographical, hydrological, and urban planning factors. These results suggest that appropriate site selection, based on robust geospatial analyses, is crucial for the success and long-term viability of biogas projects.

The use of spatial information systems (GISs) in the management of agricultural biogas plants is an example of a new approach to optimize biogas production processes. The combination of these systems with other renewable technologies not only supports efficient management but also enables dynamic responses to changing environmental and market conditions, which is essential for achieving sustainability.

The research carried out provides valuable guidance for future investments in the biogas sector, highlighting the need for a comprehensive approach that integrates advanced technological, economic, and spatial analyses. The results of this research can be immediately used in the planning and implementation of new biogas projects, further developing RESs in Poland and strengthening its importance in achieving sustainable development goals. It is worth focusing on the ever-changing legislation that can have a fundamental impact on the implementation and profitability of such projects.

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Abbreviations

GIS	Geographic information system
AD	Anaerobic digestion
pH	Pondus hydrogenii
TiF	Feed-in tariff
TiP	Feed-in premium
NFOŚiGW	The National Fund for Environmental Protection and Water Management
EU	European Union
RES	Renewable energy sources
LIS	Land information system
DBMS	Database management system
AM/FM	Methodology/facility management
QGIS	Quantum geographic information system
MPZP	Local development plan
KD—GP	Expressway
NMT	Digital elevation model
MZP	Flood threat maps

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