

Article

Fuzzy Modeling as a Tool Supporting the Energy Policy of Selected Municipalities (Poland)

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Abstract

Energy planning should focus on actions to save energy and reduce consumption while also implementing renewable energy sources to support sustainable urban development. In addition to global regulations, individual countries also have documents that facilitate energy management at the local level. This is a particularly valuable source of information about resources that influence energy efficiency at the national level. This article analyzes the Low-Emission Economy Plans (LEEPs) developed for selected cities in Poland. Based on selected provisions, fuzzy modeling solutions are proposed to support energy decisions in municipalities. The research thesis assumes that the appropriate selection of criteria for emission reduction, as well as their objectification and hierarchization, when supported by fuzzy logic modeling and multi-criteria analysis, enables local governments to identify key variables and structures and compare decision scenarios relevant to local energy policies. To verify this thesis, an analysis of the LEEP provisions of four city municipalities located in the Kuyavian–Pomeranian Voivodeship was conducted. Based on these criteria, a set was identified, and diagrams were developed to identify variables and concepts that occupy key positions in the modeled pathways leading to emission reductions. Fuzzy logic modeling and multi-criteria analysis were used as decision-support tools in the research process. A comparison of the applied approaches enables the identification and prioritization of variables of greatest importance within the adopted set of criteria. The obtained results allow us to determine how the adopted energy strategies are linked to the implementation of local policy objectives and which relationships play a key role in the modeled decision-making structure. The analysis indicates that the decision-making variants differ in their impact on the paths leading to reduced final energy consumption and greenhouse gas emissions. Variant W1, which is based on investments in renewable energy sources, is strongly associated with the path leading to reduced greenhouse gas emissions, while increased public awareness and acceptance also play a significant role in the model's structure. The strongest relationships were identified between increased energy efficiency and building energy standards, between building energy standards and reduced final energy consumption, and between reduced final energy consumption and reduced greenhouse gas emissions. The reasoning map thus highlighted the particular importance of the sequence of relationships linking energy efficiency, building energy standards, and reduced final energy consumption. The proposed approach can also provide a basis for



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further comparisons with solutions used in other countries, thus expanding the possibilities of analyzing low-emission policies at the local and national levels.

Keywords: energy policy; low-carbon policy; low-emission economy plan; fuzzy modeling; sustainable urban management

1. Introduction

1.1. Background

The European Union has long recognized the problems associated with energy emissions and their impact on the environment. The concepts of sustainable urban development and the green economy are increasingly appearing in EU documents [1]. The Europe 2020 Strategy document [2] defines the EU's path for 2011–2020 towards a smart and sustainable economy. Urbanization processes increase pressure on local energy, transport, and environmental systems, but the nature of this impact depends on the spatial development of the city. Suburbanization and the dispersion of areas increase travel distances, resulting in dependence on individual transport and the need for infrastructure development. Urban density can reduce some of these needs, but at the cost of concentrating energy demand [3,4]. The use of appropriate tools to support low-emission planning at the municipal level is therefore a good solution. One such tool is Low-Emission Economy Plans (LEEPs). In Poland, Low-Emission Economy Plans (LEEPs) were developed by local government units in accordance with national guidelines from financing and advisory institutions, particularly the National Fund for Environmental Protection and Water Management and the Voivodeship Funds for Environmental Protection and Water Management. These guidelines specified, among other things, the need to conduct a baseline CO₂ emission inventory, identify problem areas, define strategic and specific goals, and indicate actions to reduce energy consumption and emissions and increase the share of renewable energy sources [5,6]. In Poland, municipalities established them to implement the goals set out in the Climate and Energy Package and to manage change at the local level. A LEEP is a Polish strategic document that is linked to the Sustainable Energy and Climate Action Plan (SECAP) under the Covenant of Mayors [7]. The document itself remains important and relevant in the context of EU climate goals and national policies. The provisions in the plan primarily outline actions and conditions to reduce greenhouse gas emissions within the city. By creating the plans, municipal authorities aimed to develop a strategy for implementing them, specifically by utilizing existing resources while ensuring environmental protection and quality of life. Currently, the plans serve as the basis for current strategic documents, such as Municipal Development Strategies, Municipal Climate Change Adaptation Plans, and Sustainable Energy and Climate Action Plans. Their importance lies in integrating climate, spatial, and social objectives into local policies, particularly in the context of urban adaptation to climate change [8,9].

Increasing the consumption of energy from renewable sources and reducing CO₂ emissions are crucial elements of sustainable urban development for European Union countries, including Poland. The importance of local energy planning stems from the need to simultaneously address the goals of reducing greenhouse gas emissions, improving energy efficiency, increasing the use of renewable energy sources, and limiting the negative environmental impacts of urban operations. Achieving these goals requires translating them into actions tailored to local infrastructural, spatial, economic, and social conditions.

A LEEP encompasses actions aimed at reducing emissions and energy consumption within the broader context of local development, including modernizing energy infras-

structure, improving the energy efficiency of buildings, and developing renewable energy sources and transport-related measures. However, the scope and priority of these actions vary between municipalities and depend on their local circumstances. Therefore, the LEEP can be considered not only a document that defines emission targets but also a source of information on local priorities, barriers, and the potential to implement low-emission policies. Information from local stakeholders can also be incorporated into the plan preparation process, thus broadening the scope of knowledge used to formulate actions [7].

1.2. Literature Review

The United Nations 2030 Agenda supports the implementation of the Sustainable Development Goals in the EU. Ensuring access to affordable, reliable, sustainable, and modern energy constitutes Goal 7 [10]. It stipulates that by 2030, international cooperation should be strengthened to facilitate access to clean energy research and technology and to promote investment in energy infrastructure and clean energy technologies [10].

According to the above, the pursuit of sustainable urban development and the search for solutions to reduce CO₂ emissions are key elements of EU member states' documents. In [8], the authors discuss the challenges and opportunities of sustainable urban development policies within the framework of the European Union's Urban Agenda. They also address issues related to CO₂ emission reduction in the context of urban development. In [11,12], the authors point out possible solutions, including investments in renewable energy sources and a focus on the green economy. Another important direction is reducing final energy consumption through technological modernization and locally adapted energy policies [13–15]. The effectiveness of such policies depends not only on technical solutions but also on economic conditions, implementation capacity, and the involvement of local stakeholders. At the same time, reducing greenhouse gas emissions remains a central objective of sustainable urban development and must be considered alongside economic and social development goals [16,17]. At the local level, low-emission policies may therefore combine measures to improve energy efficiency, increase the share of renewable energy sources, modernize infrastructure, and strengthen public participation in energy transition processes. These interdependencies make sustainable urban development a multidimensional decision problem in which environmental, technical, economic, and social criteria must be considered simultaneously [18].

Multi-criteria methods are widely used in decision-making processes related to the built environment, including design, technical assessment, and building protection [19–21]. However, their application is not limited to a single building. A common feature of these problems and local energy planning is the need to simultaneously consider numerous, often heterogeneous, criteria. Therefore, multi-criteria decision analysis (MCDA) approaches are also used to plan urban energy systems, assess energy transition options, and support decisions regarding low-emission development [22–24]. In the context of the local energy transition, the main challenges include financial and infrastructure constraints, dependence on existing energy systems, varying building-level technical conditions, barriers to implementing renewable energy, and the level of social acceptance of transformation measures. At the same time, development opportunities arise from improving energy efficiency, modernizing buildings and infrastructure, increasing the share of renewable energy, and using local energy management tools. The multidimensional nature of these conditions justifies the need to use methods enabling simultaneous analysis of the above-mentioned criteria [25].

The challenge is to increase knowledge about the relationships between social subgroups and the environment, as well as between preferences and acceptability. Social diversity in perceptions of pro-environmental solutions and their acceptability depends

on knowledge levels, local spatial and climatic conditions, and the availability of decision-support tools. Therefore, research indicating that climate-related design solutions are not universal but require adaptation to specific conditions of the location, users, and type of development is so important [26,27].

One of the important areas of local energy policies, where the interdependence of technical, economic, and environmental factors is particularly visible, is the energy modernization of the building stock. Local regulations take into account the provisions of EU documents, which prioritize increasing energy efficiency. Research on building modernization also plays a significant role in energy efficiency analyses. Improving the energy standard of buildings is crucial, as it affects both final energy consumption and the environmental and economic impact of urban policies [28–30]. The leading document is Directive 2012/27/EU of the European Parliament and that of the Council of 25 October 2012 on energy efficiency [31]. According to the directive, each member state sets an indicative national energy efficiency target and establishes a system that requires cities to improve energy efficiency. The importance of this area justifies including the energy standard of buildings as one of the key concepts analyzed in the model structure.

Rapid urbanization and diverse local conditions mean that energy policy decisions must consider both quantitative and qualitative data. In addition to energy consumption, emissions, and technical parameters, implementation barriers, local priorities, constraints, and levels of resident acceptance are also important considerations. The complexity of these relationships justifies the use of methods that integrate diverse data and analyze the interrelationships between factors. In this context, fuzzy methods, fuzzy cognitive maps, and multi-criteria approaches are particularly useful. Decision-support tools can facilitate the evaluation of alternative actions and support the selection of investment priorities in local energy policies, where simulation tools tailored to the specificity of a given problem are particularly useful, thus enabling the presentation of action options and analysis of their potential consequences [32]. In this context, tailored simulation tools refer to models whose structure can be adapted to local conditions through the selection of specific variables, their relationships, and the decision-making options analyzed. This approach is particularly important for municipalities whose strategic documents reflect diverse local conditions. Contemporary research indicates the growing importance of computational methods supporting urban energy planning under conditions of complexity and uncertainty. One such approach is fuzzy cognitive maps (FCMs), which enable the representation of a system as a network of concepts connected by directed relationships of a specific sign and relative strength. FCMs enable the integration of quantitative data with qualitative information and expert knowledge, thus finding applications in the analysis of complex social and socio-technical systems and sustainable development strategies [33,34]. In urban energy transformation, FCMs are used to map the relationships between energy system components, social conditions, stakeholders, and transformation goals, as well as to analyze alternative action scenarios [35]. In parallel, methods that combine fuzzy modeling with other computational and multi-criteria approaches are being developed to support decision-making in urban energy systems [24,34]. FCMs can be constructed and analyzed using tools such as Mental Modeler, while reasoning maps provide additional organization of relationships among decision options, intermediate concepts, and final goals.

In this article, the provisions of the LEEP served as the starting point, highlighting key features that contribute to increased energy efficiency in selected municipalities in the Kuyavian–Pomeranian Voivodeship.

The research gap addressed in this study concerns the limited integration of qualitative information contained in local low-emission planning documents with fuzzy modeling and multi-criteria decision-support methods. Specifically, this study explores the feasibility

of transforming LEEP provisions, including local goals, barriers, strengths and weaknesses, and planned actions, into an orderly structure of relationships relevant to local energy policies. Based on this, the following research question was formulated: given the diverse circumstances of local municipalities, to what extent does the use of fuzzy logic modeling in LEEP analysis enable the identification and structuring of variables relevant to CO₂ emission reduction? The research hypothesis assumes that appropriate selection, objectification, and prioritization of criteria, when supported by fuzzy logic modeling and multi-criteria analysis, can support the identification of key variables, the structuring of relationships between them, and the comparison of decision-making options relevant to local energy policies. This study makes three main contributions: first, it transforms the qualitative information contained in low-carbon economy plans and SWOT analyses into concepts and structured relationships usable in fuzzy modeling; second, it combines cognitive maps with reasoning maps, thereby enabling the distinction of direct, indirect and mediating paths between local energy policy factors, decision options and final goals; third, it shows how the integrated application of these methods can support the identification of key variables and their role in the structure of local energy policy decisions.

2. Materials and Methods

2.1. Research Objects

In Poland, an energy policy is implemented at the central and local government levels. When developing a city's energy policy, decision-makers are not always able to base their decisions on all factors, as the information available during the decision-making process is complex and the alternatives are numerous, making them difficult to compare. Poorly implemented energy policies can lead to energy poverty, health hazards, conflicts among residents, inefficient use of public funds, and reduced energy potential in urban areas. The article analyzes the provisions of the Low-Emission Economy Plans (LEEPs) of four major urban municipalities located in the Kuyavian–Pomeranian Voivodeship—Bydgoszcz, Toruń, Grudziądz, and Włocławek. Bydgoszcz is the capital of the Kuyavian–Pomeranian Voivodeship and the eighth-largest city in Poland. Toruń is the seat of the Kuyavian–Pomeranian Voivodeship Assembly and the second-largest city in the voivodeship. Włocławek is the third-largest city in the voivodeship, and Grudziądz is the fourth-largest. All cities are also cities with county rights (Figure 1).

A significant component of the plans is a forecast to reduce CO₂ emissions and final energy consumption and to increase the use of renewable energy. It should be noted that, according to EU documents, the target year for which the forecast was to be prepared was from 2020 onwards. Table 1 contains forecast values for selected cities in the analyzed region.

Table 1. Target changes in CO₂ emissions, final energy consumption and renewable energy use in the analyzed municipalities [36–39].

Municipality	Reducing Emissions CO ₂ [%]	Reducing Energy Consumption [%]	Increasing the Use of Energy from Renewable Sources [%]
Bydgoszcz	20.0	5.0	3.0
Toruń	20.0	20.0	15.0
Grudziądz	18.0	10.0	6.0
Włocławek	5.0	1.0	0.1

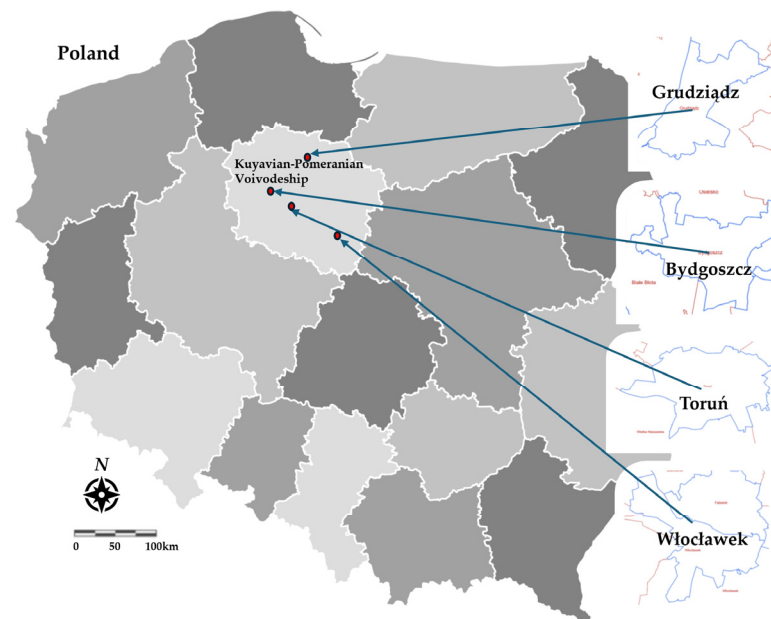


Figure 1. Location of cities in Poland.

The initial part of the plan involves comparing the base year with a control or target year. Differences in base years and data coverage result from the specific nature of individual case studies. They do not provide a basis for a direct comparison of target achievement levels between municipalities. The comparison focuses on the structure of concepts and relationships, not the direct volume of emissions or energy consumption. As mentioned, the base year varies by municipality. This is because complete data on CO₂ emissions and final energy could be obtained for a given year. Each city sets strategic goals to achieve the data specified in the forecast. To this end, municipalities, based on the collected information, determined the pace of change and identified and summarized the changes reported for the assumed reference periods and years (Table 2). The choice of the base year was left to the municipality. The values presented in Table 2 are taken directly from the analyzed LEEP documents and refer to changes identified by individual municipalities compared to the base, control, or target years adopted in those documents. Due to differences in the definitions of reference periods and data ranges, these values are treated in this study as data reported in the source documents rather than as uniformly verified ex post results. They are also not used for direct ranking of municipalities.

Table 2. Changes in CO₂ emissions and final energy consumption reported in the LEEP in relation to the adopted base and control or target years [36–39].

Municipality	Base Year/ Check Year Target	CO ₂ Emissions and Final Energy Consumption	
		Changes in CO ₂ Emissions [%]	Final Energy Consumption [%]
Bydgoszcz	2005/2013	+5.6	+15.4
Toruń	1998/2013	−13.5	−14.4
Grudziądz	2014/2020	−2.7	−9.8
Włocławek	2013/2020	−4.6	−0.9

The summary shows differences in the reported values of changes across individual LEEPs. Interpretation of positive and negative values requires referencing the method adopted in the LEEP to calculate changes relative to the base and control years. These results confirm that the LEEP documents are not fully comparable without accounting for

differences in base years, data scope, and local forecasting assumptions. Due to differences in the base and target years, the scope of available data, and local forecasting assumptions, the municipalities analyzed are treated as separate case studies. Therefore, CO₂ emission and final energy consumption indicators are not used for direct ranking of cities or for a quantitative comparison of their performance. The comparison primarily focuses on the structure of the identified factors, the relationships among them, and how the local conditions recorded in the LEEP can be reflected in decision-support models. A SWOT (strengths, weaknesses, opportunities, and threats) analysis was also included in the assessment. The table below presents its most significant components—strengths and weaknesses identified for individual municipalities (Table 3).

Table 3. Selected assessment criteria for the analyzed municipalities from the SWOT analysis performed based on the LEEPs [36–39].

Municipality	Strengths	Weaknesses
Bydgoszcz	- Active attitude of the city authorities in the field of environmental protection and climate protection; - Experience in the implementation of projects in the field of energy efficiency; - Activities of municipal units for the benefit of rational energy consumption; - A well-developed heating network and large heat sources that can provide district heating for a large area of the city; - Increasing the potential for reducing energy consumption in public facilities and universities in the city.	- Insufficient financial resources for the implementation of all activities; - Low renewable energy potential in the city; - Low public awareness of climate protection.
Toruń	- Proximity to the expressway and motorway; - Good technical condition of the gas network; - The potential for the development of solar, geothermal, and wind energy and the use of biomass; - Using a subsidy system to replace the heating source; - The presence of universities (e.g., Nicolaus Copernicus University); - A large share of green areas within the boundaries of the municipality of Toruń and a predominance of roads with an improved hard surface; - The potential of qualified staff; - Entrepreneurship of the city's residents; - A high level of recycling in the city; - Actions of the municipality towards reducing emissions, e.g., replacement of the transport fleet with a modern one; - Involvement of the commune authorities in the introduction of measures to reduce emissions and energy consumption in Toruń; - A high percentage of people connected to the sewage and water supply network (98%); - A developed heating network in the right-bank part of Toruń (including in the areas of the city with exceedances of PM₁₀); - Involvement of enterprises in the development of the use of renewable energy sources in the city; - Replacement of public transport rolling stocks with low-emission ones; - Expansion and modernization of rail public transport.	- Negative natural growth and a gradual decline in the birth rate; - An aging society; - A decrease in the number of inhabitants; - Almost 1/4 of the city covers the demand for thermal power with hard coal; - No connection to the municipal heating network of the left bank of Toruń; - The problem of building internal installations in tenement houses located in the Old Town.
Grudziądz	- The previous experience of the city of Grudziądz in the field of activities reducing energy consumption and greenhouse gas emissions; - Well-developed technical infrastructure (including a sewage treatment plant, a landfill, a high-voltage power grid and a gas main); - The city's determination to implement the low-carbon economy plan; - Developed a public transport system; - The city's achievements to date in the field of thermal modernization and the use of renewable energy sources in public facilities; - Ambitious investments of the city in the field of energy efficiency and the use of renewable energy sources in the field of public transport; - The favorable geographical and communication location of the city.	- Relatively low potential for the use of renewable energy sources in the city; - The need to perform detailed analyses and executive plans of individual projects; - Limited influence of the city on companies providing public transport in the city; - Lack of detailed information on non-network media consumed in the city; - Technical and economic barriers to the use of RES; - An increase in electricity consumption in individual groups of consumers; - Some of the city's buildings still require thermal modernization.
Włocławek	- Active attitude of the city authorities in the field of environmental protection and climate protection; - Experience in the implementation of energy efficiency projects; - The city's possibilities in the use of renewable energy sources; - Progressive development of the central heating system.	- Insufficient financial resources for the implementation of activities, including co-financing of activities to be implemented by society; - Proximity to major transport hubs; - Low public awareness of climate protection.

To build a model that would allow for the structuring of the relationships between factors relevant to local energy policies, key components were identified for each of the analyzed municipalities. Variable extraction was performed according to a structured document analysis procedure. In the first stage, the LEEPs of the four municipalities were

analyzed, with particular emphasis on the goals, planned actions, and the strengths and weaknesses identified in the SWOT analyses, as well as the barriers. Provisions relating to the same or similar energy policy issues were then grouped into broader conceptual categories. Concepts retained for further modeling were those that could be interpreted as factors related to energy efficiency, final energy consumption, greenhouse gas emissions, renewable energy development, energy standards in buildings, transport, air quality, implementation barriers, costs, or social acceptance. Concepts specific to individual municipalities were also retained if they resulted from local conditions described in the relevant LEEP. Therefore, the source of each concept was the provisions of the relevant LEEP document and the SWOT analysis contained therein, rather than an independently created set of variables.

2.2. Research Method

Mental Modeler (Web App), a fuzzy logic-based model design and forecasting tool, was used to analyze energy efficiency. The software enables the integration of diverse stakeholder knowledge for decision-making and for creating and testing solution scenarios to determine the outcomes of proposed solutions [34,40] (Figure 2).

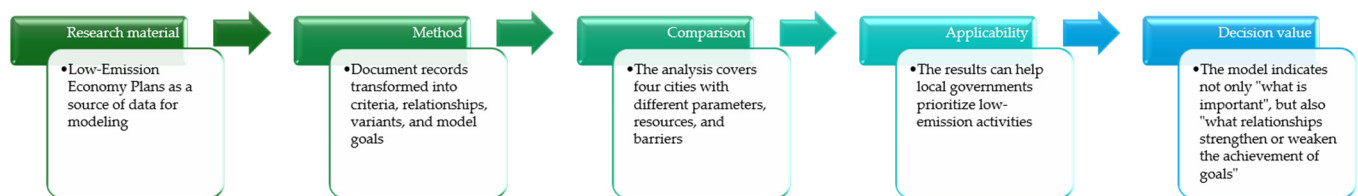


Figure 2. Diagram of the use of fuzzy logic for the operationalization of LEEP provisions as local energy policy instruments [own elaboration].

Cognitive mapping is a proven method for studying individual cognition. It is a theoretical graphical representation and analysis technique used to study decision-making, organizational cognition, and strategy. Cognitive maps can encompass various types of relationships between concepts. Still, factor maps are most used in decision-support analyses because they enable the representation of cause-and-effect relationships among concepts extracted from qualitative, expert, or strategic data [34]. In Mental Modeler, these relationships are recorded as directed connections between concepts, which can be assigned a sign and strength of influence, thus allowing for the analysis of the model's structure and the testing of change scenarios. The concept mapping interface provides a model-building framework and parameterizes the model structure in the format required for FCM analysis. The same construction procedure was used for each model. Identified concepts were entered as model nodes, causal relationships were mapped using directed connections, and each connection was assigned a sign and relative strength. The model structure was then inspected in the Mental Modeler matrix interface to ensure that all assumed relationships were mapped consistently. The scenario interface was then used to analyze how changes to selected input concepts propagate through the model structure. The same sequence was followed for the basic, extended, and municipality-specific models, with the set of concepts varying depending on the local information extracted from the relevant LEEP documents. The matrix interface clarifies the structural properties of the cognitive map. After identifying the concepts, directed relationships between them were determined based on the relationships described in the LEEP and SWOT analyses, and then related to the literature and the authors' previous research on local energy policies. The direction of the relationships indicated which concept was treated as an influencing factor and which as an affected variable. A positive sign was assigned to reinforcing relationships, meaning those

in which the growth or improvement of one concept promoted the growth or improvement of the other. A negative sign was used for relationships that weakened or limited the value of the target concept. The relative strength of the relationships was determined according to the adopted model scale. In cases where the source documents did not allow a clear determination of the strength of the influence, the authors reached a consensus assessment based on the consistency of the relationships with the documents, the literature, and the model's structural logic. The scenario interface enables the implementation and comparison of system changes in potential scenarios, as well as the re-examination and verification of models in the concept mapping interface, by taking into account new information [41]. In the basic and extended models, the adopted weights represent the relative strength of the relationship estimated by the authors based on LEEP documents, the literature on the subject, and the adopted logic of the model structure (Figures 3 and 4). Data for the maps below are included in Appendix A (Tables A1 and A2).

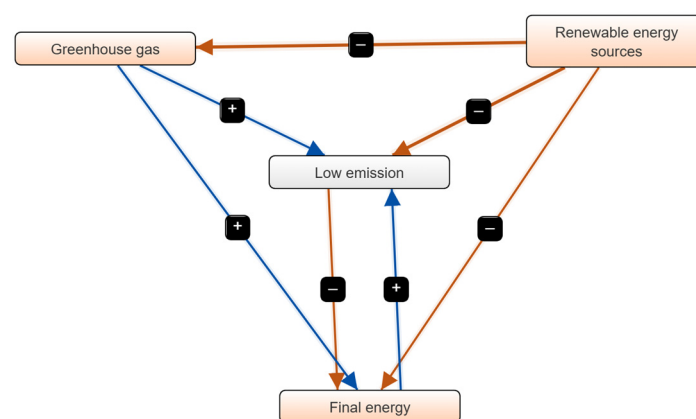


Figure 3. Basic model of the dependence of low CO₂ emissions in relation to the basic components affecting their reduction (blue arrow influence +; brown arrow influence −) [own elaboration using Mental Modeler].

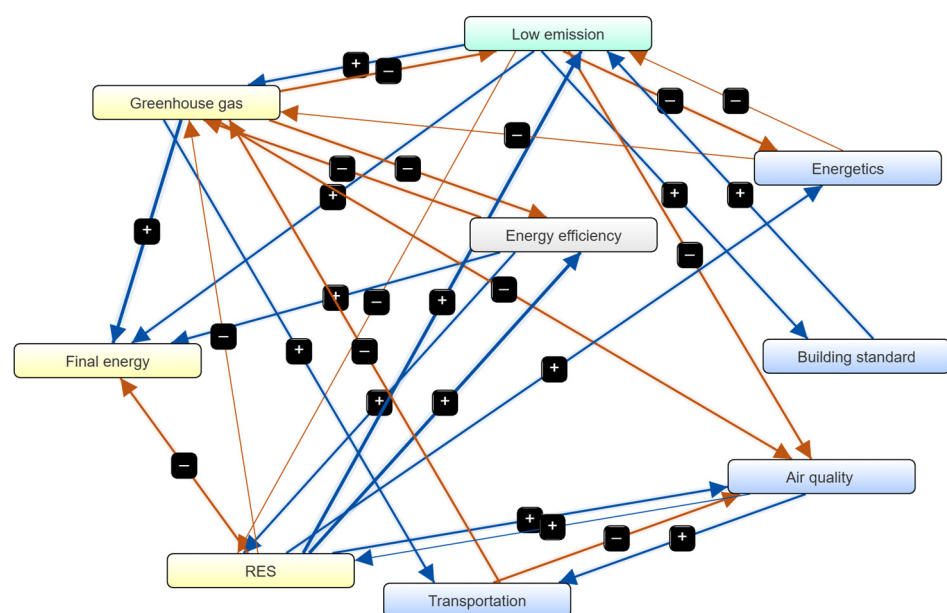


Figure 4. Extended model of dependency affecting low CO₂ emissions (blue arrow influence +; brown arrow influence −) [own elaboration using Mental Modeler].

To demonstrate the modeling capabilities, simulations were performed for each city. Separate models were constructed, with components and connections specific to each

city. Figure 5 summarizes the value and direction matrices of connections, as well as the cognitive maps. The data are contained in Appendix A (Table A3).

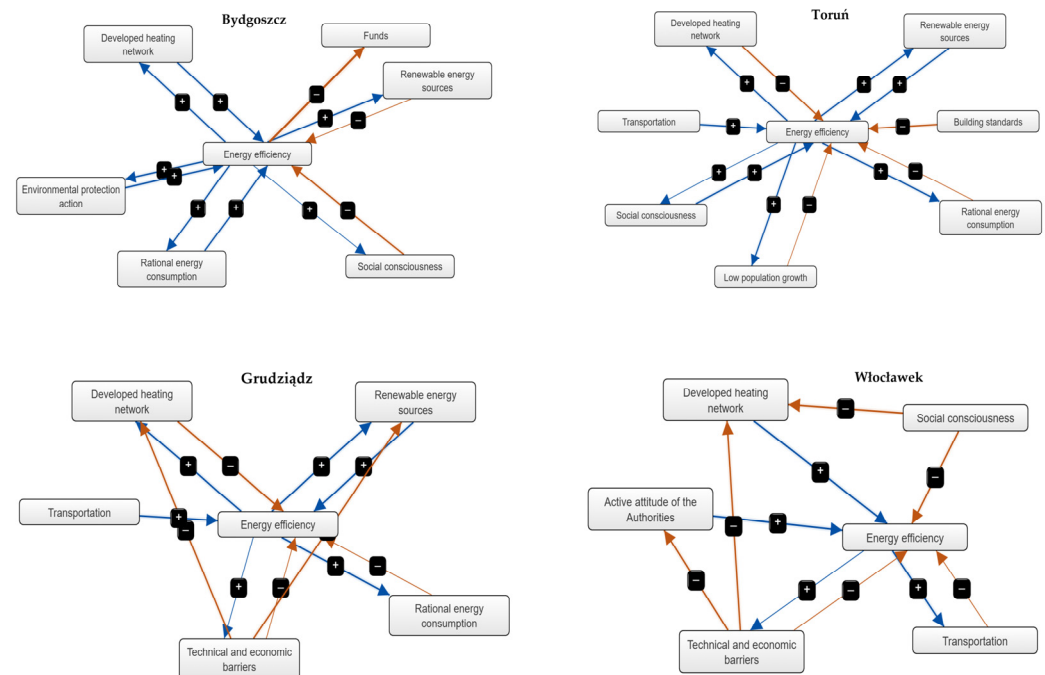


Figure 5. Separate fuzzy cognitive map for each municipality (blue arrow influence +; brown arrow influence −) [own elaboration using Mental Modeler].

Another tool used in the energy efficiency analysis of selected cities is reasoning maps. Reasoning maps are designed to support teamwork on complex problems [42]. Eden and Ackermann point out that the development of soft operational research methods requires combining theoretical reflection with practical support for strategic and decision-making processes [42,43]. The reasoning map was used to structure the decision problem, enabling the identification and assessment of links between adopted action options and end goals, including greenhouse gas emission reduction, final energy consumption reduction, and increased public awareness and acceptance. Reasoning maps are not considered models of cognition but rather tools for constructing problem structures and solving them through transparent analyses for decision-makers [44]. The use of reasoning maps has facilitated the integration of qualitative and quantitative aspects expressed by experts into decision-making processes and enabled the analysis of cause-and-effect relationships. Reasoning maps are typically drawn as concepts connected by unidirectional arrows such that the statement at the end of the arrow is considered the cause or influence on the target at the end of the arrow [45,46]. Connections exist between the heads and nodes representing the concepts contained in the reasoning map, and the arrowhead is shown with an attached sign (if negative (−))—the first pole of the tail statement implies the second pole of the head statement [45].

To assess the structural validity of the reasoning map, an analysis of the relationships between decision options, intermediate concepts, and final goals was conducted. It is important to distinguish between the experts and stakeholders involved in preparing the original LEEP documents, as well as the authors of this study. Experts and stakeholders provided the source knowledge used in developing the LEEP through consultations, surveys, and sectoral analyses; however, they did not constitute the separate expert panel established for this modeling. The LEEP documents and the SWOT analyses contained therein served as the source material for identifying concepts, local conditions, barriers,

and directions for action. The authors of this article extracted concepts and defined decision options [47,48]. They determined the direction, sign, and relative strength of relationships based on the LEEP documents, the literature, and their own research experience. The experts participating in the LEEP preparation did not directly assign weights or signs to the relationships used in this model (Table 4).

Table 4. Types of expert knowledge and institutions represented in the preparation process of the analyzed LEEPs [36–39].

Level of Knowledge	Experience Represented	Institution
Energy Management Specialist, Energy company	Energy management, architecture, urban planning, environmental protection and shaping, environmental engineering, and civil engineering	City municipal offices, specialists in related fields, and external stakeholders

Next, based on our own research on energy management and on the relevant literature, the authors defined the goals, variants, and strength of the relationships' influence. In each scenario, the change in the selected input concept was defined in the scenario interface of Mental Modeler as a relative value ranging from -1 to $+1$, where negative values indicate a decrease and positive values indicate an increase in the given component. The program then determines the relative response of the remaining concepts based on the direction and relationship weights defined in the FCM structure [49]. The authors did not specify a separate number of iterations or an update rule of their own; the analysis was conducted using the scenario interface mechanism implemented in Mental Modeler.

2.3. Reasoning Map and Multi-Criteria Analysis

The next step in the procedure was to use a reasoning map to organize the relationship between decision options, intermediate concepts, and final goals. The analysis assumed two decision options: W1: investments in renewable energy sources and W2: increased energy efficiency. These options were treated as starting nodes in the analysis, not as final goals. The modeled paths leading to goals C1–C3 were analyzed through intermediate concepts K1–K5, as presented in Table 5.

Table 5. A set of elements used in the map topology [own elaboration].

No.	Topology Elements	Component
K1	Improving air quality	Concept
K2	Implementation barriers	Concept
K3	Implementing RES cost	Concept
K4	Building energy standard	Concept
K5	Low-carbon transport	Concept
C1	Reducing greenhouse gas emissions	Goal planned to be achieved
C2	Reduction in final energy consumption	Goal planned to be achieved
C3	Increase in awareness and social acceptance	Goal planned to be achieved
W1	Investments in RES	Evaluated strategy
W2	Increase in energy efficiency	Evaluated strategy

The reasoning map for the adopted decision options, intermediate concepts, and goals is presented in Figure 6. In the map structure, decision options constitute the initial nodes, concepts K1–K5 represent intermediate mechanisms, and C1–C3 are the final nodes corresponding to the policy goals. The direction of the relationships was assumed according to the following sequence: decision option $\rightarrow$ intermediate concept $\rightarrow$ final goal (Figure 6).

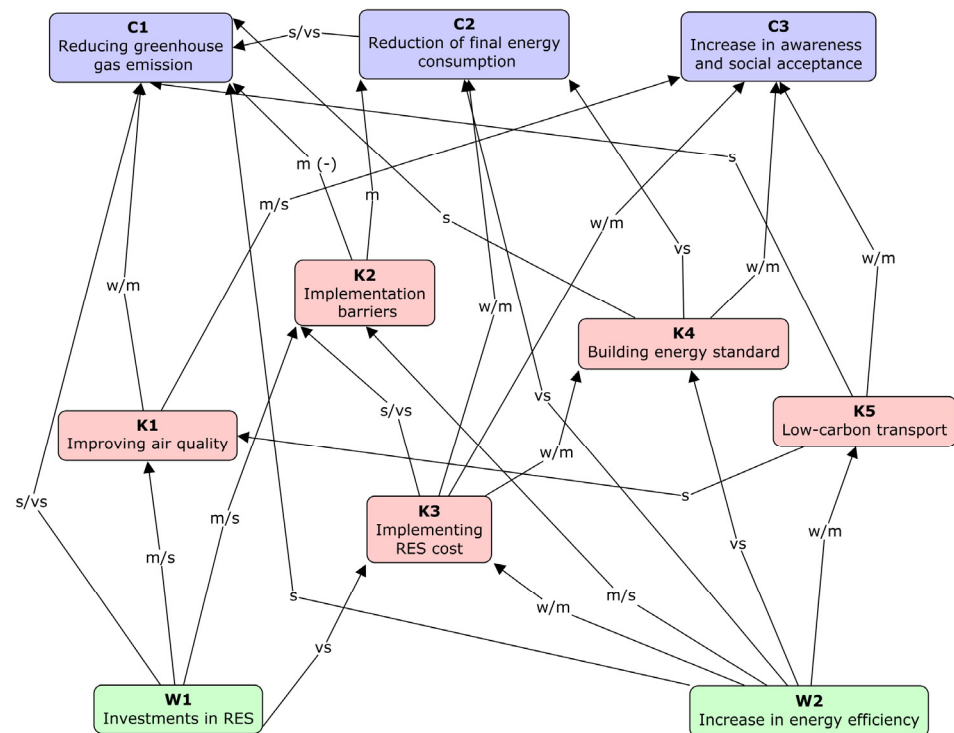


Figure 6. Reasoning map with specific variants, concepts, and goals (the arrows indicate the direction and the linguistic variables indicate the strength of the variables' influence) [own elaboration].

According to the reasoning map procedure, each relationship is assigned a power of influence, measured on an ordinal scale, and an influence sign indicating whether the relationship is strengthening or weakening [41,48]. In this study, a four-level scale of influence strength was used: weak (w), moderate (m), strong (s), and very strong (vs). Each combination was assigned an influence strength rating from the linguistic scale according to [45]. The resulting reasoning map has 10 elements and 25 connections between them (Figure 6). Each relation was then assigned a sign indicating its direction and an ordinal scale of influence strength. The corresponding numerical values (1–4) were used only in the reasoning map analysis and should not be confused with the FCM relation weights used in Mental Modeler (Table 6).

Table 6. Determining the assessment scale of the linguistic strength of influences between concepts [45].

Evaluation	Linguistic Scale	Quantitative Scale
weak	w	1
moderate	m	2
strong	s	3
very strong	vs	4

The analysis adopts an approach consistent with the reasoning map method, in which the initial vertices represent the attributes or consequences of variants, the intermediate vertices correspond to the interaction mechanisms, and the final vertices represent the objectives of the multi-criteria model. In the reasoning map, previously identified decision alternatives were represented as initial nodes, intermediate concepts were identified as mechanisms by which the alternatives could affect the system under analysis, and final nodes were represented as the adopted policy goals. The direction of each link thus resulted from the assumed causal sequence leading from the decision alternative, through the intermediate mechanism, to the final goal. This principle was consistently applied to all

relationships included in the reasoning map. The analysis assumed two decision variants: W1: investments in renewable energy sources and W2: increased energy efficiency. These are not treated as final goals but rather as starting points for analyzing the paths to achieving goals C1–C3. The impact of variants W1 and W2 was analyzed through intermediate concepts K1–K5, which represent the mechanisms linking the decision variants with the final goals. The structure of the paths linking decision variants W1 and W2 to the final goals C1–C3 was assessed using the incidence matrix, E , in the reasoning map. This matrix represents the direction and strength of the relationships between subsequent elements of structure (1).

$$E = \begin{bmatrix} 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 & 0.0 & 3.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & -2.0 & 2.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 3.0 & 0.0 & 4.0 & 0.0 & 1.0 & 1.0 & 1.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 3.0 & 3.0 & 4.0 & 1.0 & 0.0 & 0.0 \\ 3.0 & 0.0 & 0.0 & 0.0 & 0.0 & 3.0 & 0.0 & 1.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 3.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\ 2.0 & 2.0 & 4.0 & 0.0 & 0.0 & 3.0 & 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 2.0 & 1.0 & 4.0 & 1.0 & 3.0 & 4.0 & 0.0 & 0.0 & 0.0 \end{bmatrix} \quad (1)$$

Based on the E incidence matrix, the T result matrix was then determined, representing the aggregated strength of the modeled paths between the decision variants and the final goals. The T matrix was calculated according to relationship (2):

$$T = \sum_{k=1}^{n-1} E^k = \begin{array}{c} \begin{array}{ccccccccc} & & & & & \mathbf{C1} & \mathbf{C2} & \mathbf{C3} & & \\ \begin{bmatrix} 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 54.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 36.0 & 225.0 & 108.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 108.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \end{bmatrix} & & \end{array} \\ \begin{array}{ccccccccc} 144.0 & 0.0 & 0.0 & 0.0 & 0.0 & 144.0 & 336.0 & 48.0 & 0.0 & 0.0 \\ 36.0 & 0.0 & 0.0 & 0.0 & 0.0 & 72.0 & 363.0 & 120.0 & 0.0 & 0.0 \end{array} \end{array} \quad (2)$$

3. Results

3.1. Fuzzy Cognitive Map Results

Based on the basic model presented in Figure 3, an example scenario analysis was performed to assess the impact of an increase in the share of renewable energy sources and the response of the remaining model concepts (Figure 7).

In the scenario assuming an increase in the share of renewable energy sources, the model showed negative responses for greenhouse gas emissions and final energy consumption. The values on the vertical axis should be interpreted as model responses resulting from the adopted structure of relationships and weights, not as projected changes in actual energy indicators. The graph has qualitative significance and serves as a starting point for further analysis. The extended model is a representation of relationships among system components, defining reinforcing and weakening relationships within the model structure (Figure 4). The graph in Figure 8 shows changes in the values of selected components under the assumed reduction in greenhouse gas emissions. This allows us to determine which variables in the model respond most strongly to the adopted scenario and what indirect effects may accompany emission reduction.

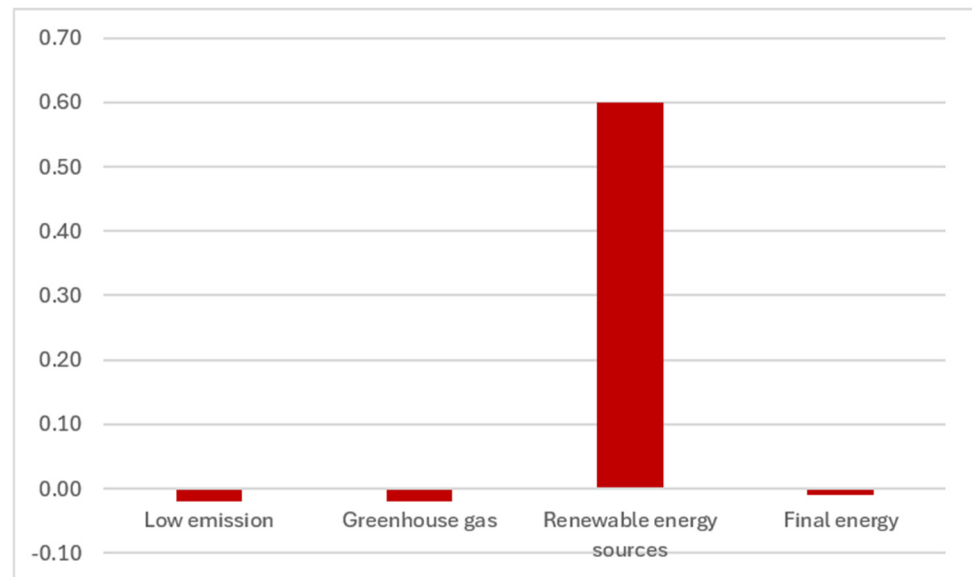


Figure 7. Graph of changes with the assumed increase in the share of renewable energy sources with respect to the input model [own elaboration based on Mental Modeler].

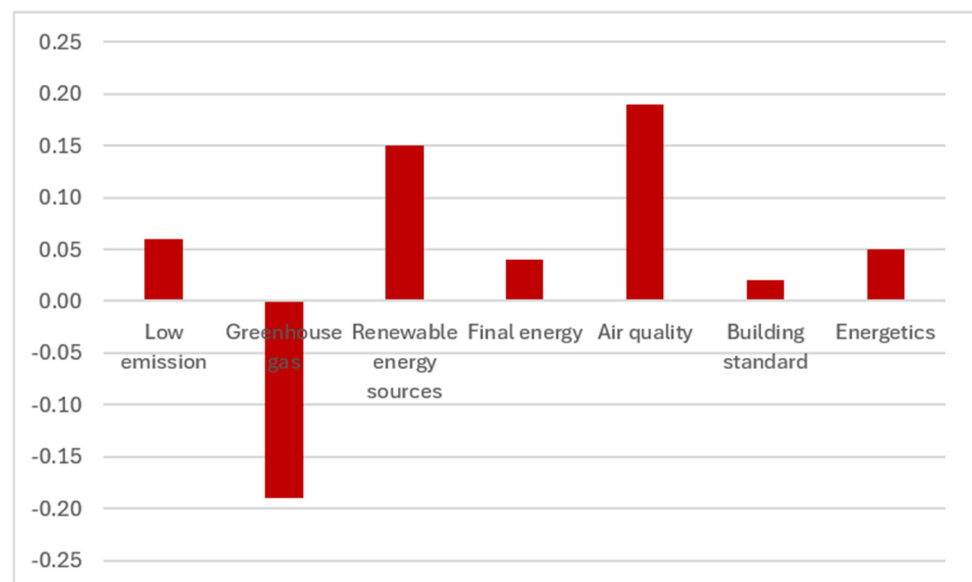


Figure 8. Graph of changes in the adopted components with the assumed decrease in greenhouse gas emissions in relation to the adopted extended model [own elaboration based on Mental Modeler].

Analysis of the graph shows that, given the assumed decrease in greenhouse gas emissions, components related to the development of renewable energy sources, reduced final energy consumption, and improved energy standards in buildings exhibit the strongest modeled responses under this scenario. Improved air quality is not a driving factor for emission reduction in this system but rather an expected effect of low-emission policies and a result of changes taking place in the municipal energy system. It means that air quality should be interpreted primarily as an outcome variable, indicating the effectiveness of actions taken to reduce emissions and improve energy efficiency.

For selected urban municipalities in the Kuyavian–Pomeranian Voivodeship, separate models of the relationships among characteristics influencing energy efficiency were developed based on the provisions of their Low-Emission Economy Plans and, in particular, on the strengths and weaknesses identified in the SWOT analysis. Cognitive maps were modeled while taking into account components specific to individual municipalities.

Figure 7 presents cognitive maps and relationship graphs for each analyzed municipality. The corresponding scenario–response graphs for the municipality-specific models are presented in Figure 9.

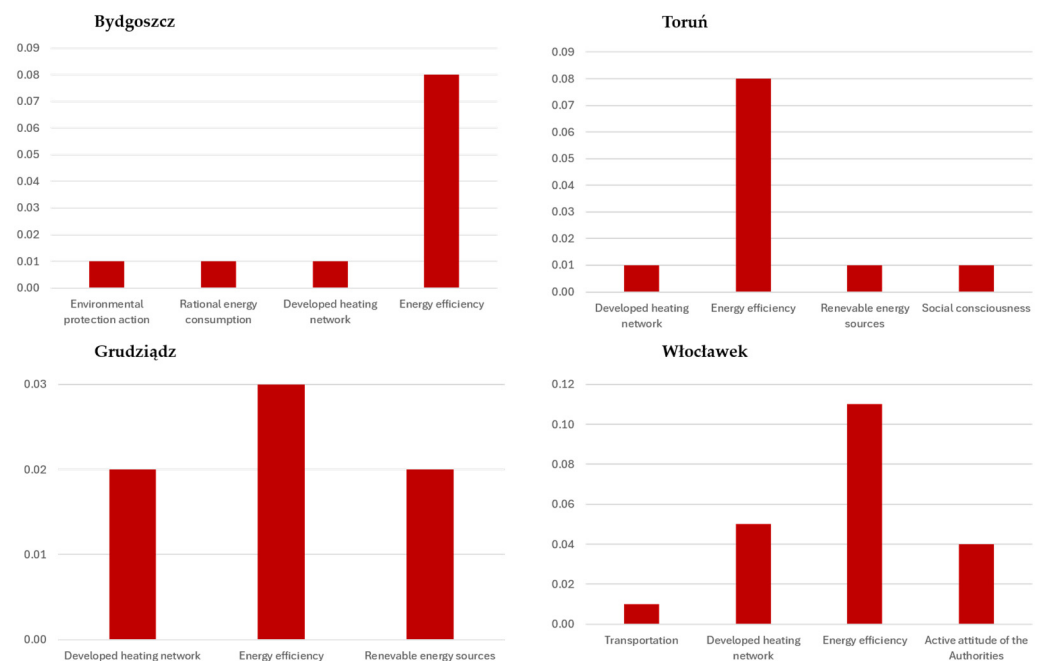


Figure 9. Model responses of municipality-specific components under the analyzed scenarios [own elaboration based on Mental Modeler].

3.2. Reasoning Map Results

The resulting values indicate differences in the modeled strength of pathways linking the decision variants with final-energy-consumption and emission-reduction goals. Variant W1 represents investment in RES and is connected, through the adopted concepts, to the greenhouse gas reduction goal. In contrast, variant W2 represents greater energy efficiency and is associated with building energy standards, final energy consumption, and social acceptance. Within the author-parameterized reasoning map, the strongest relationships occur between energy efficiency and building energy standards, between building energy standards and final energy consumption reduction, and between final energy consumption reduction and greenhouse gas emission reduction. The authors checked the logical consistency of the map by assessing the direction of the relationship, the variant–intermediate concept–goal sequence, and the consistency of the assigned signs with the strength of the relationship in relation to the adopted model assumptions.

The model highlights the relative position of RES and energy-efficiency concepts and distinguishes pathways represented as direct or mediated within the adopted structure. In the map structure, the energy standard for buildings occupies a central position in one of the strongest paths linking energy efficiency with the reduction in final energy consumption and greenhouse gas emissions.

4. Discussion

Within the adopted model structure, improving building energy standards emerges as a priority intervention area because of its central position in the pathway linking energy-efficiency measures with reductions in final energy consumption and greenhouse gas emissions. In practical terms, this implies prioritizing comprehensive building retrofitting, modernization of heating systems, a reduction in energy losses, and integration of renewable energy sources, accompanied by systematic monitoring of final energy consumption [50,51].

Properly constructed energy system models, when supported by emission documents, are essential for generating various observations and analyses, for example, regarding the impact on energy efficiency [21,52]. The results of this study, however, indicate that the importance of such modeling lies not only in identifying general energy policy drivers but, above all, in recognizing their different configurations in individual local circumstances. Therefore, the four analyzed municipalities should be interpreted as distinct case studies, where similar low-emission policy goals may require different priorities and sequences of actions.

The SWOT analysis reveals differing approaches to achieving low-emission goals across the four cities analyzed in the Kuyavian–Pomeranian Voivodeship: Bydgoszcz, Toruń, Grudziądz, and Włocławek. Analysis of individual case studies indicates that common low-emission policy goals are embedded in distinct local conditions. Therefore, the results should not be interpreted as a ranking of the effectiveness of the analyzed municipalities, but rather as a basis for identifying configurations of factors that support or limit the implementation of local energy policies. These differences relate to the potential of existing energy infrastructure, the potential for renewable energy development, financial constraints, the state of the building stock, and social factors.

At the level of individual case studies, recommendations should be based on the local strengths and weaknesses identified in the LEEP and their position in the structure of the analyzed relationships. In Bydgoszcz, the existing, well-developed heating infrastructure and the city's experience in energy-efficiency initiatives provide a basis for further modernization of the building stock to increase its efficiency. At the same time, limited financial resources, low potential for renewable energy development, and low public awareness indicate that technical measures should be combined with financial instruments and measures that increase social acceptance (Table 3).

In the case of Toruń, recommendations could further leverage the existing potential for energy diversification, including solar, geothermal, wind, and biomass energy, as well as the city's experience in modernizing public transport and replacing heat sources. However, reducing the share of coal in heating supply and expanding access to the district heating network, especially in parts of the city that remain beyond its reach, are particularly important.

In Grudziądz, further action could be based on the city's existing experience in thermal modernization, the use of renewable energy sources in public facilities, and transport modernization. Simultaneously, modeling should support the selection of measures that limit the significance of identified technical and economic barriers to the development of renewable energy sources, the increase in electricity consumption, and the continuing need for thermal modernization of parts of the building stock. Therefore, further improvement of the energy efficiency of existing buildings and careful preparation of technical and implementation analyses for new investments are particularly important in this case.

In Włocławek, recommended actions should focus on interventions that deliver the greatest impact given the city's limited financial resources. This means prioritizing energy and infrastructure modernization and linking investment activities with instruments that support their financing. Information and educational activities that increase public awareness of the benefits of improving energy efficiency and transforming the local energy system should be a significant complement.

A common finding across the analyzed frameworks is the special role of the path linking improved energy efficiency with the energy standard of buildings, reduced final energy consumption, and consequently, reduced greenhouse gas emissions. From the perspective of local government practice, this means that improving the energy standard of existing buildings should be treated as one of the primary areas of intervention. At the same time, the model indicates that the paths to achieving these goals are also linked to indirect conditions, including the costs of implementing renewable energy sources, implementation

barriers, and the social acceptance of the actions undertaken. Therefore, technical priorities should be combined with appropriately selected financial, organizational, and social instruments in individual cities.

In the adopted model structure, improved air quality is associated with increased public awareness and acceptance, indicating the potential importance of public perception of the effects of energy transformation. This is particularly significant in the case of Bydgoszcz, where the low level of public awareness of climate protection was identified in the SWOT analysis as a barrier to local low-emission policies. The obtained results are consistent with studies indicating that energy modernization of buildings and parameters influencing heat demand are key factors limiting energy consumption in cities [28,53,54]. The results of this study expand this perspective, demonstrating that the importance of these actions should be interpreted in conjunction with local infrastructural, financial, technical, and social conditions. Therefore, the model used does not identify a single universal strategy for all municipalities but rather enables the identification of different configurations of priorities and mechanisms that lead to the implementation of local energy goals. The municipality-specific models differ in the presence and relative positions of infrastructure, RES potential, financing, building stock, and social acceptance concepts. A comparison of urban models indicates that a common core of dependencies is formed by factors related to energy efficiency, building energy standards, final energy consumption, and greenhouse gas emissions. Differences between the models primarily concern the presence and relative positions of concepts that reflect local barriers and potential. In Bydgoszcz, financial constraints, low-RES potential, and social awareness are of greater importance; in Toruń, the potential for diversification of energy sources and the diversity of the heating infrastructure are important; in Grudziądz, technical and economic barriers to renewable energy sources and the need for further modernization of the building stock are important; and in Włocławek, financial constraints and the need for further development of the energy infrastructure are important. This means that the models retain a common structural logic but differ in the configuration of local intermediate concepts.

A limitation of this study is the lack of formal model sensitivity analysis. This means that the obtained variable rankings and the relative strength of the identified relationship paths should be interpreted in relation to the adopted model structure and assigned relationship weights. Therefore, the results indicate the structure of relationships within the adopted model assumptions but do not allow for a full assessment of the stability of these relationships to changes in model parameters. Further research should consider conducting a sensitivity analysis, including changing the values of key weights, removing selected concepts, and comparing the results for alternative parameterization options. This will allow us to assess the robustness of the obtained results to changes in model assumptions and the stability of the identified priorities. This study is additionally limited by the small and territorially homogeneous sample of four municipalities, the author-based parameterization of relationship directions and strengths, and the absence of validation against independently verified post-2020 emission and final energy consumption data.

5. Conclusions

The results indicate that, within the adopted model structure, improving building energy standards occupies a central position in the pathway linking energy efficiency with lower final energy consumption and greenhouse gas emissions.

The analyses indicate that local LEEP documents can serve as a source of knowledge for identifying and organizing factors relevant to local energy policies. The use of fuzzy modeling and reasoning maps enabled the mapping of relationships among decision-making options, intermediate concepts, and final goals, as well as the identification of the

most significant paths within the adopted model structure. The results also confirm that the structure of these relationships varies between municipalities and should be interpreted in relation to their local infrastructural, technical, financial, and social conditions.

From a practical perspective, the applied approach can support local governments in organizing the information contained in LEEPs, identifying key variables, and recognizing the relationship paths relevant to local energy decisions. The analysis indicates that similar low-emission policy goals may be associated with different configurations of technical, infrastructural, financial, and social factors. Therefore, the model results should be interpreted in relation to the local conditions of individual municipalities, rather than as a basis for formulating a single, universal strategy. This study is limited by the small number of municipalities analyzed, their concentration in a single region, and the lack of validation of model results based on independent empirical data on actual changes in emissions and energy consumption. Further research should therefore include applying the proposed approach to municipalities with varying functional and spatial conditions, analyzing the model's sensitivity to changes in weights and the relationship structure, and assessing the importance of non-technical factors such as residents' environmental awareness, demographic structure, and level of social acceptance.

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Abbreviations

The following abbreviations are used in this manuscript:

LEEP	Low-Emission Economy Plan
RES	Renewable Energy Source
MCDA	Multi-Criteria Decision Analysis
FCM	Fuzzy Cognitive Map
RM	Reasoning Map

Appendix A

Table A1. Data for Figure 3.

	Low Emission	Greenhouse Gas	Renewable Energy Sources	Final Energy
Low emission				−0.41
Greenhouse gas	−0.38			0.47
Renewable energy sources	−0.56	−0.59		−0.2
Final energy	0.39			

Table A2. Data for Figure 4.

	Low Emission	Energy Efficiency	Greenhouse Gas	Final Energy	RES	Energetics	Transportation	Air Quality	Building Standard
Low emission			0.28	0.38	−0.14	−0.19		−0.37	0.42
Energy efficiency			−0.28	0.47	0.3				
Greenhouse gas	−0.42	−0.23		0.5			0.25	−0.45	
Final energy									
RES	0.63	0.58	−0.12	−0.19		0.34		0.45	
Energetics	−0.09		−0.11						
Transportation			−0.25					−0.25	
Air quality					0.13		0.25		
Building standard	0.31								

Table A3. Data for Figure 5.

Bydgoszcz	Social Consciousness	Environmental Protection Action	Founds	Rational Energy Consumption		Renewable Energy Sources	Energy Efficiency	Developed Heating Network
Social consciousness							−0.19	
Environmental protection action							0.28	
Founds								
Rational energy consumption							0.45	
Renewable energy sources							−0.05	
Energy efficiency	0.14	0.3	−0.59	0.22		0.42		0.41
Developed heating network							0.41	
Toruń	Energy efficiency	Development heating network	Renewable energy sources	Rational energy consumption	Building standard	Low population growth	Social consciousness	Transportation
Energy efficiency		0.41	0.42	0.22		0.3	0.14	
Development heating network	−0.28							
Renewable energy sources	0.31							
Rational energy consumption	−0.12							
Building standard	−0.36							
Low population growth	−0.12							
Social consciousness	0.23							
Transportation	0.19							
Grudziądz	Energy efficiency	Development heating network	Renewable energy sources		Rational energy consumption		Transportation	Technical and economic barriers
Energy efficiency		0.41	0.42		0.22			0.14
Development heating network	−0.28							
Renewable energy sources	0.31							
Rational energy consumption	−0.12							
Transportation	0.19							
Technical and economic barriers	−0.12	−0.42	−0.3					
Włocławek	Energy efficiency	Developed heating network	Transportation		Active attitude of Authorities		Social consciousness	Technical and economic barriers
Energy efficiency			0.25					−0.14
Developed heating network	0.2							
Transportation	−0.12							
Active attitude of Authorities	0.36							
Social consciousness	−0.2	−0.37						
Technical and economic barriers	−0.12	−0.42			−0.37			

References

1. Cheema, A.T.; Mumtaz, T.; Nawaz, S. The climate change politics: Power, policies, and role of the European Union. *Crit. Rev. Soc. Sci. Stud.* **2025**, *3*, 218–227. [CrossRef]
2. European Commission. Europe 2020: A Strategy for Smart, Sustainable and Inclusive Growth (COM(2010) 2020 Final). 2010. Available online: <https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:2020:FIN:EN:PDF> (accessed on 4 August 2026).
3. Monteiro, J.; Sousa, N.; Coutinho-Rodrigues, J.; Natividade-Jesus, E. Challenges Ahead for Sustainable Cities: An Urban Form and Transport System Review. *Energies* **2024**, *17*, 409. [CrossRef]
4. Yatzkan, O.; Cohen, R.; Yaniv, E.; Rotem-Mindali, O. Urban Energy Transitions: A Systematic Review. *Land* **2025**, *14*, 566. [CrossRef]
5. Guidelines for the Development of PGN Valid Until 2020. Available online: <https://stara.wfosigw.katowice.pl/pgn/wytyczne-do-opracowania-pgn> (accessed on 4 August 2026). (In Polish)
6. Low-Emission Economy Plans Guidelines for the Development of Low-Emission Economy Plans, Effective from 2020. Available online: <https://www.wfos.krakow.pl/doradztwo-energetyczne-2-0/doradztwo-energetyczne/plany-gospodarki-niskoemisyjnej> (accessed on 4 August 2026). (In Polish)
7. Davide, M.; Bastos, J.; Bezerra, P.; Hernandez Moral, G.; Palermo, V.; Pittalis, M.; Todeschi, V.; Treville, A.; Barbosa, P.; Melica, G. *How to Develop a Sustainable Energy and Climate Action Plan (SECAP) Covenant of Mayors Guidebook. Main Document.* European Commission, Joint Research Centre; Publications Office of the European Union: Luxembourg, 2025. Available online: <https://data.europa.eu/doi/10.2760/4489817> (accessed on 4 August 2026).
8. Kielkowska, J.; Tokarczyk-Dorociak, K.; Kazak, J.; Szewrański, S.; van Hoof, J. Urban adaptation to climate change plans and policies—The conceptual framework of a methodological approach. *J. Ecol. Eng.* **2018**, *19*, 50–62. [CrossRef] [PubMed]
9. Dzikuć, M. Problems associated with the low emission limitation in Zielona Góra (Poland): Prospects and challenges. *J. Clean. Prod.* **2017**, *166*, 81–87. [CrossRef]
10. United Nations General Assembly. (2015, 21 Października). Transforming Our World: The 2030 Agenda for Sustainable Development (A/RES/70/1). Available online: <https://www.refworld.org/docid/57b6e3e44.html> (accessed on 4 August 2026).
11. Michalak, D.; Rosiek, K.; Szyja, P. *Low-Carbon Economy, Circular Economy, Green Economy: Conditions and Interconnections*; Wydawnictwo Uniwersytetu Łódzkiego: Łódź, Poland, 2020. (In Polish). [CrossRef]
12. Kasztelan, A. On the road to a green economy: How do European Union countries do their homework? *Energies* **2021**, *14*, 5941. [CrossRef]
13. Guðlaugsson, B.; Fazeli, R.; Gunnarsdóttir, I.; Davidsdóttir, B.; Stefansson, G. Classification of stakeholders of sustainable energy development in Iceland: Utilizing a power-interest matrix and fuzzy logic theory. *Energy Sustain. Dev.* **2020**, *57*, 168–188. [CrossRef]
14. Kuriqi, A.; Pinheiro, A.N.; Sordo-Ward, A.; Garrote, L. Flow regime aspects in determining environmental flows and maximising energy production at run-of-river hydropower plants. *Appl. Energy* **2019**, *256*, 113980. [CrossRef]
15. Maroušek, J.; Strunecký, O.; Kolář, L.; Vochozka, M.; Kopecký, M.; Maroušková, A.; Batt, J.; Poliak, M.; Šoch, M.; Bartoš, P.; et al. Advances in nutrient management make it possible to accelerate biogas production and thus improve the economy of food waste processing. *Energy Sources Part A Recovery Util. Environ. Eff.* **2020**, *46*, 9379–9388. [CrossRef]
16. Mert, Y. Contribution to sustainable development: Re-development of post-mining brownfields. *J. Clean. Prod.* **2019**, *240*, 118212. [CrossRef]
17. Simsek, Y.; Santika, W.G.; Anisuzzaman, M.; Urmee, T.; Bahri, P.A.; Escobar, R. An analysis of additional energy requirement to meet the Sustainable Development Goals. *J. Clean. Prod.* **2020**, *272*, 122646. [CrossRef]
18. Ucal, M.; Xydis, G. Multidirectional relationship between energy resources, climate changes and sustainable development: Technoeconomic analysis. *Sustain. Cities Soc.* **2020**, *60*, 102210. [CrossRef]
19. Kafel, K.; Leśniak, A.; Zima, K. Multicriteria comparative analysis of pillars strengthening of the historic building. *Open Eng.* **2019**, *9*, 18–25. [CrossRef]
20. Sobierajewicz, P.; Adamczyk, J.; Dylewski, R. Multi-criterial carbon assessment of the city. *Energies* **2024**, *17*, 4555. [CrossRef]
21. Mrówczyńska, M.; Skiba, M.; Leśniak, A.; Bazan-Krzywoszańska, A.; Janowiec, F.; Sztubecka, M.; Grech, R.; Kazak, J.K. A new fuzzy model of multicriteria decision support based on Bayesian networks for the urban areas' decarbonization planning. *Energy Convers. Manag.* **2022**, *268*, 116035. [CrossRef]
22. Mrówczyńska, M.; Skiba, M.; Sztubecka, M.; Bazan-Krzywoszańska, A.; Kazak, J.K.; Gajownik, P. Scenarios as a tool supporting decisions in urban energy policy: The analysis using fuzzy logic, multi-criteria analysis and GIS tools. *Renew. Sustain. Energy Rev.* **2021**, *137*, 110598. [CrossRef]
23. Nimako, B.K.; Carpitella, S.; Menapace, A. Novel Multi-Criteria Decision Analysis Based on Performance Indicators for Urban Energy System Planning. *Energies* **2024**, *17*, 5207. [CrossRef]
24. Yang, Y.; Zhang, C.; Zhao, Q.; Zhang, Y. A sustainability evaluation framework for the urban energy Internet using the Fermatean fuzzy Aczel-Alsina hybrid MCDM method. *Expert Syst. Appl.* **2024**, *238*, 122115. [CrossRef]

25. Akyol, I.C.; Halacli, E.G.; Ucar, S.; Iseri, O.K.; Yavuz, F.; Guney, D.; Gursoy, F.E.; Duran, A.; Akgul, C.M.; Kalkan, S.; et al. Machine learning based prediction of long-term energy consumption and overheating under climate change impacts using urban building energy modeling. *Sustain. Cities Soc.* **2025**, *130*, 106500. [CrossRef]
26. Maciejko, A.; Grześkowiak, M.; Kowalska, A. Climate and sustainability in architecture: Analysis of challenges and limitations for universal solutions in the design of single-family houses. In *Human Factors in Architecture, Sustainable Urban Planning and Infrastructure*; Maciejko, A., Ed.; AHFE International: Louisville, KY, USA, 2025; pp. 54–62. [CrossRef]
27. Nakielska, M.; Kaczmarek, A. Impact of external wall insulation of office buildings on the interior microclimate. *Mater. Bud.* **2024**, *10*, 101–108. (In Polish) [CrossRef]
28. Alsabry, A.; Szymański, K. Energy analyses of multi-family residential buildings in various locations in Poland and their impact on the number of heating degree days. *Energies* **2023**, *16*, 4648. [CrossRef]
29. Alsabry, A.; Szymański, K.; Backiel-Brzozowska, B. Analysis of the energy, environmental and economic efficiency of multi-family residential buildings in Poland. *Energies* **2024**, *17*, 2057. [CrossRef]
30. Sobierajewicz, P.; Dzikowski, P. Thermal modernization for sustainable cities: Environmental and economic impacts in central urban areas. *Energies* **2025**, *18*, 5324. [CrossRef]
31. European Parliament; Council of the European Union. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. *Off. J. Eur. Union* **2012**, *L315*, 1–56. Available online: <http://data.europa.eu/eli/dir/2012/27/oj> (accessed on 4 August 2026).
32. Stoglehner, G.; Abart-Heriszt, L. Integrated spatial and energy planning in Styria—A role model for local and regional energy transition and climate protection policies. *Renew. Sustain. Energy Rev.* **2022**, *165*, 112587. [CrossRef]
33. Michnik, J. Algebraic Modeling of Social Systems Evolution: Application to Sustainable Development Strategy. *Sustainability* **2025**, *17*, 8192. [CrossRef]
34. Schuerkamp, R.; Giabbanelli, P.J. Guiding evolutionary algorithms with large language models to learn fuzzy cognitive maps. *Neural Comput. Appl.* **2025**, *37*, 11891–11908. [CrossRef]
35. Shi, Z.; Ngion, Z.W.; Li, W.; Arras, M.; Yang, X.; Ma, L.; Li, Z. Using fuzzy cognitive maps to couple energy and social system models in planning urban low-carbon energy transition. *Energy* **2026**, *347*, 140347. [CrossRef]
36. Urząd Miasta Bydgoszczy. Aktualizacja Planu Działań na Rzecz Zrównoważonej Energii—Plan Gospodarki Niskoemisyjnej dla Miasta Bydgoszczy na Lata 2014–2020+. 2016. Available online: <https://www.czystabydgoszcz.pl/energia/plan-gospodarki-niskoemisyjnej-pgn> (accessed on 4 August 2026). (In Polish)
37. Urząd Miejski w Grudziądzu. (b.d.). Plan Gospodarki Niskoemisyjnej dla Gminy—Miasto Grudziądz. Available online: https://grudziadz.pl/uploads/files/PGN%20-%20Plan%20gospodarki%20niskoemisyjnej_1.pdf (accessed on 4 August 2026). (In Polish)
38. Urząd Miasta Włocławek. Plan Gospodarki Niskoemisyjnej dla Gminy Miasto Włocławek na Lata 2014–2020+ (Tekst Ujednolicony). 2022. Available online: <https://mst-wloclawek.arch.rbp.mojregion.info/ujednolicony-tekst-planu-gospodarki-niskoemisyjnej-pouchwale-lvii1722022-rady-miasta-wloclawek-z-dnia-28-grudnia-2022-r/> (accessed on 4 August 2026). (In Polish)
39. Urząd Miasta Torunia. Plan Gospodarki Niskoemisyjnej Gminy Miasta Toruń na Lata 2015–2020+. 2015. Available online: <https://bip.torun.pl/uchwala/36823/uchwala-rmt-177-2015> (accessed on 4 August 2026). (In Polish)
40. Gray, S.A.; Gray, S.; Cox, L.J.; Henly-Shepard, S. Mental Modeler: A fuzzy-logic cognitive mapping modeling tool for adaptive environmental management. In *Proceedings of the 46th Hawaii International Conference on System Sciences*; IEEE: New York, NY, USA, 2013; pp. 965–973. [CrossRef]
41. Sarmiento, I.; Dion, A.; Šajna, M.; Andersson, N. Four analysis moments for fuzzy cognitive mapping in participatory research. *Glob. Health Action* **2024**, *17*, 2430024. [CrossRef] [PubMed]
42. Eden, C.; Ackermann, F. Theory into practice, practice to theory: Action research in method development. *Eur. J. Oper. Res.* **2018**, *271*, 1145–1155. [CrossRef]
43. Eden, C. Analyzing cognitive maps to help structure issues or problems. *Eur. J. Oper. Res.* **2004**, *159*, 673–686. [CrossRef]
44. Ackermann, F.; Eden, C. Strategic management of stakeholders: Theory and practice. *Long Range Plan.* **2011**, *44*, 179–196. [CrossRef]
45. Michnik, J. *Multi-Criteria Decision Support Methods in the Innovation Process*; Wydawnictwo Uniwersytetu Ekonomicznego w Katowicach: Katowice, Poland, 2013. (In Polish)
46. Kobryń, A. *Multi-Criteria Decision Support in Space Management*; Difin: Warszawa, Poland, 2014. (In Polish)
47. Skiba, M.; Mrówczyńska, M.; Sztubecka, M.; Maciejko, A.; Rzeszowska, N. The European Union’s energy policy efforts regarding emission reduction in cities—A method proposal. *Energies* **2023**, *16*, 6123. [CrossRef]
48. Skiba, M.; Mrówczyńska, M.; Sztubecka, M.; Bonenberg, W.; Qi, L.; Zhou, M. Reasoning maps for solving complex location problems: Blue-green infrastructure strategies toward sustainable urban development. *J. Hous. Built Environ.* **2026**, *41*, 953–977. [CrossRef]
49. Kosko, B. Fuzzy cognitive maps. *Int. J. Man-Mach. Stud.* **1986**, *24*, 65–75. [CrossRef]

50. Skiba, M.; Karcz, N.; Maciejko, A.; Mrówczyńska, M.; Sztubecka, M.; Kazak, J.K. The European Union's sustainable energetic policy evaluation in the aspect of improving the quality of residents' life. In *PLEA 2024: (RE)Thinking Resilience. The Book of Proceedings*; Widera, B., Rudnicka-Bogusz, M., Onyszkiewicz, J., Woźniczka, A., Eds.; Oficyna Wydawnicza Politechniki Wrocławskiej: Wrocław, Poland, 2024; pp. 603–608. Available online: <https://dbc.wroc.pl/dlibra/publication/165715> (accessed on 4 August 2026).
51. Skiba, M.; Mrówczyńska, M.; Leśniak, A.; Karcz, N.; Janowiec, F.; Sztubecka, M.; Błaszczak-Bąk, W.; Kazak, J.K. Implication of the EU countries' energy policy concerning scenarios affecting the air quality improvement. *Energies* **2024**, *17*, 3892. [[CrossRef](#)]
52. Hashemizadeh, A.; Xie, Y. Optimal policy design for urban renewable energy systems: A mathematical modeling approach toward sustainable cities. *Sustain. Cities Soc.* **2026**, *148*, 107577. [[CrossRef](#)]
53. Kazak, J.K.; Chodkowska-Miszczyk, J.; Chrobak, G.; Mrówczyńska, M.; Martínat, S. Renewable energy creditors versus renewable energy debtors: Seeking a pattern in a sustainable energy transition during the climate crisis. *Anthr. Rev.* **2023**, *10*, 632–655. [[CrossRef](#)]
54. Pierzchlewicz, D.; Woźniak, A.; Widera, B. Recent Research on Circular Architecture: A Literature Review of 2021–2024 on Circular Strategies in the Built Environment. *Sustainability* **2025**, *17*, 7580. [[CrossRef](#)]

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