Optimizing biomass energy production at the municipal level to move to low-carbon energy

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ABSTRACT

In this article, we seek to analyze the regional energy policy in the West Pomeranian Voivodeship, with a particular focus on the potential for developing renewable energy from biomass. The article aims to build a mathematical model of the regional energy system, related to the strategy of sustainable development in the region. Taking into account the potential for biomass development and the sustainability criteria, this paper presents a case study of sustainable regional energy planning and implementation in the selected region in Poland. An example of optimizing biomass for renewable use at the municipal level is valuable, as the use of biomass energy requires knowledge of landscapes, energy options, and different stakeholder perspectives. Thus, "energyscapes," a complex spatial and temporary combination of energy supply, demand, and infrastructure within the landscape, can be very useful in this context. Ongoing research contributes to the development of knowledge on promoting renewable energy sources at the local level and supporting a fair transition to low-carbon energy through energy citizenship and the development of sustainable low-carbon communities at the regional level.

Keywords: Low-carbon energy transition, Regional energy planning, Renewable energy, Biomass, Barriers**,** Energy citizenship**,** Energy**,** Poland

1. Introduction

Climate change poses a challenge for countries around the world that requires local communities to reconfigure their energy systems. The low-carbon energy transition is on the energy policy agenda of all EU Member States. The Polish energy policy is part of a national development management system based on the Long-Term National Development Strategy, the Medium-Term National Development Strategy, and nine Integrated Strategies. The main objective of its energy policy is to create the conditions for the sustainable and sustainable development of the energy sector, thereby contributing to the development of the national economy, ensuring the energy security of the state, and meeting the energy needs of businesses and households. Energy security, on the other hand, depends to a large extent on environmental and economic products **Vasilyeva, Pryymenko (2014).** Three equivalent operational objectives were set to achieve the main objective, including ensuring the country's energy security, increasing the competitiveness and energyefficiency of the national economy in the EU's internal energy market, and reducing the environmental impact of energy **(Stephenson, Barton & Carrington, 2010)**.

Poland, as a member of the European Union, is actively involved in the development of the Community's energy policy and pursues its main objectives under specific national conditions, taking into account the protection of the interests of consumers, its energy resources, and the technological conditions for energy production and transmission. Due to the above, the main directions of Polish energy policy are improving energy efficiency, increasing the security of fuel and energy supply, and diversifying the structure of electricity production. The energy policy orientations adopted are largely interdependent. Improving energy efficiency reduces the increase in demand for fuels and energy, thereby contributing to energy security as a result of reduced dependence on imports, and works to reduce the environmental impact of energy by reducing emissions. The development of renewable energy sources **Geels (2002)** has similar effects. In implementing actions in line with these directions, energy policy should aim to meet these challenges and increase the country's energy security while maintaining the sustainable development of renewable energy sources **(Losch, Schneider, 2016)**.

Researchers have formulated this challenge as a systemic problem that needs to be addressed through multilevel governance **(Ryghaug, Moe Skjolsvold & Heidenreich, 2018)**. The most important step in the transition to low-carbon energy is to break down technological barriers to renewable energy by cultivating niches for these technologies and energizing changes in the sociotechnical system **(Verbong, Geels, 2007)**. A low-carbon energy transition requires significant public support and acceptance **(Geels, Schot, 2007)**. On the other hand, the transformation to low-carbon and renewable energy opens up new prospects for increasing the competitiveness of the national economy, especially in the context of agricultural development (**Bilan, Lyeonov, Stoyanets & Vysochyna, 2018; Onion, Chygryn, Chayen & Pimonenko, 2018)**. Researchers say energy cultures where energy transformations are advancing play a key role in a country's success **(Aune, Godbolt & Sorensen, 2016)**. Social and technological changes in the energy transition and the participation in sustainable energy transitions or a sustainable citizenship approach **(Sarrica, Brondi & Cottone, 2016)** should therefore be addressed. The main resistance to renewable energy technology often occurs at the local level **(Chilvers, Longhurst, 2016)**. Therefore, the involvement of citizens and society in the context of low-carbon energy transition can be achieved mainly at the local level, but there is no research on regional energy planning and the main prerequisites for the implementation of these plans **(Am, 2015; Melica et al., 2018; Neves, Leal & Lourenęo, 2015)**. Based on a broad review of the literature of the subject, including the results of secondary studies and energy policy documents, specific gaps have been identified and are key justifications for this research.

Gaps have been diagnosed in energy and low-carbon areas and the model of optimizing biomass energy production at a municipal level. Low-carbon energy is a complex and multidimensional concept. Thus far, the research has mainly focused on the definition of relationships and the role of low-carbon energy.

From the point of view of energy planning, there has been a lack of orderly approaches to the issue. On the one hand, research to date does not explain the role of biomass production at the municipal level in the transition to low-carbon energy, hence there is a need to identify this issue in a broader context to capture the complexity of biomass mechanisms in low-carbon energy.

This article aims to overcome the gap and presents a case study on regional sustainable energy planning involving local stakeholders **(Faria, Markard & Raven, 2012)**. An example is the optimization of biomass as a renewable resource at the municipal level, as the use of biomass energy requires knowledge of landscapes, energy options, and different stakeholder perspectives **(Svazas, Navickas, Krajnakova & Nakonieczny, 2019)**. Up to this point, energy resources have been discussed as if they are countable and undisputed—that is, as if energy and resources were only "raw materials that can be converted into barrels, bushes, boxes or some other handheld units" and can be attributed an exact monetary value. However, "resources" should also be understood as socially and culturally constructed to refer to parts of the natural world that are perceived as having utility or value. Thus, "energyscapes, " or a complex spatial and temporary combination of energy supply, demand, and infrastructure within the landscape, can be very useful in this context, referring to the preferences of the main stakeholders at a local level and creating the prerequisites for strengthening energy citizenship **(Ryghaug et al., 2018)**.

The reminder of the text is structured as follows: Section 2 contains the literature review, Section 3 presents the state and potential of renewable energy in the selected municipality; Section 4 presents the regional energy planning model and results for the selected municipality; Section 5 discusses regional issues related to the implementation of energy in the selected municipality; and Section 6 concludes the paper **(Parag, Sovacool, 2016)**.

2. Literature review

The transformation of the energy sector is a prerequisite to achieve climate neutrality by 2050, as pledged by the EU Member States in December 2019 based on the commitments made in the Paris Agreement. The transition to a low-carbon energy system can be difficult and requires considerable public support and commitment. Until recently, people have been conceptualized regressively: firstly, as passive consumers, as users or recipients of technologies that are mainly based on centralized energy systems powered by nuclear, coal, gas, or hydropower plants; and secondly, as a barrier to the development of new clean energy technologies because of a lack of knowledge of the environmental, social, and economic benefits that new technologies can bring **(Perger, Wachter, Fleischhacker & Auer, 2021)**. Thirdly, any critical public opinion or action to implement renewable energy is presented as a "not in my backyard" (NIMBY) situation **(Burningham, Barnett & Walker, 2015)**.

For the current EU clean energy packages, to make energy transitions more inclusive, fair, and democratic, various forms of energy citizenship can be conceptualized. Such a conceptualization is based on the theorizing of energy citizenship by **Ryghaug et al. (2018)** and **Devine-Wright (2007)**, specifically on the extent to which energy citizenship can be referred to as performative or discursive, respectively. Any energy citizenship in society can generally be classified as a spectrum of agencies with limited power to full civic power, resulting in the consumer/user of generic energy being personally responsible as an environmental citizen or only being a critical citizen.

The multilevel theory of sociotechnical change provides a useful lens for exploring how sociotechnical transitions from one energy system to another are shaped, while technology and social practices are coevolutionary **Geels (2011)**. This theory sees the transition to clean energy as a complex, adaptive system, as dynamic nonlinear changes in the social system refer to "economic, cultural, technological, ecological and institutional development at different levels." It is assumed that in the setting of sociotechnical changes, such transitions usually result from nonlinear interactions at three levels: niches at the micro level (a place for radical innovation— individual or collective), the mesothermal scale (the mosaic of regimes, the market, politics, industry, research, etc., that exists in the dominant energy system), and the macro level (landscape—various external pressures, which affect the transformation of the EU Energy Policy Directive, oil price shocks, the international climate change agenda, etc.

Issues such as building low-carbon societies, ensuring the transition to low carbon, and developing sustainable cities and regions require promoting a sustainable lifestyle and widespread education **(Awad, Gul, 2018)**. The implementation of sustainable cities, societies, and communities requires action primarily at the local level **(Neves et al., 2015)**. There is currently a discussion about what the future of energy will be:

- How much energy will come from what type of fuels?
- Does the energy system have to be entirely subordinate to the government or local authorities, or to what extent can it be a matter of private initiative?
- What amount of energy is to come from coal, atomic energy, or RES?
- What will the energy mix look like in the future, in line with EU requirements?
- Which legal and economic tools should be used to achieve the desired energy state?
- How can we build a civil society geared towards "energy democracy"?
- What econometric methods can be useful for planning energy production and building scenarios in the region?

The development and deployment of low-carbon technologies is a major opportunity to stimulate the recovery of the EU economy after the COVID-19 pandemic. Sustainable regional energy planning is also very important in this context, as it is a first step in the development of sustainable regions, prioritizing and involving different stakeholders in this process **(Melica et al., 2018; Haidar and Others 2020)**.

As centralized and fossil fuel-based production facilities are relocated to more decentralized and distributed renewable energy systems, a new type of interaction between traditional energy suppliers and citizens is becoming evident. In addition, energy decentralization provides new ways of producing renewable energy based on microgeneration, microgrids, local energy storage, feedback technologies (energy displays and continuous monitoring), as well as combinations of these technologies **(Skjolsvold, Jorgensen & Ryghaug, 2017)**. The municipality plays several important roles as a producer and supplier of energy **(Haidar, Fakhar & Helwig, 2020)**. It is responsible for meeting the energy needs of households, business structures, and public entities in the municipality **(Liao, Long, Ming, Mardani & Xu, 2019)**. Many municipalities make significant decisions on energy generation, transport, and distribution **(Aivazian, Afanasiev & Kudrov, 2018)**. Municipalities carry out their function as energy producers in municipal enterprises and suppliers in the field of heat and electricity generation, the use of solid municipal waste as a fuel for energy generation, as well as the transport and distribution of end-users. To perform its function, the municipality must cooperate with various actors and solve multifaceted problems **Anderson, Doig (2000)**.

Municipalities are involved in strategic planning processes that are widely used as a tool for regional development, including regional energy planning **(Cormio, Dicorato, Minoia & Trovato, 2003; Nasiri et al., 2020)**. Given the challenges of moving to a low-carbon path, planning for the development of the regional energy system and promoting the use of renewable energy are among the priorities in the municipal policy agenda **(Terrados, Almonacid & Hontoria, 2007)**.

Therefore, planning decisions relating to the energy system cannot be considered under a single criterion. Regional energy plans should take into account various implications, in addition to sustainable energy issues such as environmental or socioeconomic issues arising from changes in energy development. Various tools and techniques must be applied to solve this cascade of multifaceted problems **(Arabatzis, Kyr-iakopoulos & Tsialis, 2017)**. Municipalities are engaged in regional energy planning and require new tools and advice on how to deal with these complex tasks.

Another important problem is the implementation of the prepared regional energy plans, as the development of renewable energy sources faces many barriers and local public acceptance of these technologies is usually low. Therefore, the use of renewable energy generation technologies on the market is hampered by several social, economic, technological, and regulatory barriers **(Zyadin, Halder, Kahkonen & Puhakka, 2014).**

Public resistance and unfavorable evaluation of renewable energy projects are important social barriers that can only be addressed at a local level **(Paravantis, Stigka & Mihalakakou, 2014)**. Other social barriers are linked to the acquisition of land for renewable energy infrastructure, as land earmarked for this purpose could be successfully used for agriculture, tourism, etc. Agricultural land, including arable land, is being converted into roads, building structures, and other necessary infrastructure for renewable energy sources, so agriculture, tourism, and fisheries are suffering **(Boie, Fernandes, Frías & Klobasa, 2014).**

Researchers have also highlighted the important NIMBY factor, as a lack of public awareness and other information barriers are evident when investigating renewable energy projects that face resistance due to negative environmental and landscape impacts, as well as related conflicts with local communities, etc. Demonstration projects, awarenessraising campaigns, training, and capacity building are used to deal with these barriers, but not very effectively **Sovacool (2009).**

There are also economic and financial barriers to renewable energy sources, but they are taken into account in the current policy **(Kilinc, New Zealand-Ata, 2016)**. Among them, price incentives for the production and consumption of renewable energy have great potential **(Mentel, Vasilyeva, Samusevych & Pryymenko, 2018)**. Researchers have also highlighted technological barriers such as a lack of infrastructure, insufficient capacity to operate and maintain RES generators, and inadequate R&D efforts **(Seetharaman, K., N. & Gupta, 2019)**. Other researchers have recognized regulatory and institutional barriers, such as bureaucratic burdens, over-regulation, etc.

Practical political participation in energy transition (Raza and others) is crucial to overcoming social barriers. The concept of energy citizenship was developed by **Devine-Wright (2007)**. The idea of energy citizenship is based on the perception of people as active participants who will be democratically involved in a low-carbon energy transition. **Schot et al. (2016)** underlined that energy users play an essential role in a sustainable energy transition and should be considered key stakeholders in defining new procedures and driving changes in energy systems. **Devine-Wright (2007)** stated that energy users not only use energy technologies and influence innovation pathways but are also “politically engaged more comprehensively.” The concept of energy citizenship emphasizes hybrid relationships between users of energy technologies and technologies, as different energy users can also play other roles, such as protesters, advocates, and prosumers. **Devine-Wright (2007)** highlighted environmental awareness, accountability, and collective action on climate change mitigation, including the creation of community renewable energy projects. In this regard, the idea of energy citizenship primarily emphasizes awareness and literacy, as well as sustainable energy behavior and activities. **Ryghaug et al. (2018)** stressed that energy citizens are primarily actively involved as individuals in energy efficiency activities in households or large groups as climate activists or energy communities in municipalities **Radtke (2014).**

Therefore, energy citizenship can be enacted through material participation **Stokes (2013)**, consultations, formalized political arenas, or demonstrations **(Hasanov, Zuidema, 2018)**. It should be stressed that the concept of energy citizenship focuses on local communities and covers various aspects of practical participation in energy decision-making **(Paulos, Pierce, 2011)**.

Material participation may also enable a certain method of energy citizenship to be exercised since material participation is a form of special commitment **Marres (2012)**. In addition, environmental campaigns allow public involvement in material objects such as energy-efficient lightbulbs or smart meters, as new technologies that contribute to the visibility of invisible energy can contribute to raising awareness and environmental action and help to deal with the problematic aspects of the social, cultural, and material organization of society **(Sovacool, Linne r & Goodsite, 2015)**. Therefore, energy citizenship can be achieved through three processes: (a) awareness-raising, (b) the creation of new knowledge and literacy, and (c) new activities and practices **Latour (2005)**.

The concept of the "energyscape" draws attention to how a variety of different elements relate and combine energy in a given place. Additionally, the notion of the energy landscape requires an understanding of regional concerns: an environment in which everything both constitutes and affects almost everything. The key to this approach is its focus on the diversity of issues, subjects, and discourses that together make up the energy situation in the body of empirical materials. Energy permeates societies, technologies, and economies, as well as ways of communicating, thinking, and living far beyond institutional policies or market transactions. No amount of conceptual readiness can translate into the ability to capture problems and perspectives that may be lacking in real-world discussions and debates.

Energyscapes are very useful in this context, as combining an understanding of the energy system and ecosystem services is a very complex task to be solved at a local level **(Howard et al., 2010)**. Typically, ecosystem services are considered spatial processes that are associated with specific habitats that are geographically established **(Throndsen, Ryghaug, 2015)**. The energyscape approach can help solve the problems of modeling energy demand, supply, and flows in real landscapes. This allows for the definition of the main links, obstacles, and relationships, as well as ensuring the involvement of stakeholders and a fair energy transition **(Armitage et al., 2010)**.

An energyscape is a framework containing geographical and spatial characteristics and individual elements of energyscape can be plots of land having their energy flow, which must be combined to reflect larger energyscapes **(Sun, No, 2015).** This is a bottom-up approach that requires a large amount of detailed data and comprehensive analysis (opinion polls, rural surveys, life cycle analysis, input, etc.).

Energyscapes can successfully encourage energy citizenship by allowing individuals to engage in discussions about the interaction of the energy system with their local environment and other ecosystem services provided by this local environment and offering a decisionmaking mechanism that is more transparent and fair **(Shindina, Strei-mikis, Sukhareva & Nawrot, 2018)**. Researchers say that energy can help to initiate a public debate on the energy transition at a local level **(Tvaronaviciene, Prakapiene, Garskaite-Milvydiene, Prakapas & Nawrot, 2018).** For a discussion of regional development plans of local government with stakeholders, the energyscape framework can be very useful **(Kasperowicz, Pinczynski & Khabdullin, 2017)**.

3. State and potential of renewable energy in the West Pomeranian Voivodeship

The West Pomeranian Voivodeship is one of the best renewable energy sources in Poland (PEP2040 2018). Areas located on the seashor-e—that is, in the northern part of the province—have extremely favorable conditions for wind installations. Areas in the eastern part of the province can use high-temperature geothermal waters above 80 °C. The agricultural and forestry character of a significant part of the province creates the possibility of using a significant amount of biomass for energy purposes. The western part of the province is one of the areas with the largest duration of sunshine in Poland, at more than 1620 h per year. The West Pomeranian Voivodeship also has rich biomass resources.

Following Directive 2001/77/EC, biomass means: "biodegradable fractions of products, waste, and residues from the agricultural, forestry, and related industries, as well as biodegradable fractions of industrial and municipal waste" **(Biomass, 2012)**. According to the Regulation of the Minister of Economy and Labour of 9 December 2004, biomass is "solid or liquid substances of plant or animal origin which are biodegradable, come from products, waste, and residues from agricultural and forestry production, as well as from the industrial processing their products, as well as parts of other biodegradable waste." However, the Polish Energy Regulatory Office on biomass recognizes that all organic substances of plant or animal origin, including human-made substances, that can be used to produce energy. Biomass is a store of solar energy accumulated in the process of photosynthesis, and its deposits under the influence of solar radiation and social metabolism can regenerate. Biomass is not inexhaustible but is fully renewable **Janowicz (2006)**.

Biomass, the oldest and most widely used source of renewable energy, is organic matter found all over the world. It also includes kitchen scraps and garden waste. Biomass includes agricultural residues, forest residues, and industrial and municipal waste. When organic matter is incinerated, the CO2 emissions are equal to the content of this compound that the plant took in during its growth, which results in a zero CO2 balance. There is also no problem with the use of ash because it is an excellent fertilizer. Therefore, the potential amount is really large. Biomass is a low-cost source of green energy. Moreover, energy from biomass can be obtained by burning biomass plants; producing fuel oil from oilseeds; the alcoholic fermentation of potatoes, sugarcane, or any other organic material that undergoes fermentation; and producing ethyl alcohol for motor fuels. For energy purposes, except for organic matter from primary raw materials, energy may be used from crops, wood and wood waste, sewage sludge, agricultural products, and waste, as well as waste from the woodworking industry (wood, bark, woodbriquettes, wood chips, sawdust, and pellets). However, it should be borne in mind that not all wood waste is suitable for use in the energy sector. Particular attention should be paid to the source and type of waste, as it may contain unhealthy chemicals used to process wood in a factory. After incineration, these substances can produce toxic compounds that adversely affect the atmosphere through the emission of gasses. On the other hand, energy crops rich in cellulose compounds are distinguished by a significant annual growth, a high fuel value, significant resistance to diseases and parasites, relatively low soil requirements, and the possibility of automating agrotechnical work related to plantation and harvesting. Energy crops facilitate the development of not very efficient or degraded agricultural areas. The development of energy crops takes an average of 15-20 years. Energy crops can be used for briquettes or granules or can be burned completely (Pisarek 2006). There are four main groups of power-producing plants:

(a) Annual crops such as maize, cereals, hemp, oilseed rape, Sudanese sorghum, sunflower, and sugarcane;

(b) Rapid rotation of woody plants such as aspen, eucalyptus, poplar, and willow;
(c) Fast-growing grasses such as perennial grasses
(d) Slow-growing tree species.

The introduction of plants such as willow on agricultural land allows for the extraction of biomass for energy purposes and, inter alia, for the development of areas not currently used in agriculture, the extraction of heat from organic sources, and the reduction of unemployment in rural areas. These facilities may also be used for direct combustion or processing. In addition, willow energy has a beneficial effect on the environment, including degraded land reclamation, erosion protection, and regulation of water use. Pennsylvania Mallow grows in all soil classes except Classes V and VI. The areas to be cultivated must be weed-free **Kandefer (2004)**. The dry, woody stems are harvested every year. Mallow can be grown on a plantation for 15-20 years. Helianthus tuberosus is easy to grow and resistant to drought and frost. It is grown on wetlands and sterilizes the soil. Dried parts of the plant can be directly burned, or it can be processed and burned in the form of briquettes or granules. It can be grown for 15-20 years **(Energy, 2002)**. Miscanthus giganteus is a species of grass characterized by a large production of dry matter, from 8 to 25 t/m/ha. This grass has low soil requirements, but is extremely sensitive to negative temperatures in the first year after planting, so it is necessary to cover the crop **(Grzybek, Gradziuk & Kowalczyk, 2001)**. Agricultural waste is also produced. Straw is one of the raw materials obtained for heating purposes. It is mainly used in animal husbandry, as litter and feed, and for fertilizing fields. Modern agricultural production methods with limited livestock production contribute to a reduced demand for straw, which means that straw is often burned in the field. Meanwhile, there are great opportunities to use straw as biofuels **Nobility (2001)**. Thanks to innovative technologies for the combustion and modification of straw, the excess can be used as fuel for energy purposes in the combustion process, due to the high efficiency of 24 t/ha and the high fuel value. The obstacle is high humidity, which ranges from 50% to 70%. The fuel value of straw depends on its type, humidity, and storage. It is strongly recommended to use so-called gray straw. This raw material has slightly better energy properties, as well as lower emissions of sulfur and chlorine compounds than yellow (freshly cut) straw. Straw for heating purposes should be left in the field for a certain time under natural conditions, and then dried. During this time, the content of alkali and chlorine is reduced and the heating value increases. Straw as fuel is characterized by low density and at the same time a high content of volatile fractions, which causes problems during combustion. Ash, as a residue of noncombustible substances, can be a problem in boiler rooms **(Kawałko, Olek, 2008).**

The weakness of the energy system of the West Pomeranian Voivo-deship in terms of the use of renewable energy is the significant degree of depletion of the power supply network, which, due to age and a lack of adaptation to new needs, makes it difficult to connect to new renewable energy sources. The system must also be adapted to send excess production to other provinces. In **Table 1**, renewable energy installations in the West Pomeranian Voivodeship are presented.

Assessing the possibility of obtaining energy from biomass in the West Pomeranian Voivodeship is a difficult issue, mainly due to the need to take into account numerous variables. We must pay attention to:

• the potential conflict between the agricultural and energy use of agricultural space,

• the potential conflict between the natural functions of the forest and its exploitation for energy purposes,

• specific technical requirements and technological processes,

• complex financial terms Rabe (2017).

Table 1 Renewable energy installations in the West Pomeranian Voivodeship

Installation type	Number of installations	Power (MW)	(%) provincial capabilities from RES	(%) national capacities from individual RES
Biogas installations	25	17.248	1.09	7.43
Production from biogas from wastewater treatment plants	4	1.478	-	-
Production from agricultural biogas	13	12.690	-	-
Production from biogas dumps	8	3.08	-	-
Mixed biomass production plants	4	99.251	6.25	7.3
Solar installations	14	3.997	0.25	3.6
Onshore wind farms	99	1489.62	93.86	25.4
Hydroelectric power plants	65	170.531	10.74	15
Hydropower plants up to 0.3 MW	57	4.463	-	-
Hydropower plants up to 1 MW	4	2.768	-	-
Hydropower plants up to 5 MW	3	6.350	-	-
Power plants implementing co-incineration technology (fossil fuels and biomass)	2			
Power plants implementing co-incineration technology (fossil fuels and biogas)	1			
Total:	209	1780.647	100.00	20.04

Source: Own study based on data from the Energy Regulatory Office as of 31.03.2018.

In **Fig 1**, the assessment of biomass energy potential in West Pomeranian Voivodeship is provided.

Despite potential conflicts between the energy use of biomass and the agricultural or forestry function, it is possible to use the resulting biomass for energy purposes. It turns out that it is necessary to maintain a balance with the main purpose of its production. In the case of energy plantations, the economic potential of biomass has a huge impact. In practice, the theoretical potential is conditioned only by the presence of adequate soil quality and other similar factors. For this potential to be exploited, farmers must obtain a price for the biomass they receive for day-to-day production for food purposes, as well as a risk premium for new production. This condition is met by a significant part of the West Pomeranian Voivodeship.

Technical and economic potential is of great importance for biomass from forests, urban green areas, orchards, etc. The main problem, for customers involved in both the direct combustion of biomass and its processing, is ensuring the continuity of the supply of raw materials.

In **Fig 2**, existing installations producing electricity from biomass in the West Pomeranian Voivodeship in the district system, at the level of 31.03.2018, are provided.

The province is an area of traditionally developed large-scale plant production, currently characterized by large and increasing profitability, which translates into the amount of production potential for obtaining energy from biomass.

Soon, biomass from energy plantations is expected to be the most important source of its acquisition. According to various sources, biomass is expected to account for around 90%, of which as much as 70% will come from crops on agricultural land.

In the West Pomeranian Voivodeship, the soil of Classes I and II covers about 10,000 hectares. These soil types occur, among other places, in the vicinity of Kolbaskov Agricultural land where medium and low quality is dominant, mainly Class IV (51.1%), Class III (20.8%), Class V (20.5%), and Class VI (6.6%).

On medium and weak soils, it will be possible to establish energy plantations, such as:

- Pennsylvania Mallow,
- Energy willow,
- Rose or Miscanthus.

Products such as potato stalks, cereal, rapeseed straw, vegetable crop residues, and sugar beet leaves are useful waste.

The use of available straw in the province is currently small. The West Pomeranian Voivodeship currently has one of the largest straw increases in Poland. The estimated surplus—456,000 tons of straw per year—corresponds to 665 GWh of electricity, which can be obtained by combustion in cogeneration systems **(Maciej Nowak, 2017)**.

The development of the rapeseed market in the region offers significant opportunities to use surplus rapeseed for indirect combustion or as a substrate for biogas production. Currently, however, there is no demand from agricultural biogas plants for this type of biomass.

The West Pomeranian Voivodeship is the fourth most forested province in Poland, with forest cover of 35.0%. At the end of 2016, 828,700 acres of forest land was occupied.

At the end of 2016, 98.1% of wooded area was public forests. This creates favorable conditions for the implementation of the ecological and social functions of these areas.

Currently, forest biomass that cannot be used in the wood industry is used for energy purposes. It is estimated that 60% of the waste is achieved from 100 m^3 of wood harvested from forest management after processing **Płocharski (2017).**

In 2014, in provinces including Szczecin Klucz and Swinoujscie, in the municipalities of Bobolice, Grzmiąca, Kalisz Pomorskie, Kołbaskowo, Polanów, Police, Sianów, Stary Dąbrowa, and Szczecinek, there were biogas installations with a total capacity of 11.61 MW.

The exploitation of agricultural biogas plants and the potential of biofuels, in particular from animal or plant waste treatment plants, wastewater treatment plants, and landfill, depends on the availability of substrates. Currently, there are eight biogas installations with organic waste in landfills in the West Pomeranian Voivodeship, as listed in **Table 2.** Biogas installations are used for the production of biogas from plant biomass, animal waste, or organic waste.

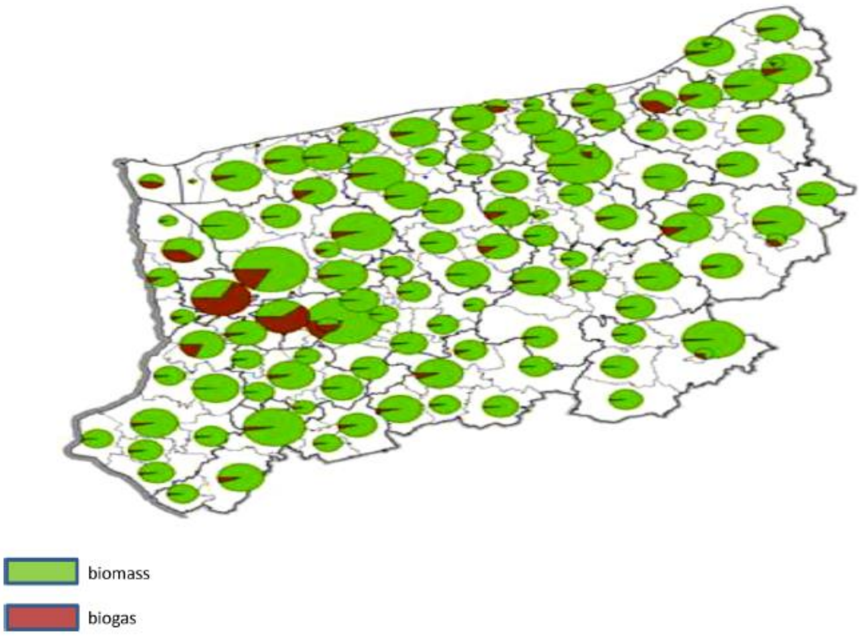

Fig. 1. Development of the RBGPWZ in Szczecin on the basis of data from the study "Production potential of energy from biomass in the West Pomeranian Voi-vodeship. Spatial policy considerations and orientations', 2013.

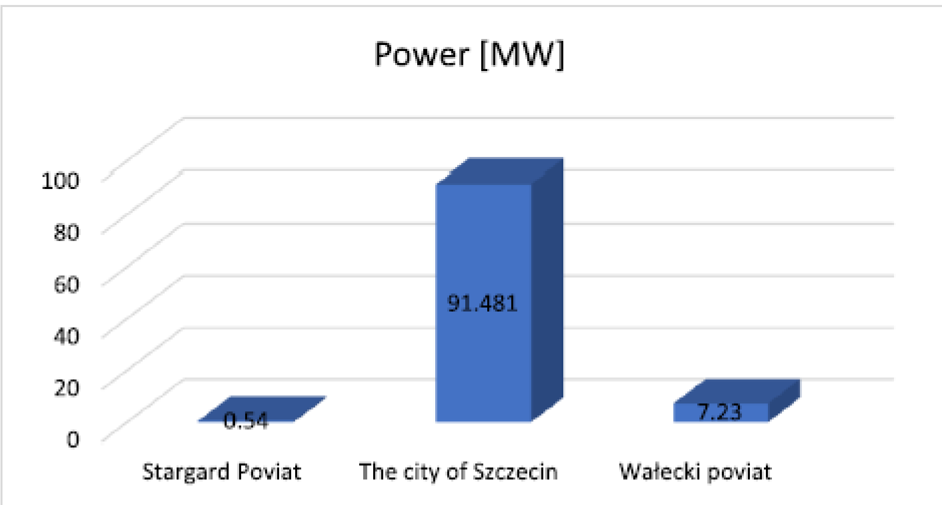

Fig. 2. own study based on data from the Energy Regulatory Office - as of 31.03.2018.

Table 2 Degassing of installations with electricity recovery in the West Pomeranian Voivodeship.

County	Number of installations	Power (MW)
Koszalin	1	0.08
Policki	3	1.164
Szczecin	1	0.40
Szczecinecki	1	0.25
Świnoujście	1	0.30
Stargardzki	1	0.20
All	8	2.1314

Source: Own study based on data from the Energy Regulatory Office.

The urban wastewater treatment plant group has 200 in the biological type and 63 in the type with increased gene removal. Large amounts of sewage sludge are produced in medium to large urban wastewater treatment plants, which is an integral part of the treatment process. One of the main processes for removing excessive sewage sludge is its biochemical decomposition, which occurs in so-called separate fermentation chambers. On average, 10-20 m^3 of biogas with a content of 60% methane can be obtained from 1 m^3 of sludge. Biological treatment plants are best suited for direct biogas production.

The main documents for assessing the development of the energy sector in Poland are existing EU documents and directives, as well as government documents and Polish legislation, the most important of which is the Polish Energy Policy until 2030, the act of 10.04.1997 Energy Law (Journal of Laws of 2006, No. 69, item 625, as amended). The assumptions of biomass potential in the West Pomeranian Voivo-deship also take into account the Polish energy policy project submitted on 23 November 2018 and the Polish Energy Policy Project by 2050 presented on 10 August 2015.

Regional and local documents, including the Report, were also included for the West Pomeranian Voivodeship area, such as “The potential and use of renewable energy sources in the production of electricity and heat in the West Pomeranian Voivodeship” report published by the Regional Office of Spatial Management of the West Pomeranian Voivodeship in November 2018 and the Energy Sector Development Program for the West Pomeranian Voivodeship by 2015 from the perspective of 2030.

At the end of 2016, the West Pomeranian Voivodeship had 954.2 thousand hectares of arable land. The report “The potential and use of renewable energy sources in the production of electricity and heat in the West Pomeranian Voivodeship” assumes that 15% of agricultural land will be used for the production of energy from biomass and the rest for the production of goods. It is assumed that, on average, 50,000 kWh can be obtained from energy crops.

It is estimated that the West Pomeranian Voivodeship has a relatively high biomass potential of 7156.5 GWh.

The main factors shaping the structure of agriculture in the West Pomeranian Voivodeship are a large area of agricultural holdings, a favorable percentage of people employed in agriculture, and a focus on plant production, especially potatoes, cereals, and sugar beet. The average agricultural land size on the farm at the end of 2018 in the West Pomeranian Voivodeship was 30.67 hectares.

As organic fertilizers, such as slurry or manure, are an important substrate for the production of agricultural biogas, it is also advisable to analyze the number of livestock in the region. The dominant breeding animals are pigs, cattle, and poultry. According to GUS data, the number of cattle and pigs is declining, while the number of poultry is increasing.

The construction and operation of agricultural biogas plants can contribute to improving this condition and reducing the downward trend. Finally, it should be remembered that the construction of a biogas plant in a certain area must be supported by adequate material for the production of biogas. Therefore, livestock farming near the plant should be concentrated or carried out on large farms **(Rzepa 2018)**.

In addition to livestock production, there is great potential for biogas production in agricultural processing plants such as sugar factories, distilleries, breweries, slaughterhouses, and fruit and vegetable processing plants.

In the West Pomeranian Voivodeship, there is also a decreasing area of meadows and pastures. In 2016, these covered an area of 157,200 hectares, while in 2018 the figure was only 143,000.

Cereals are also used for biogas plants, and are harvested at an appropriate stage and used as a complementary silage substrate. Corn silage is considered an optimal substrate for agricultural biogas plants **Jasiulewicz, Janiszewska (2018)**.

The cultivation of maize in the West Pomeranian Voivodeship is slowly growing. In 2016, there were 9200 hectares for maize crops, and in 2017 almost 22,000. Beet crops, on the other hand, are declining slightly: in 2017 there were 12,100 ha. Despite the lower area, sugar beet harvests in 2017 were higher than in 2016.

If we assume 13,200 ha, we can assume that 56.4 million m^3 of biogas will be produced during the year. However, by allocating sugar beet leaves to silage, approximately 39.6 million m^3 of biogas would be produced during the year.

It is estimated that the potential of the West Pomeranian Voivodeship is based on its resources: i.e., waste from the agri-food industry, organic fertilizers, grasses from solid grassland, sugar beet leaves, and maize, creates the possibility of obtaining about 638.7 GWh of electricity from biogas plants. It is also estimated that the waste generated in agricultural production, such as potato, cereal, and rape straw, vegetable residues, and sugar beet leaves, may be used. In 2018, agricultural waste accounted for 0.13 million tons, while in 2030 it could be 0.79 million tons.

4. Modeling the development of biomass energy in the West Pomeranian Voivodeship

The article proposes an original model for the development of biomass energy in the West Pomeranian Voivodeship, analyzing the different types of technologies that can appear in the system. Based on a multicriteria optimization model, a model has been developed that optimizes the regional energy potential of biomass including waste biomass, taking into account sustainability criteria, i.e., according to Thomson Reuters, this model provides forecasts of the EUA's 2021-2030 eligibility prices. The time range for the empirical research has been set to 2018-2030. A lexicographic method was used to find compromise solutions.

The province has chosen West Pomerania as a research facility and the time range of empirical research has been set to 2018-2030.

The West Pomeranian region, which is the subject of this research, is particularly suited to the production of renewable energy sources, especially energy from biomass. The West Pomeranian Voivodeship is characterized by low stocking and surplus biomass not used in agriculture (hay-straw).

The largest biomass boiler in the country (Szczecin Power Plant) is located in the test area. Eighty percent of forest biomass is burned in the boiler, i.e., branches, wood, and sawdust, while the remaining 20% is agricultural biomass. Szczecin power plant, due to the price of biomass, imports "green coal" from other regions of the world without using the surplus agricultural biomass located in the West Pomeranian Voivodeship.

Unfortunately, the administrative area of the West Pomeranian Voivodeship does not coincide with the energy region.

The forecast of electricity production in the West Pomeranian Voi-vodeship, according to the Polish energy policy project, will increase by about 30% by 2030 compared to 2015 **(see Table 3)**.

This will be linked both to the economic development of the region and to the shift in final energy demand from fossil fuels towards electricity, resulting from the increasing mechanization of industry and services, the proliferation of electric vehicles (plug-in hybrids), and the electrification of the heating and heat production process in many households that previously used coal or gas for this purpose.

Table 3 Forecast of electricity production in the West Pomeranian Voivodeship (GWh).

	2015	2020	2030
Energy production	10,015.6	11,217.4	11,956.08

Source: Conclusions of the forecast analysis for Polish energy policy for 2050, Appendix 2 to energy policy Polish 2050, p. 6.

The model for 2030 assumes that the potential for energy production from biomass in the West Pomeranian Voivodeship will be at 27%, following the provisions of the Energy Policy Project Polish by 2040. The capacity of energy produced from biomass will be at least 3228.14 GWh. On the other hand, the installed capacity of wind energy in 2030 will be increased to 1000 MW by the Energy Sector Development Program in the West Pomeranian Voivodeship by 2015 from a 2030 perspective. It is also planned to install 1 MW photovoltaic cells.

When optimization models were built, the technical and economic parameters were first calculated and minimum or maximum levels of balance conditions (not side conditions) were specified. Twenty-five decision variables have been adopted for this model. The following decision variables are applied to the model: x1—production of nonrenewable energy (kWh); x2—cogenerating energy generation (kWh); x3—hydropower generation (kWh) from existing installations (until the end of 2017); x4—hydropower generation (kWh) in new installations (from January 2018); x5—solar power generation (kWh); x6—generation of energy from household windmills (kWh); x7—generation of energy from wind farms (kWh) from existing installations (until the end of 2017); x8—wind energy (kWh) in new installations (from January 2018); x9—biogas (kWh) energy generation; x10—biogas generation in high-efficiency cogeneration with a total installed electrical capacity of less than 1 MW (kWh); x11—biogas power generation (kWh) in new installations (from January 2018); x12—energy production from biofuels (kWh); x13—generation of energy from biomass combustion including waste biomass (kWh) from existing boilers (until the end of 2017); x14—generation of energy from biomass combustion including waste biomass (kWh) from new boiler installations (from January 2018); x15—generating energy from geothermal energy; x16—total annual production of electricity from various energy sources (kWh); x17—energy willow yield (kWh); x18—plasticity value (kWh); x19—poplar yield (kWh);

x20— the size of the cultivation of other raw material for biomass combustion (kWh); x21— the size of cultivation of the raw material for biomass combustion - Jerusalem artichoke (kWh); x22—the amount of rape grown for biofuels (kWh); x23—the amount of cereals grown for biofuels (kWh); x24—the amount of maize grown for biogas (kWh); x25—beet harvest for biogas (kWh).

In contrast, the parameters of the objective functions from x16 to x24 include the costs of producing energy from energy crops. The cost factors for each type of energy are provided in **Tables 4-5**.

Data on production costs, the European Union Allowance (EUA) 2021-2030 entitlement price forecasts according to Thomson Reuters, the support system related to certificates of origin, the electricity generator, and the amount of soil fertility loss caused by the production of energy raw materials allowed us to determine the decision-making variables of the objective function.

The objective function included production costs, certificates, environmental costs, and EUA allowance costs for each type of energy (variables x1 to x15) and loss of soil fertility due to their exploitation in the production of biomass raw materials, biogas biofuels, and commodity agricultural production (variables x17 to x25). During the forecast period, production and demand for electricity in 2030 is forecast to be 11,956,080,000 kWh.

Table 4 Cost factors for each type of energy (in PLN/kWh)

Types of energy	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}
Production costs	0.72	0.93	0.20	0.20	0.40	0.24	0.24	0.24	0.70	0.70	0.70	1.10	0.28	0.28	0.28
Certificate cost	0.00	0.00	0.12	0.12	0.12	0.12	0.12	0.20	0.12	0.12	0.2	0.12	0.12	0.20	0.12
Environmental costs (cost of EUA allowances)	0.032	0.025	0.0006	0.0006	0.0007	0.0006	0.0006	0.0006	0.0116	0.0116	0.012	0.012	0.0004	0.0004	0.001
Total costs	0.69	0.90	0.07	0.07	0.27	0.11	0.11	0.03	0.56	0.56	0.56	0.96	0.15	0.07	0.15

Source: Own study for the model.

Table 5 Cost factors for each type of energy (PLN/kWh).

Energy Resources	x_{17}	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}
Costs associated with a decrease in soil fertility	0.18	0.35	0.17	0.07	0.04	0.5	0.34	0.5	0.21

Source: Own study for the model.

In the geothermal energy optimization model, only one function (L (x)) that was a component of the above components was minimized. The function of the decision model objective is as follows:

$$
\begin{aligned}
L(x) = {} & 0.69\,x\,1 + 0.90\,x\,2 + 0.57\,x\,3 + 0.57\,x\,4 + 0.97\,x\,5 + 0.42\,x\,6 + 0.52\,x\,7 \\
& + 0.44\,x\,8 + 0.56\,x\,9 + 0.51\,x\,10 + 1.17\,x\,11 + 0.96\,x\,12 + 0.32\,x\,13 \\
& + 0.24\,x\,14 + 0.24\,x\,15 + 0.18\,x\,17 + 0.35\,x\,18 + 0.17\,x\,19 + 0.07\,x\,20 \\
& + 0.04\,x\,21 + 0.5\,x\,22 + 0.34\,x\,23 + 0.5\,x\,24 + 0.21\,x\,25 \rightarrow min
\end{aligned}
$$

The side conditions are as follows:

Boundary conditions assume that all variables must be non-zero. $x1 + x2 + x3 + x4 + x5 + x6 + x7 + x8 + x9 + x10 + x11 + x12 + x13 + x14 + x15 = x16$ – total energy production.

This condition presupposes the production of energy from nonrenewable and renewable sources, which together constitute the total energy production. x16 > 119,560,800,000 kWh = generation of energy for the test region.

This condition assumes that energy production in the region will be equal to or greater than 11,956,080,000 kWh, according to the Polish Energy Policy Project 2050 of 10 August 2015. The project assumes that the surplus energy generated in a given area can be exported to other regions. $x3 + x4 + x5 + x6 + x7 + x8 + x9 + x10 + x11 + x12 + x13 + x14 + x15 = 0.27\,x\,16 -$ 27% of total renewable energy production.

This condition assumes that, within the framework of the Polish Energy Policy Project until 2040 of 23 November 2018, 27% of the share of electricity production in the West Pomeranian Voivodeship is renewable energy. $x6 + x7 + x8 \geq kWh$ = wind energy generation.

This condition assumes that wind energy production will be equal to or higher than 3011,640,000 kWh, following the Energy Sector Development Program in the West Pomeranian Voivodeship by 2015 with a view to 2030. It is estimated that the wind energy potential in the West Pomeranian Voivodeship, taking into account environmental constraints, is 26,600 GWh per year. x8 $\leq$ 84,000,000 kWh = generation of energy from newly created wind installations from 01.01.2018.

This condition, by the Act of 15 July 2016 on investments in wind farms, commonly known as the anti-air windmill act, assumes that the overall potential of the West Pomeranian Voivodeship is 84,000,000 kWh. x9 + x10 $\geq$ 60,850,000 kWh = biogas generation.

This condition assumes that the production of energy from biogas will be equal to or greater than 60,850,000 kWh according to the report “The potential and use of renewable energy sources in the production of electricity and heat in the West Pomeranian Voivodeship” published by the Regional Office of Spatial Management of the West Pomeranian Voivodeship in November 2018. $x13 + x14 \geq 238{,}200{,}000\ kWh$ = energy generation from biomass combustion.

This condition assumes that the production of energy from biomass combustion will be equal to or greater than 238,200,000 kWh according to the same report detailed above. x9 + x10 = 30,450,000 x 23 +10.960.000 x 24 = power generation from biogas combustion. x11 + x12 = 10,500 x 21 + 15,000 x 22—the energy generation from the combustion of biofuels. x13 + x14 = 238,200,000 kWh—the energy generation from biomass combustion. x15 $\leq$ 811,774,000 kWh generates energy from geothermal energy.

This condition assumes that the production of energy from geothermal energy will be equal to or lower than 811,774,000 kWh, according to the report detailed above. x1 = 0 kWh—the maximum conventional energy production. x2 $\leq$ 6907,531,938 kWh—the maximum energy production with co-ed.

This condition assumes that the production of energy from the cossy rod will be equal to or lower than 6907,531,938 kWh, following the assumptions of the Polish Energy Policy Project until 23 November 2018. x3 $\geq$ 313,770,000 kWh = hydropower generation.

This condition assumes that the energy production from existing water installations (at the end of 2017) will be equal to or greater than 313.770.000 kWh. x4$\leq$ 319,141,000 kWh = production of a new hydroelectric power plant.

This condition assumes that the energy production from new water installations will be equal to or less than 319,141,000 kWh. This is since, due to the lowland nature of the region, the water resources of the West Pomeranian Voivodeship do not represent a significant energy potential. The total potential of existing hydrotechnical structures predisposed for conversion into MEW is estimated to be around 5371,000 kWh, according to the results of the international RESTOR HYDRO project. x5 ≥ 9590.000 kWh = minimum solar energy production.

This condition assumes that the minimum production of solar energy will be equal to or higher than 9590,000 kWh as a result of the technological development of photovoltaic cells and that there will be an economy of scale resulting in a decrease in the cost of generating energy. The West Pomeranian Voivodeship is ideal for the development of the energy industry. A description of the model design can be found in **M. Rabe, Streimikiene & Bilan, 2019.**

Optimizing the model with this objective function includes the following solutions in **Table 6.**

Given the solution obtained, it can be seen that:

- the total energy production is 11,956.08 GWh (which covers the demand of the test area);
- 4510.07 GWh is the total energy production from coal;
- 300.50 GWh is the hydropower produced in hydropower plants created by 31 December 2018; 4.5 GWh is the hydropower that can be produced in new installations from 1 January 2018;
- 187.99 GWh is the sum of solar energy from installations by 31 December 2018 (9.59 GWh) and new installations to be built from 1 January 2018 (295.61 GWh);
- 3575.08 GWh is the wind energy generated by existing wind farms until 31 December 2018;
- 45.50 GWh is the energy that can be produced by new wind farms established from 1 January 2018;
- 30.45 GWh is the energy produced from existing agricultural biogas plants until 31 December 2018,
- 12.96 GWh is the energy that can be produced by biogas plants with high-efficiency cogeneration with a total installed electrical capacity of less than 1 MW, from 1 January 2018;
- 54.06 GWh is the energy that can be generated by new biogas installations from wastewater treatment plants and biogas from landfills, created from 1 January 2018,
- 238.20 GWh is the energy produced by existing biomass boilers until 31 December 2018;
- 2989.94 GWh is the energy that can be produced by new biomass boilers from 1 January 2018,
- 6.83 GWh is the energy that can be generated by new geothermal installations from 1 January 2018.

Table 6 Results of the optimization model.

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}
Energy production	0	4510	300.5	4.5	188	0	3575	45.5	31	13	54.1	0	238.2	2990	6.8	11,956
energy resources	x_{17}	x_{18}	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}							
Crop size	0	0	0	0	0	0	0	0.04	0							

The average cost of building one MW of energy will be PLN 9635,118.

Implementation of regional energy planning results in the West Pomeranian Voivodeship

The Energyscape tool **(Howard et al. 2012)** can be used to implement regional energy plans in the West Pomeranian municipality. The use of landscape energy allows for the construction of scenarios, which also provide a good opportunity to inform and engage local stakeholders for energy citizenship.

This method allows for a better understanding of the perspectives of the various stakeholders on the impact of changes in the energy system of their local area. A two-layer approach can be applied. First, each party is asked to identify ecosystem services that they believe are provided by specific habitats. The dominant habitats have been identified using the Rio Convention for Biological Diversity approach, which allows for the mapping of broad habits locally **(Aivazian et al., 2018).**

Table 7 Energy space tool for pricing ecosystem services: example questions for stakeholders.

Cultural services	…
esthetic	… think it is beautiful?
heritage	… think about the past?
tasks	… think about employment opportunities?
recreation	… want to spend more time here?
scientific and educational	… learn or observe something interesting?
Habitual services	…
flora	… wild plants
fauna	… wild animals
Provisioning services	What do you get from the habitat?
fiber	… fibers such as wood, linen, or wool?
food	… food for humans or livestock?
freshwater	… freshwater?
fuel	… fuel such as firewood or biodiesel?
genetic	… genetics for the future?
Healing/ornamental	… medicinal or ornamental plants?
Regulatory services	…
air quality	… improve the air we breathe?
carbon assimilation	… block carbon from the atmosphere in soil or plants?
buffer—chemicals	… reduce pollution caused by acid rain? nutrients, or pesticides?
buffer—physical	… reduce erosion or flooding?
buffer—economical	… create "safe" jobs in times of recession?
climate	… moderate the local (or global) climate?
diseases, pests and natural hazards	… reduce the impact of pests, diseases, etc.?
erosion	… prevent erosion?
fire	… prevent fires?
pollination	… create nectar resources for bees and other pollinators?
water flow	… moderate water flow (quantity)?
water quality	… improve water quality?
esthetic services	…
cycling nutrients	… nitrogen and phosphorus losses?
primary productivity	… growing vegetation?
soil formation	… encouraging soil formation?
hydrological cycling	… encouraging water circulation in the environment?

Source: Based on Howard et al. 2012

Various stakeholder groups should be invited to answer questions about common wild habitats in the area. The main types of habitats are arable and horticultural plants; grass improvement; neutral grass; broadleaved, mixed, forests; standing open water; rivers and streams; boundaries and linear features; and urban and built-up areas.

First, questions should be asked about cultural value, habitat, supply, and regulating and supporting ecosystem services, and then questions should be asked about people's views on the sensitivity to various changes in the energy system (Howard and Others 2012). Therefore, local stakeholders should be asked to assess which ecosystem services have been provided by a specific habitats, using the questions set out in **Table 7.** This allows one to determine the relative position of the different stakeholders and suggests where problems can cause friction and where similar beliefs exist.

All questions should be asked about each existing habitat. Table 9 provides an example of a question about the pricing of a selected habitat.

In addition, stakeholders should be asked to assess the impact of the local biomass stock option on habitats jointly, stating whether they consider it beneficial or harmful. **Table 8** provides an example of the results of one interested party' s answer to questions on the use of biomass in a particular municipality. The table shows the sum of the results, representing the perception of risks by stakeholders by applying results from -2 to -1 and benefits by providing results from 1 to 2.

Using the energyscape helps us to understand how changes in the local energy system interact with ecosystem services in terms of regional energy planning decisions. The standard approach includes energy planning applications and environmental impact assessment procedures. However, this narrow approach excludes other important issues. Energyscapes provide an understanding of the largely unknown synergies and conflicts generated by renewable energy technologies, which can have unexpected negative effects on local ecosystems, including the resistance of local communities.

5. Applications

1 The state' s existing energy policy is not conducive to the creation of autonomous regional biomass energy production systems at the municipal level to move to low-carbon energy, where the main decision-maker on the size and structure of the energy produced would be decided by the local government, not by energy companies and the Energy Regulatory Office.

2 The mathematical model of optimizing energy production from biomass at the regional level and its validation confirm that it can be a tool for moving to low-carbon energy.

Table 8 Summary of stakeholders' views

Energysource	Ecosystemservice group	Broad habitat type Arable plants andgardens	Border andlinear features	Broadleaved, mixed, andforests	Improvedgrassland	Rivers andstreams	Permanent openwater and canals	Urban and built-up areas
Biomass	Cultural	–1	–6	–2	0	0	0	4
	Provisioning	–1	0	3	–i	0	0	0
	Regulation	1	0	0	–2	0	0	0
	Supporting	3	0	0	4	0	0	0
	Total	2	–6	1	1	0	0	4

Source: Based on Howard et al. 2012.

3 The authors' multicriteria model for optimizing energy production from biomass, taking into account the Energyscape criteria, allows for the generation of various types of solutions that can be helpful in

the development of future low-carbon energy development strategies by regional governments or municipalities.

4 The compromise solution has provided local authorities with a lot of information on the implementation of low-carbon policies. Therefore, my research, as well as calculations for optimizing energy production from biomass, confirm the correctness of the construction of a regional biomass energy harvesting system for the transition to low-carbon energy.

5 The main document on energy policy in Poland on the transition to a low-carbon energy transition, the country' s energy policy for 2040, does not take into account the socioeconomic specificities of municipalities. Regional energy planning can help implement a low-carbon energy transition to cope with local conditions, environmental constraints, and public perception.

6 A case study of regional energy planning developed for the West Pomeranian Voivodeship has allowed for a repeat of the multilevel management of promoting renewable energy sources and breaking down technological blockades of renewable energy and other barriers by stimulating social change and cultivating energy citizenship.

7 An important factor in the energy balance of the West Pomeranian Voivodeship is the price of CO_2 emission allowances—a more restrictive climate policy will lead to the need to invest in fewer carbon sources, which will lead to a reduction in emissions and higher investment. High CO_2 emission allowance prices will determine the viability of replacing coal blocks with new ones that have higher efficiency, the scale of the increase in the share of RES, as well as the increased competitiveness of biomass.

8 The role of renewable energy sources, including biomass, will depend on whether renewable energy achieves economic competitiveness compared to other energy generation technologies.

9 Due to the increasing share of renewable energy in the West Pomeranian municipality, it will be necessary to develop transmission and distribution infrastructure and gain public acceptance by removing any significant barriers to the development of renewable energy. One can apply an approach to energy citizenship and a tool for energyscapes to link the energy system with ecosystem services in real landscapes.

10 The use of Energyscape in the West Pomeranian Voivodeship also promotes energy citizenship and a fair transition to low-carbon energy systems, taking into account the informed opinions of local stakeholders and obtaining their support of and commitment to the use of clean energy technologies.

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