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A Theoretical Framework for a Local Energy Innovation System Based on the Renewable Energy Case of Poland

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Abstract: The aim of this research is to create a theoretical framework for a local energy innovation system based on renewable energy sources. For this purpose, four types of clusters were outlined based on energy-generation capacity and socio-economic factors such as "local wealth", "relational capital", "scientific and research capital" and "energy demand". This classification revealed areas of Poland that have diverse features in terms of energy-generation capacity and innovation abilities. For each type of area, energy potentials combined with innovation abilities were established. To understand how areas with insufficient energy and innovation capacities could be supported in their development of local energy sovereignty, the concept of the regional innovation system has been adjusted. The results of the research can serve as an aid in the development of national and regional energy policies focused on the specificity and capacity of energy generation and innovation of each area.

Keywords: local energy system; innovation; renewable energy; energy policy; local innovation system; regional innovation system

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1. Introduction

The current international situation, conflicts and energy crises have a significant impact on economic prospects and energy policy throughout the world. Therefore, almost all European countries have been forced to take immediate steps and verify the assumptions of long-term policies related to energy production and acquisition. Broken energy supply chains to Europe have put the issue of the European Union's energy dependency at the center of attention in the planning of energy policies and systems for the coming years.

Countries of the European Union started to realise the importance of not relying mainly on one major energy supplier. Thus, in order to avoid becoming addicted to only one energy supplier, decisions have been made, on the EU level, to create a common energy policy for all the states involved in the Union. In 2015, the so called "Energy Union" was established, which is a policy that stipulates certain objectives in terms of energy security such as [1]:

- Diversify Europe's sources of energy, ensuring energy security through solidarity and cooperation between EU countries;
- Ensure the functioning of a fully integrated internal energy market, enabling the free flow of energy through the EU through adequate infrastructure and without technical or regulatory barriers;
- Improve energy efficiency and reduce dependence on energy imports, cut emissions, and drive jobs and growth;
- Decarbonise the economy and move towards a low-carbon economy in line with the Paris Agreement;
- Promote research in low-carbon and clean energy technologies, and prioritise research and innovation to drive the energy transition and improve competitiveness.

The above objectives indicate a route for the European energy sector and individual member countries in terms of policy creation. As stated, EU energy policy is focusing on renewable energy and research in clean energy technologies, a fully integrated internal energy market, and probably what's most important in terms of energy security, diversification of energy imports. Since 2015, when Energy Union was established, the EU managed to succeed in some of these fields. For instance, the current policy agenda is driven by the alignment of the EU energy targets to the climate targets of the new Fit For 55 package proposed in July 2021 [1], including a reduction of at least 55% in greenhouse gas emissions compared to 1990 levels by 2030 and reduction to net zero greenhouse gas emissions by 2050.

What is more, the comprehensive integrated climate and energy policy adopted by the European Union sets out to achieve targets to increase the share of renewable energies in energy consumption, an improvement of energy efficiency and the interconnection of the EU's electricity systems.

EU energy policies indicate a guideline and a route for nation states within the Union. Nation states' energy policies have to be in line with the EU energy policy. Therefore, it is no different in Poland, where, in February of 2021, a new national energy policy was established, known as the "Energy Policy for Poland until 2040". The Energy Policy for Poland indicates routes of development for the internal energy sector, based on three pillars of energy transformation [2]:

- Pillar I "Just transformation"—transformation of coal regions, reduction of energy poverty, and new branches of industry tied with renewable and nuclear energy;
- Pillar II "Zero-emission energy system"—marine wind energy, nuclear energy, and local and individual energy;
- Pillar III "Air quality"—transformation of district heating, transport electrification, and eco-housing.

The goals adopted by 2040 as part of the energy policy are [2]: a focus, among others, on optimizing the use of own energy resources, on the diversification of natural gas and crude oil supplies and on the development of renewable and nuclear energy.

The objectives indicated within these pillars of energy transformation for Poland seem to express the need for major changes in the current energy sector within the country. The policy was created in order to meet the EU energy agenda's goals in terms of green energy, energy security and diversification of energy sources, which makes individual energy supply one of the most important areas of the policy.

Another mutual part of the nation's policy and EU policy is to ensure that energy supplies from third countries should be diverse and limited, in order to ensure the stability of the internal energy market. This has been marginalised by some member states in recent years, as shown in the charts below (Figure 1), which had some unpleasant effects in the months before and after the aggression of February 2022.

In this context, the Polish government decided to strengthen the security and independence of activities aimed at obtaining energy sovereignty. This was facilitated by the previously adopted policy related to the diversification of supplies of energy resources. The currently updated energy policy of Poland will take into account a fourth pillar: energy sovereignty, the special element which will ensure the rapid independence of the national economy from imported fossil fuels from the Russian Federation. The starting point on the road to energy sovereignty is to look for alternative solutions for energy production and to create and implement innovative technologies in the energy sector. Renewable energy sources (wind, solar, hydroelectric, ocean energy, geothermal energy, biomass and biofuels) are an alternative to fossil fuels and are considered one of the most effective tools in the fight against climate change and the reduction of greenhouse gas emissions into the atmosphere. However, beyond this, renewable energy sources offer an opportunity to diversify energy supplies and reduce dependence on uncertain and unstable markets of fossil fuels, especially oil and gas. This is an important element of creating a new development policy, which is focused on the pursuit of energy sovereignty.

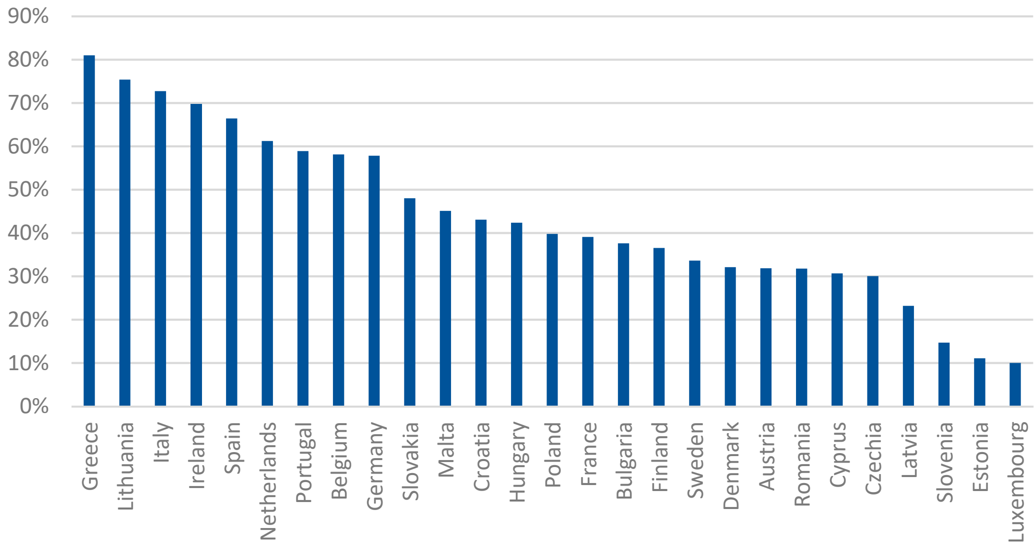

Figure 1. Total energy dependency from third countries in 2021, EU nations. Source: Eurostat [3], own presentation.

A fundamental question arises as to how to overcome the barriers to the development of renewable energy and create effective energy systems based on dispersed local innovation systems and new energy technologies. The aim of this article is a spatial diagnosis of energy systems and the development of the concept of an innovation system in such a way that it allows the creation of a theoretical framework for local energy innovation systems based on renewable sources. The innovation system itself accelerates the transfer of knowledge and technology between various entities and supports research and development in order to create new innovative value for products, technologies and business models [4]. Therefore, we assume that innovation systems will play a key role in building energy sovereignty in the context of supporting the development and implementation of technologies for the production of energy from renewable sources. The systems should implement energy policy which takes into account the spatial and local conditions of energy systems. In other words, we have made an attempt to show that there is no "perfect model" of innovation policy, because innovation activity varies significantly due to local conditions [5]. In this context, we have assumed that building energy sovereignty requires the creation of dispersed local innovation systems that perform the functions of knowledge and technology transfer through the involvement of actors and institutional solutions.

The contribution of this article is to provide empirical and theoretical evidence for the existence of diverse energy systems based on renewable energy sources. With the use of the analysis of spatial data on renewable energy sources, four types of innovative energy systems were distinguished. The results show that energy systems should be combined with innovation systems, which allow the creation of various strategies sensitive to local conditions, knowledge and relationship potentials. The task of innovation systems is to accelerate the processes of distribution and implementation of innovative energy technologies.

2. Literature Review

2.1. Barriers for Renewable Energy Technology Diffusion

The literature points out that, in Poland, the barriers to the implementation of investments are the excessive requirements of planning documents as well as frequent changes in regulations [6]. A very large portion of the local plans of Polish subnational divisions either do not refer to renewable energy or do so in a general and unclear way.

The study of spatial planning acts shows that, in almost half of the communes in Poland, the issue of renewable energy sources is not addressed at all in their strategic documents [7]. Errors in spatial planning can lead to a situation where excess wind energy in a given area does not necessarily bring positive spatial effects. This opens up a wider discussion on the role of spatial planning in sustainable development and responding to the challenges of climate change.

In addition, Hołuj et al.'s [8] research raises an important issue, which considers the determinants of investments in solar energy in suburban areas in connection with the process of urban sprawl. The authors believe that it is worthwhile to develop small photovoltaic farms, which will help maintain the energy security of cities in crisis situations, and that the creation of compact and efficient low-emission spatial structures should be a priority.

The main barriers to the development of renewable energy include limited possibilities of financing investments by entrepreneurs, legal support regulations, administrative and procedural difficulties, and problems with the functioning of transmission networks. The possibility of providing support for investments and the development of renewable energy sources (RES) results from the energy policy of the European Union.

Building energy sovereignty on the basis of innovative technologies using renewable energy sources depends to a large extent on local socio-economic and institutional conditions. Typically, advanced energy technologies require large capital expenditures, which extends the period of return on investment and increases the risk and uncertainty of investors. Therefore, various types of incentives and regulatory support are created to help mitigate the effects of unpredictable market conditions [9]. In addition, innovations within the dispersed energy systems are groundbreaking [10] and need social acceptance due to the costs, cognitive aspects and knowledge that allows the implementation of technology in everyday economic processes.

Research on the development of renewable energy provides evidence that institutional and regulatory solutions are a superior factor in relation to economic and management factors of companies [11]. Institutional and regulatory arrangements play a key role in the development of renewable energy as they provide a favorable and predictable environment for companies to invest in renewable energy technologies and projects. A special role is played by numerous international energy policies that determine the policies of individual governments and accelerate the implementation of sustainable technologies [12]. The vast majority of research on renewable energy adoption focuses on energy policy analysis [13–16]. Potential benefits from the implementation of energy innovations are long-term; they can ensure, for example, energy security, sustainable development and increased use of local resources [17]. Governments are aware of these benefits and combine energy planning with economic planning. By diversifying their energy supplies, they can strategically reduce dependence on imported fuels and create new domestic markets. Governments are creating plans for the development of national renewable energy in order to meet global requirements at the national level and create a regulatory framework for the implementation of environmentally friendly technologies.

The literature specifies examples of various market barriers to the implementation of renewable energy technologies [18]. One of them is insufficient knowledge and lack of information about technologies that should be widely available. Another barrier is the financial risk, which is associated with a long return on investment and a high entry threshold. This is particularly difficult in the case of limited financial possibilities, when relatively poor regions and their inhabitants will less often decide to implement new and expensive technologies. Inappropriate regulations may also be a barrier, especially energy policies that are outdated relative to new conditions and often support traditional technologies. What are also associated with barriers related to technology are outdated infrastructure and deficiencies in the field of technological know-how. Barriers resulting from socio-economic conditions are also an important issue. The most common ones are limited funding opportunities, market uncertainty, weak institutional support, internationalization challenges and market-driven technology development [9,19].

Energy technologies require a well-defined energy policy, simplified standards, qualified staff and a large number of existing leading examples to lead the way for others to ensure their widespread deployment [20]. Since renewable energy sources are diverse and the technology diffusion process is multi-faceted and complex, scientists are considering various specific renewable energy technologies, for instance: photovoltaics [21], solar collectors [22], biogas [23] and wind energy [24]. However, in order to gain a holistic view of energy structures, the study focuses on a multi-dimensional approach to present socio-economic and regulatory barriers to the diffusion of different technologies, which is in line with the methods previously used in the literature, which serves as an overview of the entire renewable energy industry, rather than focusing on a specific technology [9,17,25,26].

The creation and diffusion of energy technologies requires the involvement of the entire innovation system. It is a multi-dimensional approach where, in addition to the policy framework and the activities of the system actors, the acceptance of the technology and the market pull effect are important key factors for the successful adoption of innovations in the field of sustainable energy [27]. The level of social awareness and knowledge of the wider context of implementing ecological technologies help to build bottom-up initiatives aimed at improving the overall quality of life. At this level, social relations, strengthened by various types of formal and informal organizations, become a carrier of knowledge and accelerate the acceptance of innovative solutions. High ecological social awareness also forces producers to apply a policy of socially and ecologically responsible business.

The combination of spatial planning and renewable energies is of great importance, both academically and politically [28]. The article aims to broaden our understanding of the relationship between spatial conditions and renewable energy investments. Its purpose is to analyze the types of renewable energy systems and to determine how social and economic factors influence the development of investments in renewable energy.

2.2. Local Innovation Systems and the Development of Renewable Energy

The phenomenon of processes of innovation and its meaning to widely acknowledged economic growth has been under scholarly debate since Schumpeter's (1960) idea of "creative destruction". Currently, the debate has come to an assumption that the systematic approach may be one of the most accurate ways to explain the phenomenon of innovation [29,30]. The systematic approach, or "systems of innovation", is commonly associated with evolutionary economics [31–33] and concentrates predominantly on territorially embedded institutional networks of actors that may support the creation and adoption of innovations within the market [31]. Embeddedness may be considered to happen on various territorial scales, starting from the national level, through the regions and ending in localities [34–39]. The concept of systems of innovation, no matter what the spatial scale, is built upon more or less similar assumptions and rules:

1. Innovation processes within the systems are characterized by a pronounced division of labor. Due to the division of labor, effective linkages between the "knowledge generators", "knowledge exploiters" and "knowledge transferring" institutions are of key importance for innovation processes [40].
2. The linkages appear to construct a large net of connections between various actors, who play different roles within the system. Some produce ideas or supply the market with a qualified labor force (universities and public or private R&D institutions) [41–43], some, such as small or medium sized enterprises, adapt and introduce the innovations to the markets [44], and some appear to be a linkage with other systems, playing the role of "gatekeepers" or "knowledge brokers" (scholars, corporations) [40,45].
3. The institutional embeddedness of the innovation system is created mainly by the cultural customs and traditions of the society [43]. Traditions and customs impact the way the policies for innovation are shaped within a territory, and they also affect the relations and interactions which occur within the network between the actors [46]. Both relations and interactions amongst the actors may be formal or informal, based on hard codified knowledge and legal mandatory communication channels, or via face-to-face contact, which includes verbal, physical, context-specific and uncodified knowledge transfers [40,47].

Innovation systems, as per the pointed-out rules and assumptions, may happen to be vastly differentiated, not only because of their territorial scale, but also by culture, customs, traditions, institutional embeddedness and history, as per "one size does not fit them all" [5]. Therefore, due to the cultural differences and key role of face-to-face uncodified knowledge transfers, it is thought that most of the innovation processes occur amongst the actors within the regions with connections to outside sources of knowledge [43,46,48].

The concept of a regional innovation system (RIS) consists of two main subsystems: firstly, a subsystem of knowledge generation and diffusion (universities, public and private R&D institutions, etc.) [49] and, secondly, a subsystem of knowledge application and exploitation which consists of enterprises and small and medium firms located regionally [36]. In the platonic case, all the actors within the subsystems engage in interactions in order to maintain the knowledge, resources and human capital in circulation amongst them [36,37]. The third important aspect of the RIS concept is the subsystem of regional policies, which is created by local authorities and could promote regional competitiveness by stimulating innovation clusters, linkages, smart specializations and the integration of localities within the region [5,38,39,50]. What is more, another role which is assigned to local or regional authorities is perceived to be the creation of the institutional background [5,37,51,52]. Actors such as regional governments (local councils, parliaments etc.) are capable of creating laws, regulations, declarations, etc., that may, in certain way, affect the formal and informal institutions which are considered to be highly significant in terms of knowledge transfers amongst the actors within the system [41,43,53,54]. In other terms, all the actors within the regional innovation system seem to be embedded in a territorial institutional network that could favor or deter innovation processes amongst them [31,55]. Such a network consists of both formal (laws, regulations) and informal (routines, habits, lifestyle, culture) institutions which are thought to key factors in shaping the relations and interactions amongst the actors, and which are, in fact, crucial for knowledge flow and innovation emergence [5,37,56]. The capacity of the regional network to act as a synergist depends on the institutional, relational and social combination of conditions within the system, better known as a "social filter" [31,57]. Therefore, the combination of previously mentioned factors seems to determine the areas where so-called "knowledge spillovers" happen [58,59]. "Knowledge spillovers" intermittently appear to occur more locally, which is thought to be often associated with the importance of informal relations amongst the actors [41,60]. Local networks based on mutual trust and understanding are fostering face-to-face communication and relations which allow the flow of the uncodified tacit knowledge. The knowledge which is passed face-to-face, usually verbally, leads to processes of collective learning, whether intended or unintended [47,61,62]. In these circumstances, it is thought that a set of actors, embedded locally in a certain institutional background, who interact with each other not only through official means, but also via face-to-face informal methods, is capable of creating so called "local buzz" [46,47,63]. "Local buzz" refers to the co-localization of individuals, firms, governmental structures, policies and laws, and their intensity of cooperation, which generates specific information and its constant updates. The generated information is usually the result of casual and purposeful interactions modeled by cultural traditions and institutional embeddedness [46]. The phenomenon of "local buzz" correlates with the previously mentioned "knowledge spillovers" due to the fact that all the knowledge generated within the buzz will, sooner or later, lead to the spillover of the knowledge to the exterior areas and actors within the region.

It has been widely agreed upon that areas within the regions do not develop in the same manner, which might be correlated to the concept of "local buzz" and local abilities of adoption and generation of innovation. On the other hand, regions are supposed to mobilize resources and institutions towards the development of local areas [64,65]. Therefore, localities are both affected by external (regional policies, flows of knowledge within the region, and regional actors) and internal innovation abilities (the buzz) [66]. Due to the above-mentioned facts, it is thought that regions are not consistent structures which have homogeneous institutions, culture and actors, but are, rather, a diverse spectrum of smaller cooperating cluster-like structures which are more or less capable of creating their own "local buzz" and generate "knowledge spillovers" [66,67]. Those cluster-like structures are systems within a system [68], and therefore could be called local innovation systems [69].

The local innovation system, in terms of theoretical structure, is very similar to the concept of the RIS [36]. It is also thought to be constituted by subsystems of knowledge generation and knowledge application and diffusion, which coexist in an institutional and cultural background which is shaped by local and regional laws and policies. Local innovation systems are based on "the generation of regionalized learning systems where some local innovation policies are activated to transfer technologies" [67] in order to act as "knowledge pipelines", connecting localities with the region and the world. A LIS is considered to be a cluster, or district-like structure, which is regarded as a place where institutional environment, close inter-firm communication, society and culture all encourage mutual education and learning processes, therefore creating continuous innovation [48]. Nonetheless, the concepts of clusters and RIS should not be amalgamated [68], even though they are similar, due to their geographical scale [70]. Regions, in fact, are simply "bigger" areas, combining significant amounts of clusters or districts, but those must not necessarily overlap [65]. Furthermore, a RIS is also defined by administrative borders of regions within a nation [68], which may not necessarily be the case in terms of a LIS.

Therefore, in order to define the bounds of the local innovation system, it is necessary to determine the word "local" itself. From the linguistic perspective, "local" as an adjective means "existing in or belonging to the area where a certain person lives, or to the area that is being talked about" [71]. In that case, it is possible to define a local innovation system, in terms of territory, as a system located in the nearest area from a point of view of a certain person, firm, or university, or, in other words, an actor. Such a definition implies that a LIS does not certainly have to be embedded within some artificially created administrative bounds, but rather in terms of an endogenic cultural and institutional background. That means, as long as there is so called "local buzz" occurring amongst the actors within a nearby area, the LIS's circumference could be shaped by either "cultural" or administrative borders of a county, city or borough itself, as long as those entities have, as previously mentioned, a complete set of factors necessary to create a functional innovation system.

2.3. Local Energy Systems

Nowadays, increasing demand for energy is bringing a great challenge for almost all the countries around the world. That, combined with climate instability caused primarily from reliance on fossil fuels [72,73], and the geopolitical situation, mainly in terms of countries dependent on importing energy carriers from others, is causing a major acceleration in a worldwide trend to shift energy supplies from centralized massive fossil-fueled power plants to localized interconnected individuals like households and firms, based on "green" technologies [74–77].

Due to the importance of sustainable energy transitions, scholars have come up with a considerable number of theoretical concepts. Some indicate that the localized energy system might be just a market with an evolving technological innovation system [78] within it, which slightly differs from other markets in terms of vulnerability to politics [79]. Others consider the energy system within the limits of a MLP (multi-level perspective) theoretical concept [80,81]. Nevertheless, both standpoints seem to be criticized by academics for not sufficiently addressing spatial issues, mainly due the energy conversions at the local level [82,83]. Therefore, in this paper, the local energy system is considered to be highly correlated to the earlier described local innovation system, due to its ability to explain localized processes within the energy transformations.

It is widely acknowledged that energy is a field which cannot be assigned to one place, but rather an interconnected system which allows power transfers from one area to another via dedicated infrastructure [77,79] known as the power grid. Therefore, actors and institutions at numerous levels have to interact in order to create and introduce energy innovations [84]. Thus, the local innovation system, with the assumption of having interconnections with regional and national innovation systems, seems to ideally combine the concepts of systematic innovation, MLP and market TIS in terms of sustainable energy transitions in localities, or, in other words, the emergence of local energy systems.

Local sustainable energy transitions are predominantly bound with innovative technologies which can source energy from the sun, wind, water, tides, the earth and biomass [79,85]. Those technologies can be applied both by individuals such as households and firms within the localities and centralized, usually state co-owned, energy suppliers [85]. Thus, the innovation processes within the local systems seem to be of crucial importance in terms of the creation and diffusion of the sustainable energy technologies and appliances.

As in any innovation system, it is important that a certain set of actors should be co-localized within the same area, institutions and cultural practices [5,86] in order to create "local buzz" [46,47,63] and "knowledge spillovers" [29,67].

Innovations related to energy transitions, just like other innovations, are most likely developed by local subsystems of knowledge generation and diffusion [36,37,86]. Thus, local actors like universities, public and private R&D organizations, human capital or knowledge transfer institutions cooperate in order to generate sustainable energy innovations.

On the other hand, energy innovations also need a subsystem of knowledge application and exploitation [36,37,86], where the energy-related knowledge generated by universities etc., is adapted within the local market, which implies the importance of the role played by enterprises and households themselves [87].

Both the knowledge generation and knowledge utilization subsystems, just as in innovation systems, are affected by a subsystem of politics, law and policy. Regional and local development strategies are usually a central driver for the innovation processes within certain areas. Strategies may involve plans for infrastructure development, energy innovation funding for both households and firms, financial support for the knowledge generation subsystem in terms of energy innovations, etc. [81,83,86,88];

In the ideal case, all the actors within the system should constantly circulate resources and knowledge amongst themselves via relations and mutual interactions [5,36,37,86] which are shaped by informal and formal institutions [82,83]. This, in fact, means that so-called "local buzz" [46,47,63] within a locality, in terms of sustainable energy transitions, is dependent on both official and face-to-face means of communication, as well as on mutual trust amongst the actors and, most importantly, regular citizens [89,90].

Furthermore, cultural background is also of key importance for local energy systems, as communication amongst the actors is shaped by specific socio-institutional patterns of behavior, for instance, values, routines, culture of cooperation, attitudes etc. [37,90]. Thus, the development of energy innovations due to society's attitude to sustainable energy within a locality might be significantly different than that in other spatial levels or areas [83,86,91].

Interaction and relation-building, and, later, knowledge transfers, not only appear locally, but also take place globally. Knowledge spillovers in one place within a region, country or the world, may be transferred to localities via actors known as gate-keepers [40,92], who, due to their capacity to maintain relations with the outside world, are capable of transferring energy innovations in and out of the local cluster.

Consequently, the diffusion and application of innovative sustainable energy appliances by the system's actors transfer the means of energy production from centralized state co-owned energy enterprises to local entities (regular households and local firms) [93]. The ability to create their own electricity gives a major energy independence to the local communities, from the region, country and the world, especially when the energy is created from renewable sources [85].

Nevertheless, the power grid still plays an important role, as it interconnects local clusters with other areas, and therefore acts like "local-global pipelines" [92], allowing overproduced energy to be transferred elsewhere, but also, in times of need, to be transferred back from outside [94].

3. Materials and Methods

In order to analyze innovative energy systems in local governments, in diverse ecosystems, we applied the conceptual framework of regional innovation systems. Economic capital, together with knowledge and relationship (network) capital, are the key elements that allow us to explain the mechanism of development of local energy systems based on renewable energy sources. In the system, flows of knowledge and energy technologies are the result of policies and informal rules within organizations and local communities. The energy system in the structure of local innovation systems can be represented by two subsystems, embedded in a common institutional socio-economic and political environment [36].

Local authorities implement goals aimed at meeting the energy needs of residents, enterprises and public utility facilities such as schools, kindergartens, offices, sports halls, swimming pools, etc. They also deal with shaping public space, including low-emission transport and transmission networks. The first subsystem is the system of application and exploitation of energy technologies, which consists of the infrastructure of the public sector as well as households, entrepreneurs, the natural environment and social infrastructure. Within the system, we distinguish technologies of energy production and transmission as well as energy recipients. Currently, energy systems are characterized by a high degree of diversification. In addition to traditional centralized production centers, there is an increase in the importance of small- and medium-sized energy producers that use renewable sources and technologies, such as wind turbines, photovoltaics, heat pumps, biogas plants and biomass. This creates a multi-element system rooted in the innovation system that provides new technologies and knowledge of how to build independent local energy systems based on local resources.

The second subsystem is the system of knowledge institutions, which include research centers, universities, business environment institutions, organizations intermediating in technology transfer (technology licensing offices, innovation centers, research centers, etc.), educational institutions (universities, polytechnics, vocational training institutions, etc.) and organizations intermediating in employment and business contacts (associations of entrepreneurs, economic self-government, labor market institutions). Due to the local nature of the discussed systems, it should be noted that the availability of knowledge infrastructure is spatially differentiated. Not all local governments are equipped with knowledge creation infrastructure in the form of universities or research units. Therefore, innovation brokers are of key importance for such entities. They function in a network of relations that arise within innovation systems. Cooperation complements knowledge deficits and allows the use of innovative solutions used in the surroundings.

A key element of the system is the policy dimension. Political actors at this level can play an important role in sustainable local development, provided there is sufficient local autonomy (legal competences and financial resources) to formulate and implement energy and innovation policy [95]. An efficient and effective system means that the relationships within and between subsystems facilitate transfers of energy technologies and usable energy. In practice, however, there are noticeable deficits in such systems in relation to organizations and institutions, and poorly developed relational mechanisms within and between subsystems. In this study, we refer to the concept of the regional innovation system and its subsystems. We assume that the central point of creating and managing the energy sector is the local government rooted in the innovation system (Figure 2).

Combined, the subsystems create a technology-transfer mechanism which, due to being a dynamic system, strives for the development of the energy sector and sustainable development. In this context, it was assumed that three categories of capital—economic capital, relational capital and scientific and research capital—support the functioning of the energy system, which is created by energy producers and consumers. In the diagram, the overlapping spheres indicate the links between the elements of the subsystems on a local and regional basis. In this study, at first, we operationalized the potentials of the capitals based on empirical indicators, and then conducted an analysis for counties in Poland to determine the typology of energy systems and their spatial distribution.

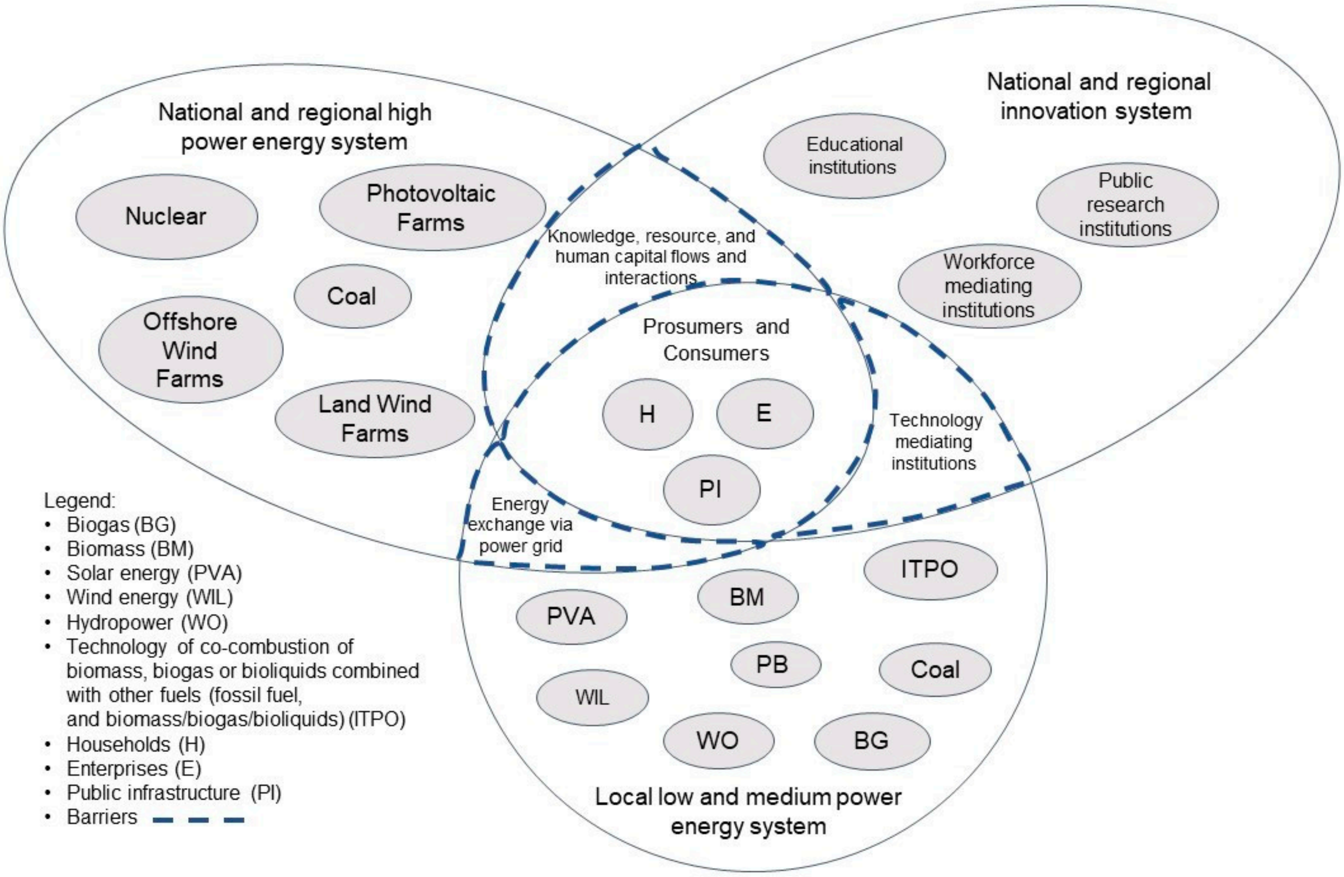

Figure 2. A conceptual approach to a local energy system (LES). Source: Own study.

In this section, we have proposed a new theoretical framework resulting from the combination of the concepts of energy systems and systems of innovation. This is the starting point for further analysis in this article. The main feature of the proposed framework is the combination of the mechanisms of the two systems in order to accelerate the processes of implementing energy technologies in local systems. What distinguishes this approach from those previously used in the literature is the peek at local systems through the prism of their potentials, which are diverse and require separate local development policies combining the energy systems and innovation systems and the energy market. In connection with the above, we highlight three areas of barriers. The first one is at the junction of the innovation system, the local energy system and the local energy market, where deficits may appear due to the lack of technology-transfer institutions. These are most often systemic and regulatory deficiencies resulting from the lack of an appropriate regional policy for the implementation of innovations and technologies. The second area, which arises at the junction of innovation systems and the national energy system, covers problems with the creation of innovative energy technologies in a given area, the creation of which may supply the local market of prosumers and energy consumers. Creating breakthrough innovations in the field of energy requires an integrated policy of financing research institutions and universities under R&D programs and various initiatives that connect the science sector with the energy production sector. The third area integrates various systems of energy producers and consumers. The development of inter-local power grids based on renewable energy may encounter various barriers. These are high investment costs, problems with power supply during periods of lack of wind or sun, lack of technological standards, lack of transmission infrastructure, and a problem with energy storage. Due to the above barriers, the implementation of inter-local power grids requires cooperation between various sectors and institutions, as well as support from the government through, for example, regulatory and financial policies.

Measuring Conditions for Energy Systems in the Public Sector

An innovative energy system is described by various types of renewable energy sources (RES). The renewable-energy-generation potential in the region depends mainly on the capacity of generation installations based on renewable sources [26]. In order to better understand this phenomenon, the below-listed statistical data on the regional capacity of installations dedicated to the generation of renewable energy were collected:

- Biogas (BG);
- Biomass (BM);
- Solar energy (PVA);
- Wind energy (WIL);
- Hydropower (WO);
- Technology of co-combustion of biomass, biogas or bioliquids combined with other fuels (fossil fuels and biomass/biogas/bioliquids) (ITPO).

To assess the conditions for the development of innovative energy systems in counties of Poland, we used 12 indicators, each representing one of the three capitals—economic, scientific and research— and social (relational) and energy demand (Table 1). The concept of regional innovation systems describes the mechanisms that are the cause of innovation in regions. The concept uses institutional mechanisms and social relations that determine the method of operationalization of its basic components. The area adopted for the construction of the model covers 380 counties (powiaty) in Poland at the NUTS4 statistical classification level. NUTS4, also known as "Nomenclature of Territorial Units for Statistics Level 4", classifies the fourth level of European subdivisions in order to standardize and facilitate statistical analyses. It includes the smallest administrative units, such as counties, districts, or regions.

The values of individual capitals were used to develop a typology of Polish counties, which was conducted with the use of the k-means classification method. When selecting indicators, the assumptions of the concept of innovation systems and its institutional, social and technological dimensions were taken into account. The statistical data had been standardized and then grouped, which made it possible to obtain synthetic indicators for each capital. Due to the purpose of the research, which was to determine the potentials of counties and spatial regimes, the same weights of model indicators were used. The process of preparing the typology of counties in terms of the energy potentials included the implementation of the following actions: determination of capitals; selection of empirical features; standardization of variables; calculation of the zero sum of unitarization for capitals; grouping of units of the surveyed population by capital groups; and assessment of the durability of the indicator structure (k-means classification).

The level of capitals were assessed using the method of linear ordering of standardized total data. The procedure starts with standardization by normalizing one-dimensional variables according to the following formula:

$$x'_{ij} = \frac{x_{ij} - x_{minj}}{x_{maxj} - x_{minj}} \times 100 \quad (1)$$

where:

j is the next feature number,
i is the next spatial unit number,
x'_{ij} is the normalized feature j in spatial unit i,
x_{ij} is the the value of feature j in spatial unit i.

If the nature of the variable is different, e.g., destimulants or nominants, the stimulant substitution procedure should be used:

$$x'_{ij} = \frac{x_{maxj} - x_{ij}}{x_{maxj} - x_{minj}} \times 100 \quad (2)$$

Table 1. Indicators used for the analysis of development of innovative energy systems in Poland.

Capital	Indicator	Characteristic	Year	Source
Local Wealth	X1 PIT per capita	Value of personal income tax in PLN per 1 inhabitant	2021	BDL GUS
	X2 CIT per capita	Value of corporate income tax in PLN per 1 inhabitant	2021	BDL GUS
	X3 Gross value of fixed assets per capita	Gross value of fixed assets in enterprises per 1 inhabitant	2021	BDL GUS
Social Capital (relational)	X4 Business enviroment institutions	Business environment institutions per 10,000 entities of the national economy	2021	BDL GUS
	X5 Foundations, associations and social organizations	Share of foundations, associations and social organizations in the total number of entities of the national economy	2021	BDL GUS
	X6 Senior social participation	Share of people who are members of senior clubs or sections and Universities of the Third Age in the total population aged 70 and more	2021	BDL GUS
Scientific and Research Capital	X7 Patents granted by UPRP	Patents granted by the Polish Patent Office per 100,000 inhabitants	2021	BDL GUS
	X8 University graduates	University graduates in total per 10,000 inhabitants in 2021	2021	BDL GUS
	X9 Foreign capital	Foreign capital per working age inhabitant	2021	BDL GUS
Energy Demand	X10 Electricity consumption	Electricity consumption per capita in kWh	2021	BDL GUS
	X11 Heating energy	Sales of heating energy for residential buildings, offices and institutions per 1 inhabitant in GJ	2021	BDL GUS

4. Results

For easier interpretation, the indicators have been grouped into four clusters (Table 2), which are the components of the model. The k-means algorithm is a clustering technique widely used in numerous studies to classify input data into k-clusters. The neighborhood-based clustering method is a partitioning algorithm that aims to divide the data into several clusters, where each observation belongs to only one group. The data are divided in such a way that the degree of similarity between two data cases is maximal if they belong to the same group and minimal if they do not [96]. The selection of the best clustering model is carried out by comparing the statistical parameters presented in Table 3. The first column shows the number of clusters generated. The next column, N, shows the sample size. R squared indicates the amount of variance explained by the model. The AIC is a value which estimates the quantity of information lost in representing data with a model, compared to other models; lower values represent better clustering outputs [97]. The BIC or Bayesian Information Criterion is a method for scoring and selecting a model, where lower values represent better clustering outputs [98]. Both AIC and BIC are metrics that measure the relative prediction errors of different models. The lower the value, the better the model. The Gaussian Mixture Model AIC and BIC scores can help us decide the optimal number of clusters. The Silhouette refers to a method of interpretation and validation of consistency within clusters of data. The Silhouette value is a measure of how similar an object is to other clusters, and ranges from −1 to 1, where 1 represents a perfect score [99]. The comparison of the obtained parameters shows that the model with four clusters is the best possible variant.

Table 2. Cluster information.

Cluster	1	2	3	4
Size	55	199	95	31
Explained proportion within-cluster heterogeneity	0.050	0.372	0.226	0.353
Within sum of squares	20,823.711	154,851.425	93,947.330	146,898.824
Silhouette score	0.442	0.429	0.012	0.122
Center Biomass (BM)	0.417	0.821	0.488	0.021
Center Solar Energy (PVA)	5.327	1.300	8.625	8.604
Center Hydropower (WO)	0.840	0.442	2.313	0.611
Center Wind Energy (WIL)	34.093	0.612	3.885	103.737
Center Biogas (BG)	0.498	0.450	0.603	1.384
Center Co-combustion of (BG, BM) with other fossil fuels (ITPO)	0.000	0.116	0.273	0.000

Note. The Between Sum of Squares of the four-cluster model is 321,533.34; Note: The Total Sum of Squares of the four-cluster model is 738,054.63.

Table 3. K-medians clustering.

Clusters	N	R^2	AIC	BIC	Silhouette
4	380	0.436	416,569.290	416,663.850	0.300

Note. The variables in the model are unstandardized.

Tables 4 and 5, Cluster means and Evaluation metrics, contains the basic parameters of the model. The maximum cluster diameter in Euclidean distance is 261.065. Minimum separation: The minimum cluster separation in Euclidean distance is 0.920. Pearson's γ: The correlation between distances and a 0–1-vector is 0.316, where 0 means the same cluster and 1 means different clusters. Dunn index: The minimum separation/maximum diameter is 0.004. Entropy: The entropy (Figure 3) of the distribution of cluster memberships is 1.170. Calinski-Harabasz index: The variance ratio criterion of the cluster memberships is 143.000.

Table 4. Cluster means.

Clusters	Biomass (BM)	Solar Energy (PVA)	Hydropower (WO)	Wind Energy (WIL)	Biogas (BG)	Co-Combustion of (BG, BM) with Other Fossil Fuels
Cluster 1	0.382	6.910	1.244	40.877	0.785	0.000
Cluster 2	6.026	1.487	0.787	0.700	0.596	0.739
Cluster 3	0.284	9.110	7.876	5.923	0.675	0.240
Cluster 4	0.054	4.898	0.554	126.088	1.010	0.000

Table 5. Evaluation metrics.

	Value
Maximum diameter	261.07
Minimum separation	0.920
Pearson's γ	0.316
Dunn index	0.004
Entropy	1.170
Calinski-Harabasz index	143.000

Note. All metrics are based on the Euclidean distance.

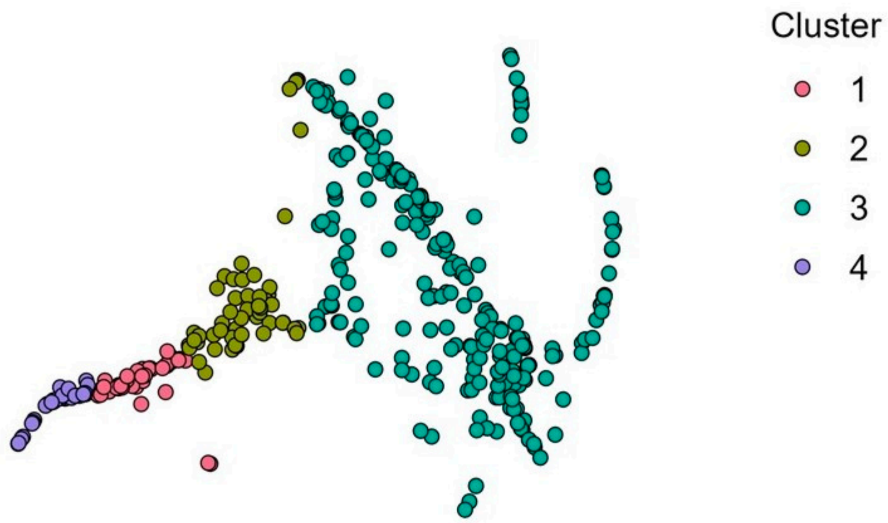

Figure 3. t-SNE Cluster Plot. Source: own calculations.

Each type of region can be described according to the existing level of capitals. In order to specify the structure of each type, the value of a capital of a given type was determined and an appropriate symbol was assigned to it, which facilitated the interpretation of the obtained results. The value of the capital was estimated in relation to the mean M and standard deviation SD of the entire study population in accordance with the following classification:

$$\begin{gathered} M' > M + 0.3SD \text{ veryhigh } (+++ +), \\ M' > M + 0.1SD \text{ high } (++), \\ M' > M - 0.1SD \text{ medium } (\sim \sim\sim), \\ M' > M - 0.3SD \text{ low } (--), \\ M' < M - 0.3SD \text{ verylow } (- - --), \end{gathered} \tag{3}$$

where:

M'—average capital value for a type,
M—average capital value for the entire set,
SD—standard deviation for the entire set.

After applying the above formula, we obtained a matrix of assessments of individual capitals. A high level of capital value balance occurs when comparable high values of all capitals are obtained, which differ from each other only by one class. On the other hand, an unbalanced type occurs in a situation of high disproportion in the assessment of at least one of the capitals in relation to the others (Figure 4).

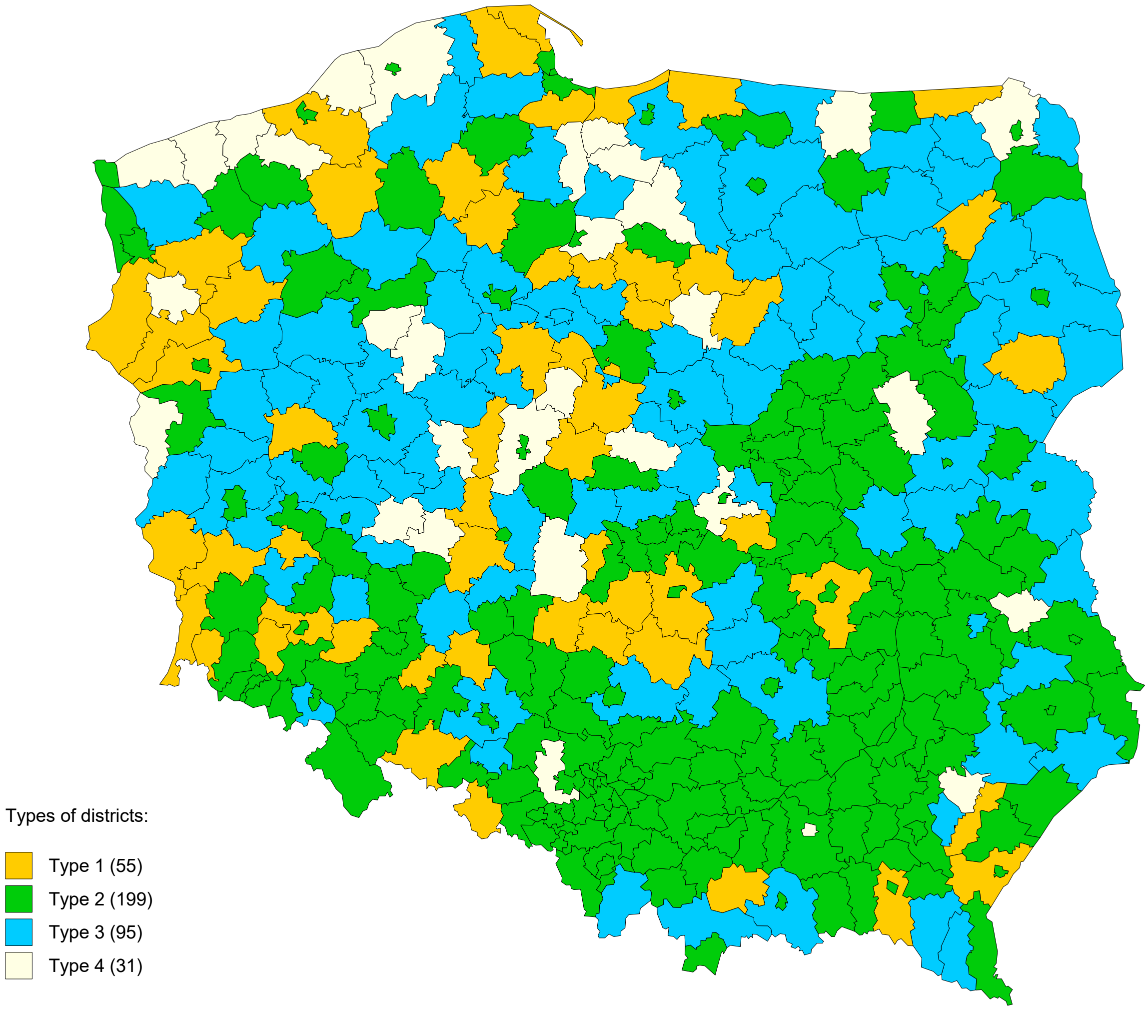

Figure 4. Spatial distribution of districts according to outlined types in Poland in 2021.

Local Innovation Energy System

The counties were grouped into four clusters using the k-means cluster analysis algorithm. The result tables of the profiles present data on both the location of the center of gravity of individual types, as well as symbols for numerical values. Table 6 shows the potential of economic, social (relational), scientific and research capitals and energy demand in Poland in terms of structure. In total, 380 counties at the NUTS4 level were included in the study. The conducted research shows that the largest group is type 2, which represents 199 counties and covers about 52% of the examined region. Type 2 clusters consist of counties which can be identified as developed in terms of the analyzed capitals. Those counties are predominantly located in south and central Poland, mainly around major population centers such as Warsaw, Wroclaw, Krakow or the Silesian agglomeration. Type 1 clusters are a group of counties with very low capital values in almost all categories, consisting of 55 counties which cover up to 14.5% of all analyzed entities. Type 1 counties are mostly located in the west of the country, in the areas with relatively low population density. Type 3 clusters are counties which have developed quite strong relational capital, with a potential to foster other analyzed types of capitals, which can be considered rather average in comparison with the remaining parts of the country. This type includes 95 counties, which makes it the second largest group, with a share of precisely 25%. Those counties are located principally in central and northeastern Poland, usually right next to Type 2 areas. Finally, Type 4 clusters, which are the smallest group, include only a little over 8% of all the counties. This type can be referred to as slightly below average in terms of all analyzed capitals. Having relational capital, in particular, being just average, those counties are slightly better developed, in terms of analyzed capitals, than Type 1 clusters.

Table 6. Mean value of indicators for the clusters.

Capital	Indicator	Type			
		1	2	3	4
		Mean Value of Indicators for the Clusters			
Local Wealth	X1 PIT per capita in PLN	247.33 −− *	731.36 ++	293.91 −−	276.31 −−
	X2 CIT per capita in PLN	12.77 −−	59.80 +	18.57 −	15.66 −
	X3 Gross value of fixed assets per capita in PLN	43,796.09 ~	54,025.18 +	38,451.24 −	44,700.23 ~
Social Capital (relational)	X4 Business enviroment institutions	790.96 ~	772.79 ~	706.72 −	763.94 ~
	X5 Foundations, associations and social organizations	3.68% ~	3.46% −	3.9% ++	3.65% ~
	X6 Senior social participation	2.25% ~	2.1% ~	2.56% +	2.14% ~
Scientific and Research Capital	X7 Patents granted by UPRP	1.64 −	5.55 +	2.79 −	1.77 −
	X8 University graduates per 10,000 inhabitants in 2021	3.85 −−	43.48 +	15 −	7.88 −
	X9 Foreign capital in PLN per capita	2260.02 −	4475.55 +	2180.6 −	2857.74 ~
Energy Demand	X10 Electricity consumption in kWh per capita	792.69 −	805.86 ~	822.44 +	793.74 −
	X11 Heating energy in GJ	2.6 −−	4.91 +	2.72 −−	2.88 −
	X12 Gas energy—% of population using gas network	35.98% −−	54.79% ++	33.98% −−	38.5% −

K-means clustering description: k = 4, item = 10, sum squared error (SSE) = 12.13355174. * symbol description of standardized value of centroids: ++ very high (>$M + 0.3SD$), + high (>$M + 0.1SD$), ~ medium (> $M - 0.1SD$), − low (>$M - 0.3SD$), −− very low (<$M - 0.3SD$).

The obtained results for the energy systems in the counties may be linked with the presence of reneweble energy sources in the regions, such as wind, agricultural biomass or water energy potential. The wealth of households is also an important factor which determinies individual investments in photovoltaic installations and heat pumps. Cooperatively, both issues construct a diverse picture of the structures of energy systems based on renewable energy throughout the country of Poland. The statistical classification algorithm made it possible to distinguish four types of clusters.

Type 1. **Sustainable renewable energy potential**. (Tables 6 and 7) This is a type with a balanced and diversified renewable energy production potential. This type is dominated by photovoltaic installations for processing solar energy, but also wind farms and hydroelectric power plants. Counties are usually located in the vicinity of large and medium-sized cities. Clusters have low or very low capitals in terms of economy, relations, research and science and energy demand, and consist mainly of areas with low population density. Type 1 is dominated by sparsely located societies, which can be characterised by low income and low entrepreneurial activities with relatively small energy demand. What is more, this type also features rather average quality of social relations, which may be caused by the previously mentioned low population density. Due to lack of population centres, type 1 counties have no academic institutions and therefore potential research activities are very limited. On the other hand, the average value of the relational capital allows a very limited diffusion of knowledge and innovation, which in terms of the energy market, may affect decisions based on the experience of other market participants, thus allowing the spread of innovative energy technologies.

Table 7. Energy system power [MW].

Clusters	1	2	3	4	Total
Wind Energy (WIL)	2248	139	563	3909	**6859**
Solar Energy (PVA)	380	296	865	152	**1693**
Biomas (BM)	21	1199	27	2	**1249**
Hydropower (WO)	68	157	748	17	**990**
Biogas (BG)	43	119	64	31	**257**
Co-combustion of (BG, BM) with other fossil fuels	0	147	23	0	**170**
Total	**2760**	**2057**	**2290**	**4111**	

Type 2. **Biomass energy potential**. (Tables 6 and 7) This is a type where the major role of reneweble energy potential lies largly in biomass of agricultural origin, which is predominantly used for combustion and co-combustion. Other sources of reneweble energy are of less importance in the energy mix. This type predominantly consists of the counties which could be considered to be agricultural. Clusters have very high or high economic capital, scientific capital and energy demand rather average relational capital. This type of cluster is the one most often occurring in Poland, with 199 counties, which is just over 52% of all entities. These counties can be mainly found in the south of the country and around major centres of population such as cities on the Baltic coast (Szczecin, Koszalin, Słupsk, Gdynia, Gdańsk) or the southern agglomerations of Silesia, Lower Silesia, Lesser Poland and Warsaw. Population density is perhaps not the only factor for localization of this type of clusters. Areas of appearance of type 2 clusters are also highly correlated with areas where most of industry and entrepreneurial activities take place in the country. Thus, very high or high scores for this cluster in terms of economical capital could be easily explained by business and work opportunities which occur in industrial areas. What is more, the main cities with intense economies usually tend to have academic structures within them, which is typical for Poland, as some of the counties of type 2 are also homes for most Polish universities and other third-level educational institutions. Therefore, type 2 clusters tend to have a very influential scientific and research capital, with by far the most university graduates per 10,000 inhabitants, patents granted and foreign investments per capita when compared with other types of clusters. With "big" business comes great power demand; therefore, high values of indicators in fields of energy demand should be not surprising, as businesses, especially advanced, tend to be very dependent on power supply. Type 2 clusters may not have the highest average power consumption, but seem to have almost twice as high sales of heating energy and usage of the gas network when compared with other types of clusters. Thus, high energy demand, combined with the capacity of the remaining analyzed capitals may lead to creation of local powerhouses of innovative energy technologies and their generation and diffusion. Type 2 counties could be considered as areas of knowledge spillover and pioneers for energy individualization, from which other clusters could transfer energy technologies and ideas in order to utilize them for their own purposes.

Type 3. **Photovoltaic and water energy potential.** (Tables 6 and 7) This is a type with a dominant role of sun and water in terms of electricity production, which mainly occurs with the use of individual or commercial photovoltaic installations. Counties of this type are generally located in regions with access to bodies of water, lake districts or river networks. Clusters have visible advantages in terms of relational capital. This type features high or very high relational capital, on average wealthier society, better science and research capital than types 1 and 4, and the highest energy consumption per capita, but also the lowest share of population having access to the gas network. This type consists of 95 counties unevenly spread throughout the country, with visibly more located in the north than the south. Due to high or very high score in relational capital, this type has an ideal background for the diffusion of innovative technologies, especially if electricity usage is taken into consideration. The highest electricity demand, combined with well-performing relational capital and weak accessibility to the gas network, allows efficient diffusion of energy innovations amongst the local societies, which could be easily proven by the fact that most of the renewable energy in Poland is being produced in the windfarms in the north of the country

Type 4. **Wind and biogas energy potential.** (Tables 6 and 7) This is a type with a dominant role of wind energy, where the renewable energy is created mostly in windfarms. This type also has a high potential for biogas production. Counties are usually located in windy zones, the coastal belt and lowlands. Biogas plants are mainly distriubuted in the neighbourhood of large farmlands where it is simplier to gain access to necessary supplies such as waste from animals or agricultural production. Clusters have low capitals in terms of economy, research and science, and average relational capital with low energy demand. This type consists of 31 counties which are located mainly in the central and northern parts of Poland, most significantly on the coast of the Baltic sea. This type is very similar to type 1, but rather wealthier, with higher entrepreneurial activity of local societies and more financial support from abroad. Type 4 also has low science and research capital in comparison to other types, but is still better than Type 1, which may be explained by the existence of some medium-sized cities within the counties, hence centres of population, thus academic facilities. Low energy consumption (higher than type 1), is very likely a derivative of tourism, which especially occurs during the summer months on the Baltic coast. With the excessive amount of tourists comes higher energy demand in local businesses such as restaurants, hotels, etc. This type is also characterized by the average value of relational capital, which, in fact, on average, is slightly worse than that of type 1, but still good enough to allow limited diffusion of knowledge and innovation, which, combined with the energy demand in these counties, may be the catalyst for innovative energy technologies.

The research shows that Poland has various structures of energy systems based on renewable energy sources, which are conditioned on the availability of renewable energy sources in the regions and access to capital, which affects individual investments in photovoltaic installations and heat pumps. The four types of energy clusters in Poland differ from each other in the types of energy sources, availability of knowledge capital, and location. In Poland, a significant portion of the regions have a low capacity for research and innovation in the field of renewable energy. The innovative potential is concentrated mainly in academic cities with access to knowledge and innovation. Therefore, an important conclusion can be drawn that Poland has the capacity to develop and improve its energy system based on renewable energy sources, but this requires a balanced approach to investment in energy sources, developing research and innovation, and improving the ability to transfer knowledge and innovation between different regions.

5. Discussion

The conducted research shows that there are four different types of renewable energy systems in Poland. They are made up of structures based on the production of energy from the sun, wind and water, as well as biomass combustion and gasification. Each type has different social, environmental and economic characteristics. The specificity of innovations and energy technologies, as well as the preconditions for their implementation, confirm the thesis that one universal policy of their development and implementation in regions cannot be applied [5]. Clusters also differ in terms of energy power and capacity of energy production. The highest energy power is possessed by systems dominated by wind farm technologies and photovoltaic technologies. These are strategic technologies whose development may significantly increase the country's energy security. At the same time, the development of such systems is severely limited due to the atmospheric conditions. Locations of renewable energy production which are mainly in northern Poland are geographically distant from highly urbanized areas in the south of the country. The consequence of this is a strong concentration, which results in large disproportions in energy production throughout the country and indicates the need to build and maintain transmission networks and overcome barriers to connection capacity.

The barriers indicated in this study partly overlap with those indicated in the previous research, but are also unique. The majority of the other research states that the most critical barriers to decentralized renewable energy systems are: inappropriateness of technology; unavailability of skilled manpower for maintenance; unavailability of spare parts; high cost; lack of access to credit; poor purchasing power and other spending priorities; unfair energy pricing; lack of information or awareness; and lack of adequate training on operation and maintenance [100]. All of these are of high importance; nevertheless, this article indicates additional barriers from the point of view of the combination of energy and innovation systems, such as problems with the development of inter-local power transitions, which require significant investments, and involve problems with power supply due to unpredictable atmospheric conditions or problems with energy storage.

Other research indicates that the two most important categories of barriers include economic aspects and policy and political factors [101], which indeed seem to be essential for the development of renewable energy, as demonstrated in this article, which indicates policy and public sector involvement as one of the most crucial factors for the development of renewable energy sources. The authors of [101] achieved quite similar conclusions to those exposed in this article using the AHP methodology.

Eleftheriadis and Anagnostopoulou indicate the most similar point of view on barriers to local renewable energy systems. Their research points out that inadequate financial resources, low grid capacity, delays in the issuance of building permits, opposition from local communities to the construction of wind farms and the lack of a stable institutional framework are among the most important barriers [102].

Previous research and that conducted in this article seem to come to essentially similar conclusions, exposing policy and political factors has having a key importance to renewable energy diffusion within localities [100–102]. The barriers that energy systems have to face are regulations and political programs. The complexity of legal and formal procedures, as well as systematic changes in the regulatory framework, are perceived by investors and local governments as a destabilizing factor that increases investment risk. Nevertheless, it is important not to underestimate the significance of economic factors as shown in [100], which could also be supported by remedial measures such as long-term conducive policies, an appropriate regulatory framework, financial incentives (capital subsidies and soft loans) to users, technology and skill development, internalization of externalities in the cost of energy, withdrawal of subsidies presently being given to fossil fuels, development of specialized institutions, cooperation with international agencies, participation of the local community and awareness generation [100].

Research has shown that there are similarities between energy systems in some socio-economic categories. An example is visible in balanced access to business environment institutions, to which there is similar access in all types of clusters. What differentiates the types is the existence of foundations and social organizations. Areas with a relatively low population density are commonly dominated by single-family housing, in which photovoltaic technologies with a high degree of dispersion are more often used. The process of implementing these technologies is largely dependent on the knowledge about these technologies; therefore, relational capital plays a key role in their development. Practical knowledge on the use of innovative energy technologies, transferred through social networks, is an effective form of energy education.

In the case of systems based on biomass technology, demographic conditions and high concentration of population in urban areas play an important role. In this case, centralized biomass combustion or co-combustion plants play an important role, from which heat is then transferred to households by means of district heating networks. The domination of multi-family housing limits the possibility of using photovoltaics, which requires sunny areas, which are relatively scarce in highly urbanized entities. Multi-family and multi-story houses also have a high energy demand and low exposure to sunlight, therefore causing the main barrier for the development of such systems.

The level of social awareness is very important in the case of innovations that are to reach a mass audience [102]. Mind maps of perceiving new, sometimes difficult-to-understand, solutions are shaped at different levels and by different actors. Innovation systems can play an important role in this area due to their relational potential, social rooting and political and institutional dimension. Education, research, financial support, and investments in transmission networks combined constitute a catalyst for the processes of diffusion of energy innovations. The role of innovation systems is therefore not to create radical discoveries that revolutionize the energy market, but to stimulate a wide diffusion and intelligent adaptation in a diverse and changing local and institutional conditions. The challenge for innovation systems in the field of energy is not only to overcome the deficits of technological knowledge and information on the impact of renewable energy on the economy and the environment, but also in various social areas.

6. Conclusions

The thesis was confirmed that the key factors determining the diffusion of energy technologies are regulations and policies. The political sector seems to have the most significant impact on the regional development of the energy sector in Poland. In the control report of activities carried out in Poland for renewable energy, it was indicated that, currently, the main barriers related to the development of renewable energy include limited possibilities of financing investments by entrepreneurs, legal support regulations, administrative and procedural difficulties, and problems with the functioning of transmission networks [103].

The development of energy systems will be possible if they are connected with systems of innovation. The linkage of the two systems will mean the adoption of key mechanisms and dependencies for innovation systems within the energy systems. Building on previous research and innovation system theoretical frameworks, we believe that, as with many technologies and innovations, regulation and policy will play a key role. At the same time, we do not underestimate the role of other factors. The government can promote the adoption of renewable energy by providing favorable policies, regulations and incentives that encourage companies to invest in renewable energy. Therefore, apart from economic and management factors, institutional and regulatory solutions are of key importance for the development of renewable energy. This is confirmed by the results of the analysis of local wealth indicators (Table 6), which obtained similar low or moderate values in each of the examined types. It can therefore be assumed that the local economic factor does not differentiate the development of renewable energy.

The conducted research indicates the need to further develop the issues raised in several fields and directions. An important issue appears in the use of intelligent innovation systems in the development of renewable energy in order to optimize spatial planning in relation to urbanization processes and the development of public services, transport systems and local entrepreneurship and production plants. It is also necessary to develop the topic of the productivity of energy systems in relation to the geography of settlements, which was addressed in the article. It is also worth considering a larger comparative review supporting discussions on the implementation of the smart city and smart village concepts in the context of spatial conflicts around renewable energy sources. It is also important to understand the relationship between various actors in the process of implementing energy innovations. Finally, it must be determined how to modify regional innovation systems (RIS)—as a concept and policy approach—to meet energy challenges.

The contribution of the article to the theory and future research is the indication of various spatial regimes for the occurrence of local energy systems for the purposes of creating spatial development plans in relation to selected socio-economic features. Applicable research methods for creating a typology for describing the potentials of renewable energy sources in spatial terms have been proposed. Another important contribution is the indication of possible ways of analyzing the content of spatial development plans. This applies in particular to those countries where spatial development plans are legal acts binding investors. Analyzing such regulations beyond mere legal analysis is a major challenge. However, it is necessary from the point of view of a comprehensive diagnosis of planning conditions. The article shows how this legal dimension can be combined (through statistical methods) with other relevant thematic levels.

The limitations of these studies lie in the lack of access to measurement indicators, which can lead to differences in results and difficulties in comparing between studies. In addition, many studies focus on one or a few factors, such as public policy or technology, while simultaneously excluding other important aspects, such as local community or economic issues. Future research on the development of renewable energy systems should focus on developing uniform definitions and measurement indicators in order to allow comparison of results between studies. What is more, future research should take into account a wider range of factors influencing the development of innovative energy systems, such as the local community, institutional aspects or innovative business models. It is also worth focusing on comparative studies between different countries and regions to better understand how different factors influence the development of renewable energy in different contexts.

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