TÉCNICO LISBOA

Preparation of the concept and model of an energy self-sufficient region based on distributed generation in the Chrzanów district - Poland

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Thesis to obtain the Master of Science Degree in

Energy Engineering and Management

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September 2022

I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Acknowledgements

I would like to sincerely thank the supervisors of my thesis - Professor Rui Castro from Instituto Superior Técnico in Lisbon and Dr. Janusz Zyśek from AGH University of Science and Technology in Kraków for their engagement in the process of creating this thesis. I am also grateful to all the people I had the opportunity to meet and who supported me during the InnoEnergy Masters Degree Programme.

Abstract

The purpose of this thesis is to prepare a concept of an energy self-sufficient district, at the same time eliminating gas and coal from the current energy utility process. Within a study such a district is understood as an energy cluster. The analysed area was defined as Chrzanów county, located in the south of Poland. Concepts was based on three levels – energy, community and financial. On the first level the county's RES potential and energy consumption were investigated. Based on obtained data, the energy balance model was developed together with innovative technology proposal. At the societal level, an innovative governance and administrative structure for the cluster was proposed. The social challenges associated with the transformation of the region were also identified and initiatives were proposed to assist this process. At the financial level the estimation of investment and operational costs was performed. Moreover, research was presented with regards to potential sources of project funding. In addition, it was identified which actions are beyond the scope of the study but are recognized as necessary for project implementation. In conclusion, it was found that an energy cluster is currently a very complicated entity on each mentioned level, however its implementation is possible under certain conditions like liberalization of legislations regarding wind energy in Poland. Overall construction of energy renewable self-sufficient district requires a great investment. However, it is a very effective way to facilitate the energy transition and contribute to climate neutrality through energy efficiency and net zero energy balance. The entire developed concept as well as its individual elements can be treated as a basis for further energy self-sufficient districts studies and even be an inspiration of an actual model implementation.

Keywords: Energy transition, Renewable Energy, Energy management, Energy clusters

Resumo

O objectivo desta tese é preparar um conceito de distrito auto-suficiente em energia, ao mesmo tempo que elimina o gás e o carvão do actual processo de abastecimento de energia. Dentro de um estudo, tal distrito é entendido como um cluster energético. A área analisada foi definida como distrito de Chrzanów, localizado no sul da Polónia. Os conceitos foram baseados em três níveis - energia, comunidade e financeiro. No primeiro nível, foi investigado o potencial das FER do concelho e o consumo de energia. Com base nos dados obtidos, o modelo de balanço energético foi desenvolvido em conjunto com uma proposta tecnológica inovadora. A nível da sociedade, foi proposta uma estrutura de governação e administrativa inovadora para o agrupamento. Foram também identificados os desafios sociais associados à transformação da região, tendo sido propostas iniciativas para apoiar este processo. A nível financeiro, foi efectuada a estimativa dos custos de investimento e operacionais. Além disso, foi apresentada investigação relativa a potenciais fontes de financiamento de projectos. Além disso, foram identificadas as acções que estão para além do âmbito do estudo, mas que são reconhecidas como necessárias para a implementação do projecto. Em conclusão, verificou-se que um cluster energético é actualmente uma entidade muito complicada em cada nível mencionado, contudo a sua implementação é possível sob certas condições como a liberalização das legislações relativas à energia eólica na Polónia. A construção global de um distrito auto-suficiente em energia renovável requer um grande investimento. No entanto, é uma forma muito eficaz de facilitar a transição energética e contribuir para a neutralidade climática através da eficiência energética e do balanço energético líquido zero. Todo o conceito desenvolvido, bem como os seus elementos individuais, podem ser tratados como base para futuros estudos de distritos auto-suficientes em energia, bem como ser mesmo uma inspiração para a implementação de um modelo real.

Palavras-Chave: Transição energética, Energias renováveis, Gestão de energia, Clusters de energia

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Nomenclature

CAPEX	Capital cost
CF	Capacity factor
DER	Distributed Energy Resource
DHC	Districy heating and cooling
DSO	Distribution system operator
EBITDA	Earnings before interest, taxes, depreciation and amortisation
END	Energy Neutral District
EPN	Energy Positive Neighborhood
EU-28	European Union (EU) which consists a group of 28 countries
GHG	Greenhouse gas
gP2H	Green Power to heat
HP	Heat pumps
IRR	Internal rate of return
JV	Joint venture
LTDH	Low-temperature domestic heating
MG	Microgrid
MW	Megawatt
NMCs	Networked microgrid clusters
NPV	Net present value
OPEX	Operational cost
P2H	Power to heat
PED	Positive Energy District
PV	Photovoltaic
RES	Renewable energy sources
SDT	Solution development team
toe	Tonne of oil equivalent
TWh	Terawatt hour

Chapter 1

Introduction

1.1 Motivation and problem origin

As energy demand increases, so does awareness of the importance of properly distributing energy sources in order to achieve energy security and independence. There are multiple ways to do so, however according to global trends, what can be observed is a diversification of energy sources. Such diversification also raises further challenges and must be very well thought out if it is to be implemented on a large scale in, for instance a country. Sustainable transformation is undoubtedly a complex and long-term endeavour, which involves the safe replacement of existing technologies with more modern solutions, energy management and storage, as well as financing, risk assessment, and public acceptance. Nevertheless, it seems to be a challenge that cannot be avoided and moreover should not be avoided. Our climate is constantly changing and the demand for energy is increasing. This pushes, among others, the leaders of the European Union and European nations to take courageous steps and set ambitious goals, such as a 55% reduction in greenhouse gas emissions by 2030 and climate neutrality by 2050 [1]. Hence, there is a lot of work to be done especially in countries like Poland, which is in the scope of this paper.

Heavy reliance on a single source of energy, particularly fossil fuels, is still very evident, especially in Poland. Although the energy mix is changing mainly towards renewable energy sources, the prospect of energy security and even more so of being self-sufficient in energy is a very far away. Thus, given the complexity of the problem and its scope, herein lies the opportunity for pilot programs to conduct energy transformations at the scale of minor districts like counties. Such energy self-sufficient areas are known as ”energy clusters” and may include a city, municipality or county [2]. Moreover these solutions don’t have to be just sample projects. With proper development of the natural capabilities of a given area, clusters could eventually be spread across the country, providing significant relief to large central power supply centres. Such solutions are already present in several places in Europe, while in Poland they are still innovative and their introduction requires a lot of work on many levels. Thus, for the time being in this study, looking from the standpoint of the condition of the Polish energy sector, it is assumed that the proposed solutions will be conceptual and their possible implementation would have a pilot character.

In line with the global energy transition and the need for alternative approaches to achieving energy security and climate neutrality, undertook the preparation of a concept for an energy self-sufficient district, which could eventually be disconnected from external coal and gas supplies. The study area was identified as the county of Chrzanów, as one of the energy-poor and environmentally distressed areas.

Using available data provided by ENSPRESO - the EU28 wide data-sets - the renewable potential was assessed. The research included wind energy, solar, biomass, hydro-power, geothermal and heat pumps utilisation capabilities. Naturally to develop well-balanced and feasible concept the proposed model needs to be adequately addressed to the district energy demands including mostly electricity and heating. Therefore, based on provided data describing the utilisation of energy carriers in Chrzanów district, an analysis of their consumption was conducted, covering industrial, residential and agricultural requirements. In addition, a preliminary proposal of renewable energy technologies was made in accordance with district's needs which still fulfill the original intent and purpose of this study.

Disconnecting from the central power and heating systems and switching to distributed energy, involves also primarily capital costs and operating costs that need to be carefully evaluated in order to establish the feasibility of the project. Funding and economic viability is often what stops innovation implementations, thus it was decided to assess preliminary costs and propose possible financial streams. The social and policy aspects were also taken into consideration. Many local energy projects emphasise promoting training, education, events and communication in their local communities [3]. This concept is no exception, as for such radical changes in a region, community acceptance is extremely important and has a significant impact on the pace and ultimate success of transition so as existing right and legislation, which are often not adapted to new solutions.

All these aspects form a complete concept of the region, which undoubtedly has the potential to become one of the pioneering areas based on green distributed energy, eliminating dependence on fossil fuels and gas in the main local energy consumption sectors.

1.2 Thesis purpose and scope of work

1.2.1 Thesis purpose

The purpose of this thesis is to develop the concept of an energy self-sufficient county, at the same time eliminating gas and coal from the current energy utility process. The analysed area is strictly defined and is located in the south of Poland called Chrzanów district. The study objective can be characterized as theoretical, although it is based on practical aspects. It is closely related to the energy transition taking place globally and the needs for alternative approaches to achieving energy security and climate neutrality.

1.2.2 Thesis scope of work

The scope of this work includes the following measures:

1. Familiarisation with current energy trends and policies in Europe, confronting them with the situation in Poland, and outlining the characteristics of the studied transition district, which is the Chrzanów county.
2. An introduction to the topic of energy self-sufficient areas and the identifying of the basics of their operation.
3. Determination of the scope in which the concept will be developed and making adequate assumptions to establish the exact framework of the project.
4. Investigation of the county's RES potential based on available databases, comparison of the results obtained with the provided data of energy consumption by individual sectors
5. Development of the energy balance model that meets the district's energy requirements based on characteristics of the fuel consumption by each sector and RES energy potential combined with innovative technology proposals.
6. Development of an energy community model that includes management and administrative structures with the identification of project stakeholders and their respective roles within the concept.
7. An analysis of the social and legal challenges associated with the energy transition in the district and the proposal of initiatives and incentives to assist this process.
8. Development of the financial model with investment and operational costs estimations and presentation of research done with regards to potential sources of project funding.
9. Identification and description of actions that were not covered in the development of the concept, but which are necessary for its implementation.

Chapter 2

Project background

2.1 EU policy and energy transition

European Union policy is undoubtedly one of the most important drivers of change in almost every economic sector of the member countries. However, particular emphasis has been placed for some time on the energy sector, whose changes are dictated mainly by climate change. Europe, led by the European Commission, has decided to take the lead in mitigating the adverse effects of gas emissions not only in energy production but also in industrial and agricultural processes. As part of its climate and energy policy, the European Union has set very specific and ambitious targets including by 2030.

- a reduction in greenhouse gas emissions of at least 40% (compared to 1990 levels), including mainly transport, municipal and agricultural sectors, as 30% compared to 2005 levels,
- increasing the share of energy from renewable sources to at least 32% of gross final energy consumption,
- achieving at least a 32.5% improvement in energy efficiency [2].

Moreover, a long-term strategy has been created with the main goal of achieving climate neutrality by 2050 [1]. Looking at the enormity of this challenge, its implementation has become a priority. The whole movement associated with a series of actions to achieve it is now known very widely as the energy transition.

Energy transition is a broad term. One of its definitions is "Achieving Sustainable Energy for All" [4]. Thus, if everyone is to have access to sustainable energy, everyone should contribute to achieving it. Of course there is a need for involvement of the superior institution setting the above mentioned goals, but also of individual countries, regions, counties and finally citizens themselves.

The main goal of the transition is to decarbonize the energy sector by shifting to renewable energy production and utilisation. The "shifting" towards more sustainable sources will initially be the focus of this paper. It can be achieved through policy frameworks, digital infrastructure, smart systems, market-based instruments and innovative energy and storage technologies. These are a lot of fields to cover simultaneously which means that the mutual contribution of all stakeholders is necessary. Hence, it can be said that the transformation process pushes us to develop and thus create new new fields of study and job opportunities. However, each country has its starting point which can be set up as a reliance on fossil fuels, that is evident in the energy mixes of individual countries. This starting point determines the strategy that should be taken in order to achieve affordable and clean energy [5]. There are some directions and guidelines from which to plan the transformation processes provided as 2030 climate and energy policy framework included in documents like the European Green Deal or the Paris Agreement [6], nonetheless each country has its own climate, social and legal conditions needed to be adapted accordingly.

The key tasks are to analyze the potential of renewable energy sources in the various regions of the country and the decarbonization potential of individual sectors. This determines which technological solutions can be chosen and helps to estimate the direction and costs of potential investments. We cannot imagine a sudden, complete elimination of coal and gas, as they are currently crucial for maintaining continuity of economic processes and, consequently, energy security. The strategy of transformation while maintaining energy security is an absolute priority here. Hence another strategic decision is at what pace and in what order to become independent of fossil fuels and gas supplies to meet energy needs now and in the future. In addition to the technologies themselves, appropriate legal and legislative instruments are needed to create all kinds of incentives and other financial support, as well as decisions as to who these funds should be addressed to. Here, finally, we come to the social layer itself, the owners of smaller or larger businesses, representatives of local communities and the end users of energy in its final form. As mentioned earlier, the goal is for everyone to be a beneficiary of the transition made. Often the social aspect gets lost in ”the big picture”. It turns out however, that public involvement on a smaller scale, such as a county, a municipality or even a neighbourhood, can be just as effective and is one way to drive the energy transition in the country. In order to effectively plan in what scale and at what pace to introduce particular innovations, it is worth looking first at the current state of the energy sector of the analysed country, in the case of this study, Poland.

2.2 Polish energy sector

Poland is one of the European countries that are unfortunately in an earlier stage of energy transition. Polish power industry began to develop as early as the beginning of the 20th century. At that time, however, it was rather modest, and electricity was used only to power individual factories. The greatest development can be noted after World War II. It was then that the current path that Poland is following was determined, namely the focus on coal as the main energy resource. At first, the main reason for this was the geographical location of the country, as it was abundant in this fossil fuel. The consequences of historical actions persist to this day, but the share of renewable energy sources continues to grow rapidly even month after month. Figure 2.1 shows the current situation with regard to electricity production in Poland. It can be seen that the share of coal in 2021 was 72.4%, corresponding to 130 TWh of energy.

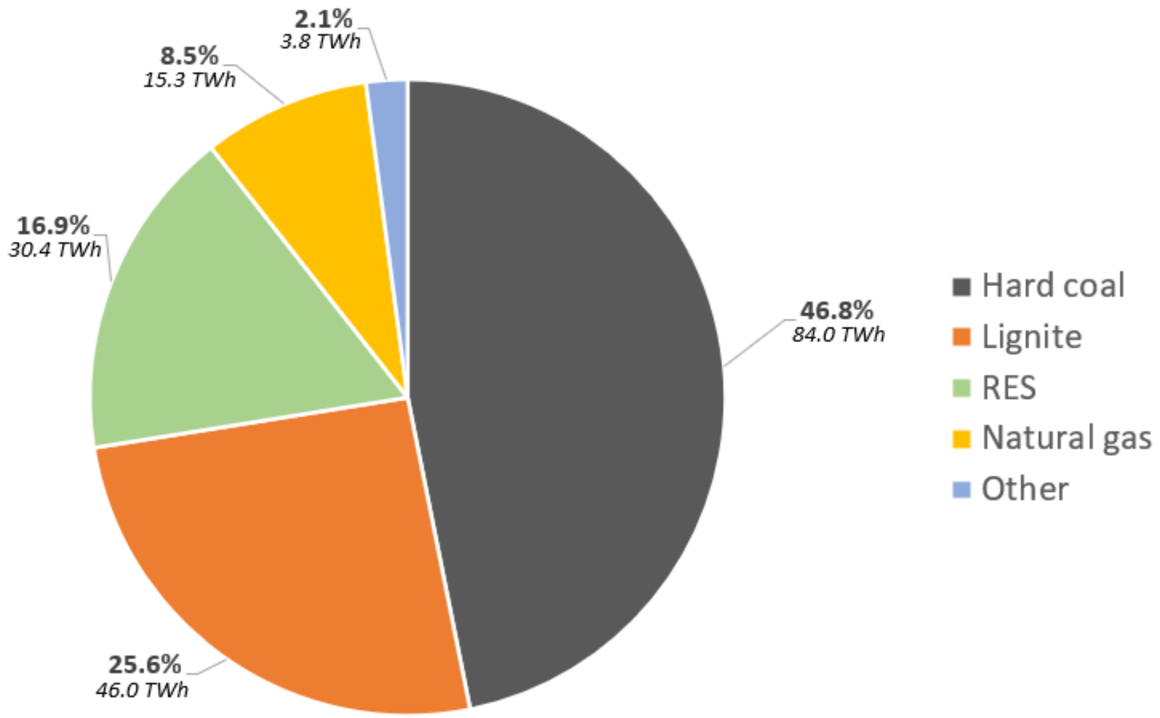

Figure 2.1: Electrical power generation in 2021 in Poland [7]

On the other hand, energy production from all RES sources reached a record high of 30.4 TWh. However, despite this, the share of RES in the production mix fell from 17.7% (in 2020) to 16.7% [7].

It is worth noting that energy does not strictly refer only to electricity but also to heat. Therefore, in the context of the need to cover the energy demand, a good methodology is to take into account the primary energy production and the energy consumption. Listing from the above values the share of energy coming from renewable energy sources gives the best picture of to what extent the country is dependent on non-renewable sources and thus how far it is from energy independence. There are many sources describing the state of the Polish and European structure of energy consumption and generation. However, it is recommended to use data provided by official sources such as the Polish Central Statistical Office, which regularly records key data for the national development.

Table 2.1: Production of primary energy (including RES) in Poland and EU-28 [8]

Specification	2016	2017	2018	2019	2016	2017	2018	2019
	Production of primary energy							
	Total (Mtoe)				from RES (Mtoe)			
Poland	66.6	64.2	64.6	62.1	9.2	9.2	12.1	12.3
EU-28	760.4	758.8	756.6	739.4	217.4	226.3	234.4	242.5

Table 2.2: Final energy consumption in Poland, EU-28 [8]

Specification	2016	2017	2018	2019	2016	2017	2018	2019
	Final energy consumption							
	Total (Mtoe)				from RES (Mtoe)			
Poland	64.7	68.6	72.2	70.9	5.2	5.3	8.4	8.2
EU-28	1050.3	1062.0	1063.3	1057.0	96.4	102.7	105.2	108.0

Table 2.3: Share of energy from renewable sources in Poland and EU-28 [8]

Specification	2016	2017	2018	2019	2016	2017	2018	2019
	Share of energy from renewable sources							
	Total primary energy (%)				Total energy consumption (%)			
Poland	13.8	14.4	18.7	19.7	8.1	7.8	11.7	11.6
EU-28	28.6	29.8	31.0	32.8	9.2	9.7	9.9	10.2

It is important to emphasise that in the case of the given data, final consumption is the consumption of energy carriers by consumers (industry, services sector, households) for their technological, production and personal needs. The final consumption does not include the conversion to other energy carriers, but it does include the consumption of fuels for the production of heat consumed by the producer [8].

On average, primary energy production has been on a decreasing trend in the European Union countries during 2016-2019, while an increasing trend can be observed for primary energy production from renewable energy sources. The same tendency can be seen in the case of Poland, where the increase in the share of green energy in primary energy over 3 years was 6 percentage points. For EU-28 it was 4.2 percentage points. The above growth resulted in an overall increase in the share of renewable energy in primary energy. Based on the official 2019 readings, renewable energy in total primary energy was 32.8% for the EU-28 and 19.7% for Poland. Analysing the data in terms of the growth rate of this indicator in the past years, for Poland the share of RES grew at a rate of 12.8%, while for the EU-28 it was 4.7%. The share of renewable energy in Poland's final energy consumption in 2019 was 11.6%, so it increased by 3.5 p.p., compared to 1 p.p. for EU countries[8]. Thus, it can be seen that more energy is extracted from RES than is actually used. This is a consequence of the emergence of more and more prosumers on the market, who are able to produce in this case usually electricity and give the excess back to the grid. In Poland, this trend was particularly evident when the ”mój prąd” programme was launched as an incentive.

”Mój prąd”, which means ”My current” is an incentive financed by the Polish Operational Program Infrastructure and Environment, whose main objective is to increase the production of electricity from photovoltaic micro-installations in Poland. It takes the form of a one-time subsidy for a photovoltaic installation. The beneficiaries are private entities producing electricity for their own needs, which have signed a comprehensive agreement regulating the introduction of the electricity produced by the micro-installation to the grid. The projects submitted by eager citizens must contribute to the achievement of the national target concerning the share of RES in the total energy consumption and must ensure respect for the environment and landscape protection.The first intake, concluded in 2020, attracted great interest. Approximately PLN 132 million was spent under the project and the installed PV power amounted to 152 MW. It is estimated that the program contributed to the reduction of CO_2 by about 122 thousand tons/year [9].

Despite the growing popularity of photovoltaics in Poland, the first place in terms of green energy generation is taken by wind farms. At the end of 2020 wind was responsible for 70% of energy production from RES [10]. It is even more interesting, because wind energy in Poland is extremely limited by legal barriers. With the entry into force of the Act of May 20, 2016 on Wind Farm Investments the so-called 10H rule [10] was introduced. According to the rule the construction of a wind farm is only permitted within a minimum distance of ten times the total height of the wind power plant from a residential building (or a building with a mixed function including a residential function). This distance must also be maintained when locating a wind farm from nature protection forms and forest promotion complexes [10]. This is an extremely restrictive force, even on a European scale, and its implications will have a major impact in the context of this study. Nevertheless, Poland is a diverse country geographically and also in terms of potential use of individual energy sources. Almost every region of the country has its specifics in this matter. These regions are usually divided into voivodships, of which there are 16 in Poland. This regional diversity will be very important for the feasibility study of the project that is the subject of this work.

The energy system in Poland is seemingly fragmented. That is, there are several main operators that cover specific areas of the country as indicated in the figure 2.2. These companies are based on the principle of building a value chain to include extraction, generation and distribution. The vast majority of electricity is mainly generated in coal-fired thermal power plants. Long-distance transmission of energy from power plants to the consumer is possible thanks to an extensive network of power lines and substations. However, it involves losses. The main way to reduce these losses is to increase the voltage of the power transmission lines. Raising the voltage for transmission, and then lowering it to a level where it is possible to use common electrical appliances built for 220/230 or 380/400 volts, requires the use of the system's extra-high voltage substations, many high-voltage distribution substations and numerous transformer stations that convert the medium (distribution) voltage to the commonly used consumer voltage [11]. All these facilities - lines and substations - make up the electricity system. The whole infrastructure for generation, transmission, distribution, storage and use of electricity is called the National Electricity System. It can therefore be concluded that, primarily, the energy distribution system is highly centralised within the strictly defined operating boundaries of one of the major Polish energy companies. Such a solution is not very flexible. The problem of transmission functioning in this way is, for example, the lack of possibility to store electricity, which means that at any moment the amount of energy generated in power plants must be equal to the amount of energy consumed by consumers [11]. The electricity system must therefore be capable of changing the direction and amount of energy transmitted. This means, for example, that the grid cannot reliably adapt to the prosumer photovoltaic strategy mentioned earlier.

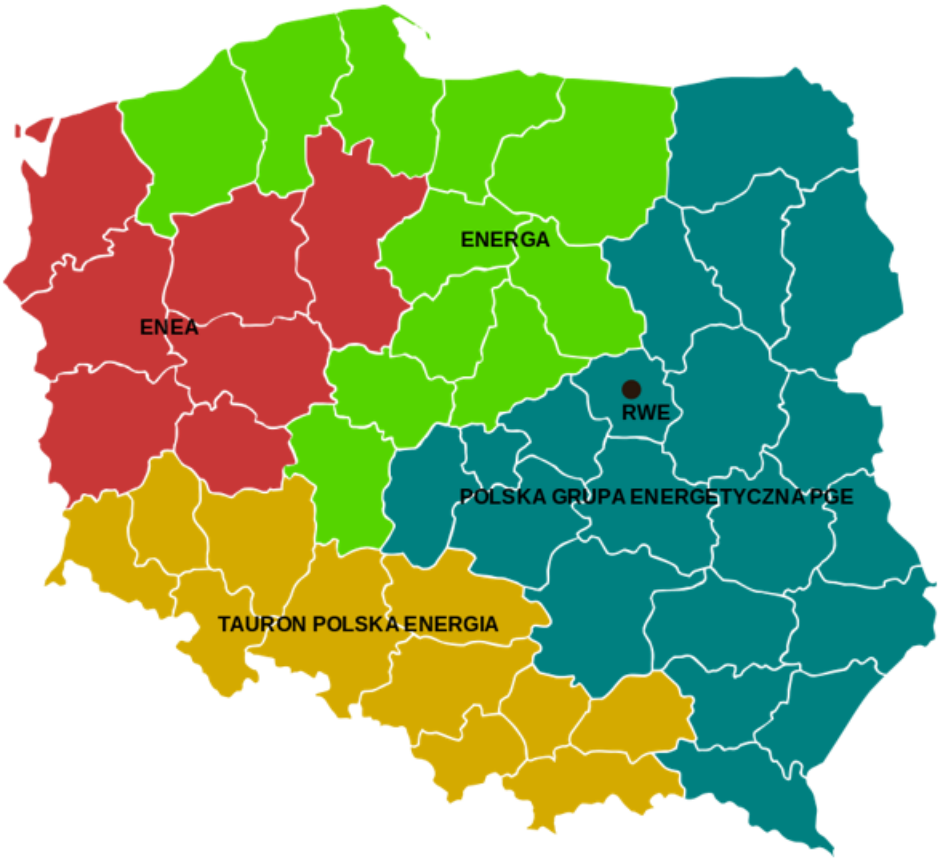

Figure 2.2: Map of the largest Polish operators along with their areas of operation. [12]

The term ”energy” often immediately brings to mind electricity. However, we should not forget about the heating sector, which is a huge part of the problem of the energy transition in Poland and it is sometimes neglected. District heating includes district heating networks as well as the supply of heat to households, which account for as much as one half of heat consumption. The Polish district heating sector is based to a large extent on coal. For district heating and individual heating, the share of coal is 72.5% and 47.7% respectively [13]. Unfortunately, this results in a reduction in air quality, the formation of smog and emissions which, in the light of current European Union policy, are not only costly for health.

The government's response to such high values of coal consumption for energy purposes and to the strong requirements of the European Union's climate policy was to be the plan ”Energy Policy of Poland until 2040” (PEP2040) [14], approved on 2 February 2021. The document sets the framework for the energy transformation in Poland. It includes strategic decisions regarding selection of technologies to build a low-carbon energy system. PEP2040 is a a contribution to the implementation of the Paris Agreement concluded in December 2015. The project is built on three main pillars that are supposed to be the guidelines for everyone who is involved in it [14]:

- **Fair transition** - there are regions in Poland that rely very heavily on the coal economy. This relates not only to the system for providing electricity or heat, but also to jobs and businesses in this area. This pillar is a declaration that the areas most affected by the energy transition, i.e. requiring the most effort in respect of low-carbon policies, will be provided with new opportunities for regional and social development. The transformation of carbon regions will be supported with approximately PLN 60 billion. ,
- **Zero-emission energy system** - an extremely ambitious provision, which involves decarbonising the energy sector to zero, mainly through the deployment of nuclear power, offshore wind and distributed energy. The last is to play a very important role, as it directly involves citizens, strengthening climate awareness on the part of users and local communities. Moreover greater diversification of energy sources ensures energy security. While the diversification is increasing there is also a need of a transitional use of technology based, for example, on gaseous fuels is proposed,
- **Good air quality** - there is no doubt that moving away from fossil fuels improves air quality. This can be achieved by transforming the heating sector (both systemic and individual), electrifying transport and promoting zero-emission homes using local energy sources.

The strategy has several key assumptions in terms of the energy transition approach [14]:

- it will be performed so as not to leave anyone behind,
- focused on modernisation and innovation,
- if should be boosting economic development, efficiency and competitiveness,
- locally driven, bottom-up participation in the process - everyone will be able to contribute in it.

It is worth to highlight the last point of these objectives. Once again there is a theme of the scale at which particular transitional activities can be carried out. The best way to reach consumers, the potential beneficiaries of the transition, is to engage them directly. Showing and presenting to them specific actions and their implications. Atomic energy is a great solution, as is offshore energy, but these are still distant concepts, especially for the energy-poor regions. And yet the whole idea of energy transition is not only about technology, but above all about a change of mindset. This is where we come to the concept of the energy cluster [15] - an energy self-sufficient area, which needs the engagement of almost its every inhabitant in order to successfully operate. Therefore, if, as Europe, we are aiming to build a more sustainable environment with people who are aware and willing to cooperate, energy clusters are undoubtedly one of the more promising directions for development.

2.3 Self-sufficient energy district - energy clusters

The idea of clustering promotes a local perspective on energy and fits into the trend of supporting distributed generation based mainly on the use of renewable energy sources and co-generation of electricity with heat and cold. It is a consequence of deepening liberalisation mechanisms, adjusting regulations as well as in the complex process of optimising generation structures. It is also a consequence of policies forcing the domestic energy sector to comply with EU guidelines. A cluster is defined as *"a civil law an agreement, which may be made up of private entities, legal entities, scientific entities, research institutes or local government units, concerning the generation and balancing of demand, distribution or trade in energy from renewable energy sources or from other sources or fuels, within a single distribution network, respectively within the boundaries of one municipality or county"* [16]. In this paper, the subject is to develop the concept of an energy self-sufficient area within the district of Chrzanów. Therefore, this area falls within the definition of the Act. However, it is a very fluid definition and due to the rather innovative nature of the cluster idea, there is quite a lot of freedom in defining specific guidelines as to the degree of energy independence of the cluster from the rest of the system providing energy (in this case in the county). Thus, for the purposes of this work, a cluster will be understood as an energy self-sufficient area, which can meet its energy demands from low-cost, locally available, environmentally friendly renewable sources [5].

Local community energy projects like this, have real potential. In this scenario, individuals, communities and local authorities controll and produce their own renewable energy thus promoting the transition to more equitable and decentralised energy systems. A more familiar term in literature for such an area is EPN - Energy Positive Neighborhood, which is a neighbourhood area that generates more electricity than it consumes [5]. Here we take a step further to the district level. There are two main concepts on this level. END - Energy Neutral District, (which refers to self-sufficiency) and PED - Positive Energy District. These two scenarios are quite similar since both are energy-efficient and energy-flexible systems or a group of connected urban, agriculture areas, which produces net zero greenhouse gas emissions and actively manages their energy balances [5]. The main difference is that in case of PEDs, they have an annual regional surplus of renewable energy. The goal however remains the same - achieving energy balance, so the amount of energy produces is equal to energy consumed. As one might imagine, creating a perfectly balanced system has many challenges. While working on the concept of such an area and exploring the available literature, 3 basic levels have been identified on which to operate. Therefore according to them, the concept will be developed on the further stages of this paper:

1. **energy level** - Selection of appropriate technologies based on the capacities of individual types of renewable energy sources and the way in which energy and heat are stored and distributed. In addition, an analysis of the current state of the energy infrastructure of the studied area, the condition of the building insulation and energy efficiency. Analysis of necessary to know the region's demand for fuels and energy and to examine the structure of the use of specific energy carriers for concrete purposes.

2. **community level** - Establishment of a structure for cluster management and decision-making in matters concerning the broad direction of the area's development. Building a clear division of competences in selecting technologies, conducting research, establishing social policy, taking care of maintaining relations with project shareholders, applying for project financing, attracting investors, hereafter referred to as the ”Energy Community Model”. A huge part of this level is the mentioned social policy. It is understood to mean the development of a range of activities aimed at the continuous provision of information, engagement and education for all individuals, but also for business.

3. **finantial level** - Estimation of investment (CAPEX) and operating (OPEX) costs. It can be predicted that the development of renewable energy is characterised by high CAPEX, which are, however, usually compensated by lower OPEX and a relatively high rate of return. Therefore, at this level it is most important to find out about appropriate sources of financing, which are available in the form of many incentives for energy cluster development at national as well as EU level. Already in the initial stages of Poland's transformation, activities supporting investment in coal regions amounted to around PLN 60 billion, and the pools of funds for this purpose are being constantly updated [14].

Due to the complexity of the concept of an energy self-sufficient area, these 3 points will be the pillars on which the concept that is the subject of this work will be built. As the concept develops, these points will be clarified and the solutions given will try to respond to the challenges that have been encountered so far in the construction of existing or emerging regions of this kind. There is some material to base on because The European Union (EU) has introduced the Strategic Energy Technology Plan with a target to establish 100 PEDs by 2025 in order o contribute to climate neutrality [5]. Moreover the Polish government assumed the creation of 300 energy clusters by the end of 2030, however many clusters that have been certified are developing very slowly or not at all. The chances of creating a significant number of new clusters by 2030 are uncertain and seem to be very ambitious [15]. The challenge is even more ambitious, because the proposed conception concerns the whole county, that is the district consisting of several municipalities, towns, many neighbourhoods. Therefore, in order to create a sensible proposal for such a large undertaking it is necessary to get familiar with the area to be transformed and the necessary data.

2.4 Chrzanów County

Poland has a three-level administrative (territorial) division. It was introduced on 1st January 1999. According to it, the Polish territory was divided into voivodeships, then into counties and communes. The conception assumes that Chrzanów County will be self-sufficient in energy and therefore we are dealing with the second level of administrative division.

Figure 2.3: Administrative division of the Chrzanów county [17]

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Chrzanów county is located in Małopolska voivodeship and consists of 5 communes as presented in figure 2.3. Małopolska is situated in southern Poland and has a population of 3.35 million. The region is composed of 182 municipalities, of which 6 are significantly or directly affected by coal mining activities. Małopolska is one of the regions which has been notably affected by low-carbon transformation in Poland and the European Union. The region's energy transformation began in the 1990s. The closure of 3 mines (in Trzebinia in 2001, and some mine shafts in Libiąż and Brzeszcze) still has negative social, economic and environmental effects in the region. Małopolska is one of the five largest Polish regions in terms of the number of coal mining entities. In the western part of the region, their share in the total number of companies is about 30%. Among all European regions, Małopolska ranks eleventh in terms of the number of jobs directly related to coal and twelfth in terms of the risk of socio-economic impacts of the energy transition [18]. It is worth noting the last item in Table 2.4 which is the CO_2 emissions in the district. 1,33 million tons per year is the highest value in all the sub regions of Malopolska voivodeship. On the other hand, Western Małopolska was the second sub-region, after the city of Kraków, in terms of the size of this indicator (2.53 million tonnes/year) in the Małopolskie Voivodeship [19].

Table 2.4: Basic data about Chrzanowski county [20]

Specification	Value
No. of inhabitants (-)	123 099
Area (km^2)	372
Population density (ppl/km2)	339
Urbanisation rate (%)	62.9
No. of communes (-)	5
No. of cities (-)	4
No. of properties	44 995
Residential units with central heating (%)	86.93
Residential units with gas mains (%)	74.28
Business operators (thousends)	12.4
Business operators (per 1000 inhabitants)	99.9
CO_2 emission (M ton/year)	1,33

Table 2.5: Status of RES use in Chrzanów county [19]

	Power (kW)	No. of instalations (-)
Photovoltaicks	291.63	516
Solat collectors	3 111.11	360
Heat pumps	948.53	59
Biomass	ND	815
Biogas	85.09	2
Total	4 436.30	1 752

It is estimated that in the districts of Chrzanów, Olkusz, Oświęcimski i Wadowicki counties there are a total of 5 290 installations of renewable energy sources (15% in the scale of the whole voivodship) of a total installed power of at least 48 989.9 kW (which is less than 9% of the power installed in Małopolska). There are no RES installations based on hydropower, wind energy, geothermal and cogeneration in the analysed district as shown in table 2.5. [19]. Therefore looking at its presented characteristics and the current state of energy utilisation and its sources it can be seen that this area is far from meeting the guidelines of both the European Commission and the plan of energy policy of Poland until 2040. Therefore, the concept that was developed in this study assumes a complete transformation of the region. Such a transformation, of course, has to be appropriately timed while preserving the energy security of the region. It requires a number of analyses of available data and assumptions included in project further stages.

Chapter 3

Scope of concept development

3.1 Main concept assumptions and scope of work

Within the scope of the work to develop the concept of an energy self-sufficient county, individual steps were identified. At each of these stages, specific goals were set that had to be achieved in order to have a final picture of a district that meets the definition of energy self-sufficiency. However, obtaining this complete picture required certain assumptions both at the scoping stage of the concept and during the more advanced phases of its development. Therefore, it is absolutely crucial to get familiar with this part of the project in order to understand on what basis the different parts of the concept were established, what is the overall purpose of the concept, the objectives of its different phases, but, above all, to get acquainted with the main assumptions and the reasoning behind them. Hence, the detailed scope of work is presented below, along with the assumptions assigned to each step of the process.

3.1.1 Defining the main objectives

Two main objectives were defined within the project:

1. Defining the region to be the subject of the project.

2. Elimination of coal and gas from region's energy utility process.

For the first point, the Chrzanów county was selected as the county covered by Regional Climate action and Energy Plan [2], which is in an advanced state of development and for which the Marshall Office of the Małopolska Region has already received support from the European Union. It is therefore a concept, which refers to the county that is an actual object of the energy transition in Małopolska. This means that the individual solutions proposed in this study have the potential to be actually applied if the project is implemented. Point two is a very specific goal. Based on the developed energy carrier consumption model in the county and the potential of other green energy sources, the goal is to eliminate coal and gas from energy-using processes in the defined area. However, due to the nature of the energy transition process and a number of implications associated with getting rid of coal and gas, it was decided to take into account not only the technological aspect and not be limited to the energy balance, but also include the financial and social aspects in order to obtain the already mentioned complete picture of the concept.

At this level, some core, major assumptions were defined as a basis for further scope of work:

- **It is not said that the total transformation of the county to a self-sufficient district will be successful under no additional circumstances** - there is a possibility that during the process of concept development it might occur that additional conditions need to be fulfilled in order to conduct the county transitions. Moreover it might even occur that the total transition cannot be achieved due to technological, environmental, social, financial or any other reason. In that case however, the right justification is required. Therefore this study can be considered as an attempt to develop a complete concept of self-sufficient energy cluster consisting of various solutions that touch different aspects of the subject.
- **As the concept progresses, new assumptions might be introduced in accordance with conducted research and analysis** - assumptions made at this stage of the project are the basis which will be take under consideration during duration of the study. However with an introduction of new variables, data and issues, additional assumptions related directly to them might be made.
- **The proposed concept is inspired by conducted research, but is tailored directly to a defined, specific county.** - it is assumed that all proposed specific solutions are tailored to the Chrzanów county. Thus, they are not fully universal, although they may be used in the case of similar projects.
- **The concept does not include a program or a schedule for implementing individual project phases over time** - the final picture of the project is presented along with possible approaches for achieving it. The final transition picture is presented along with possible ways to achieve it. Nevertheless, the activities that are not described in detail in the paper but which should be performed for the successful implementation of the project were included in the form of a concise summary as a suggestion for further actions in case the concept would be implemented.

3.2 Concept development

3.2.1 Initial data preparation and research

At this stage two main tasks were required:

1. RES potential investigation
2. Energy consumption analysis performance

The first step directly related to the technical part of the project was a research on the current renewable energy sources potential in the selected county. Following this approach, the following renewable energy sources were analysed for their potential: Solar energy, wind energy, biomass, geothermal, hydropower, geothermal and heat pumps. Several baseline assumptions were also made at this stage:

- **Data obtained during the RES research phase are considered as the best approximation of actual values calculated based on reliable sources** - nonetheless an actual concept development would require data obtained directly from appropriate county or voivodeschip entities.
- **Obtained final values of solar, wind and biomass potential are already appropriately adjusted and brought down to the same units by data provider** - this means taking into account factors such as the efficiency coefficients of individual technologies, environmental conditions and similar. There is no need of further data processing therefore they can be used in required calculations.

The second task at this point was an energy consumption analysis. According to the characteristics of provided data a division into three main sectors was applied:

- **Economy** – businesses, industrial installations, production processes,
- **Buildings** - energy utility in flats, administrative buildings, family houses, other immovables.
- **Agriculture and forestry** - agricultural production, farming processing, heating and cooling.

One very important assumption was made here, which has a substantial impact on the overall energy model:

- **Energy consumption of transport sector was not included as an energy utility area** - hence, it is not an objective to include its consumption in the entire concept. This is due to too significant users' independence and therefore market volatility. Included sectors' energy usage is considered to be generated by either an immovables or their users located on the Chrzanowski county area. Meaning, they are directly related to the county and can be changed as a part of top-down decisions and initiatives taken by county representatives.

3.2.2 Concept formation

The phase of building the actually model of the overall concept is based on the previously mentioned 3 levels - energy level, community level and financial level. Each of these levels is a pillar of this concept and has its own listed objectives within the scope of work.

Energy level is directly related with initial data preparation and research which are necessary to proceed with building the energy balance model. Thus, two main significant objectives were set for implementation:

1. Energy balance model development - performing energy balance calculations to establish if there is a possibility of meeting energy demand.
2. Technological solutions proposal with choice justification.

Within the community level, the following objectives were established to be implemented:

1. District management model proposal with specified positions and their roles.
2. Administrative/business model proposal with relationships between stakeholders included.
3. Identification of challenges and potential benefits, advantages and disadvantages of proposed energy community model
4. Description of the role of communities in the energy transition and the obligations of local authorities.

At the financial level, two main tasks were identified:

1. Investment and operation costs estimation.
2. Research and identification of potential sources of funding.

Each objective listed under a particular conceptual stage has its own characteristics and therefore may require additional assumptions. In this case, adequate justification will be necessary for the proposed solution to be considered credible.

Knowing the action plan and the guidelines according to which it will be realised, it was possible to start actually building the concept of an energy self-sufficient district.

Chapter 4

Energy level - Energy balance model

4.1 RES potential analysis

In order to replace coal and gas, which are the dominant energy sources in the energy balance of Chrzanów county, it is first of all necessary to check whether there is something to replace them with. Obviously, in line with the trends of energy transition, renewable energy sources are the subject of analysis. It was decided to investigate the potential of RES such as: solar energy, wind energy, biomass, deep geothermal, hydropowe and additionally heat pumps. The values determined in this section come from independently conducted research and analysis of available data. For the first three a specific study was used, called ENSPRESO - ENergy System Potentials for Renewable Energy SOurces, an EU-28 wide, open dataset for energy models on renewable energy potentials, at national and regional levels for the 2010–2050 period. [21]. It was inspired by European Commission that published the EU's vision for a prosperous, modern, competitive and climate-neutral economy by 2050 – A Clean Planet for All (COM(2018) 773 final). The need for transparent and consistent data across the EU to meet the planning requirements of future energy systems was evident. Therefore the ENSPRESO database is build with the assumptions that are naturally implemented in this paper as they go as follows [21]:

- it covers solar, biomass and wind (onshore and offshore) resources,
- it is transparent in its input assumptions with regards to key parameters, such as meteorological data, land use and technical hypothesis allocated to relevant energy sources,
- derives the raw available area for the different renewable resources, thereby allowing analysis of the competition between technologies,
- provides GIS-based estimations for the physical availability for every location and time slice combined with the technological options

As for the division of the territory according to which the analysis was made, it is based on the NUTS classification, established at the beginning of 1970 by Erostat. Is is a single, coherent system for dividing up the EU's territory in order to produce regional statistics for the Community. This analysis, from which the data are drawn, is based on the latest NUTS2 breakdown of 2021. In the case of Poland, the most accurate breakdown includes voivodeships. For Małopolskie Voivodeship this is NUT PL21 and it is mainly for this NUT that the data are referred to in the analysis. The main assumption at this stage is that the values presented in the analysis are estimated, since there are based on data provided indirectly in aforementioned paper.

4.1.1 Solar potential

Solar potential estimation is based on ENSPRESO document. Solar irradiance analysis was performed using spatial disaggregation on the basis of satellite pixel data with a resolution of approximately 1 km by 1 km. For calculating irradiance on problematic areas such as tilted planes like rooftops or facades, authors used the Muneer Model [21], which provides global and direct normal irradiation conversion onto an arbitrarily oriented surface. As a result, both built-up areas and open fields are included in the analysis. Irradiance was estimated as an average based on data from 2005 to 2013. Calculations were made on an hourly basis and aggregated (as annual average values) to temporal disaggregation into annual sub-periods (timeslice level). Finally the overall solar potential was based on 3 sets of assumptions:

- with 85 MW/km_2 PV and land efficiency, assuming 100% of the available natural areas
  with 85 MW/km_2 PV and land efficiency, assuming 3% of the available natural areas.
- with 170 MW/km_2 PV and land efficiency, assuming 100% of the available natural areas
  with 170 MW/km_2 PV and land efficiency, assuming 3% of the available natural areas.
- with 300 MW/km_2 PV and land efficiency, assuming 100% of the available natural areas
  with 300 MW/km_2 PV and land efficiency,, assuming 3% of the available natural areas.

The ENSPRESO database provides an extensive data describing potential of solar power generation values for each of country's NUTS only in case of one option: "with 170 MW/km_2 efficiency, assuming 3% of the available natural areas". Detailed data on NUT PL21, which applies to the Małopolska voivodeship, are also provided there. It is due to these reasons the aforementioned option was selected and further used in this study. When the data for the voivodship were determined, the solar potential in the studied region was obtained based on the ratio of the area of the county and the voivodship. A summary of the estimations adopted in the project is presented in Table 4.1.

Table 4.1: Summary of annual solar potential in Chrzanów county

Solar Potential	PV - roof/facades	PV - ground	CSP	Total
for Małopolska (TWh)	7.15	32.58	0.00	39,72
for Chrzanów county (TWh)	0.115	0.797	0.00	0.972

4.1.2 Wind potential

In this section only onshore wind energy is considered due to district location. There are three scenarios that reflect different levels of land availability for wind farms since land availability is the major limitation [21]:

1. **EU-Wide high restrictions** - A hypothetical scenario in which the exclusion of surfaces for wind converges in all countries to a high level. A hypothetical scenario in which the exclusion of surfaces for wind converges in all countries to a high level.
2. **EU-Wide low restrictions** - A hypothetical scenario in which the exclusion of surfaces for wind converges in all countries to a low level. Setback distances in all countries converge in 2030 to the lowest setback currently observed: 120 m and 400 m for small and large turbines, respectively. Setbacks remain the same in subsequent years.
3. **Reference restrictions** - Current legal requirements for exclusion zones and setback distances. Current setback distances remain the same in future years.

The setback distances for onshore technologies are determined by varying degrees of stringency for the minimum allowed setback distances from settlements. Using high-resolution wind climate maps and the spatial analysis, a series of capacity factors can be determined for each specified area. In terms of turbine technologies Vestas turbines were used as benchmark with 5 MW/km_2 power density assumed at 100 m hub height [21].

At this point it is worth noting that Poland is the only EU-28 country included in the report for which the high restriction scenario limits wind power generation less than the reference scenario. This is an absolute exception caused by the 10H rule [10] that was mentioned earlier in this study. Therefore, it was decided to consider assumptions related to both low restriction scenario and reference scenario when developing the model. Hence taking into account the available data sets in terms of capacity factor, and again the ratio of the voivodeship to the studied district, the estimated wind energy potential is as presented in table 4.2.

Table 4.2: Summary of annual wind potential in Chrzanowski county

Wind Potential	CF	EU-Wide low restrictions	Reference Scenario
for Małopolska (TWh)	15%<CF<20%	7.78	1.09
	20% <CF <25%	12.77	1.79
	CF >25%	5.15	0.72
for Chrzanów county (TWh)	15%<CF<20%	0.191	0.027
	20% <CF <25%	0.313	0.044
	CF >25%	0.126	0.018

4.1.3 Biomass potential

Agricultural, forestry, and waste processing are the main sources of biogenic resources used to generate energy. Energy sources in the agricultural sector are energy crops and residues. The term ”energy crops” refers to the crops that are grown primarily for their ability to produce final energy carriers, including sugar, starches, oils, energy maize silage, and lignocellulosic biomass. While wet and dry cattle manure are considered ”primary residues” [21]. Thus, the estimation of agricultural biomass potential in the district was based on the ratio of agricultural land in the district to agricultural land in the county.

Biomass from the forestry sector is classified into roundwood production and primary and secondary residues. As for ”secondary residues”, they include wood chips, sawdust and black liquor. ”Primary residues” include logging residues and other pre-commercial thinnings. The biomass potential from this source was determined in the same way as described above, but forest land was taken into account.

The last source comes from the waste sector. Here tertiary and primary residues categories are considered. The first ones cover biomass residues from different industries and municipal solid waste. The primary residues consist of residues from landscape care management, roadside verges and abandoned lands [21]. In this case, the indicator used to estimate the potential energy from waste was the population.

Again, 3 scenarios are made in this case - high, medium and low bioenergy availability scenarios. They differ in assumptions related to land use, agricultural practices, available land, harvesting and the limitations of biofeedstocks for each biomass type, and protected areas, but they are described more broadly in the literature source [21]. To determine the potential of agricultural, forestry and waste biomass, the authors used consequently the following tools: CAPRI model, EFISCEN model and EuroStat Waste data. The assumption was made that the methods used do not require further verification. Hence, the final data taken for energy development for reference scenario are as follows.

Table 4.3: General data regarding Poland, Malopolska and Chrzanów county [20]

	Poland	Małopolska voivodeship	Chrzanów county
Area (km2)	312 679.0	15 182.9	371.6
Population (ppl.)	38 179 800.0	3 408 505.0	123 664.0
Population density (ppl./km2)	122.0	224.5	335.1
Agricultural land (ha)	31 268 630.0	-	36 135.0
Forestry land (ha)	9 264 200.0	-	19 275.9

Table 4.4: Summary of annual biomass potential in Chrzanów county

Biomass potential	Agriculture	Forestry	Waste	Total
for Poland (TWh)	122.0	105.6	21.6	249.3
for Chrzanów county (TWh)	0.141	0.220	0.070	0.431

4.1.4 Geothermal potential

With geothermal, deep geothermal is being investigated, which extends up to 8-10 km underground. In Małopolska, in the context of geothermal energy, from the north of the voivodship to the level of Kraków there is essentially nothing that could convince one to invest in geothermal energy. Even deep within the Earth, the low-angle limestone monoclines (Jura Krakowsko-Częstochowska) are relatively cool. Krakow itself lies in the Pre-Carpathian Foredeep, filled with sediments of the sea, which covered the area in the Miocene. It is not until crossing the unique structure of the Pieniny Rock Belt that the most productive sources of hot underground water are to be found. There is even a company called PEC Geotermia Podhalańska S.A., but this area is about 140 km away from the studied county. Therefore, no geothermal potential was found to such an extent that this source is worth further analysis and use in the model [22].

4.1.5 Hydropower potential

The surface of Małopolskie voivodship is definitely mountainous and upland in character. This is desirable for the development of hydropower. Unfortunately, the County of Chrzanów is located in rather flat terrain with relatively low elevations. This eliminates the potential for pumped storage power plants. However, it lies on its southern border along the Vistula River, the longest river in Poland. At present, the Vistula is quite shallow and interference in such an important part of the natural environment of the whole country involves not only huge financial expenses but also administrative issues. Despite this, there are two measuring stations in Chrzanów County (Gromiec and Miętków), from which historical data on the flow of the Vistula and Chechło rivers were collected.

Table 4.5: Historical data on flows in the Vistula and Chechło rivers

	Average flow (m^3/s)	
Year	Vistula river	Chechło river
1991	-	0.96
1992	42.36	1.02
1993	34.63	0.99
1994	40.18	0.97
1995	49.05	1.20
1996	73.84	1.26
1997	83.55	1.52
1998	63.72	1.69
1999	58.48	1.28
2000	-	1.58
Average flow	55.73	1.25

On the basis of the measured flows it can be concluded that there is a potential for building a hydroelectric power station on the Vistula, but such an investment for the purposes of one district would be almost unrealistic. The flow of the river Chechło is much smaller, which is immediately visible, but a diversion facility could be considered.

4.1.6 Heat pumps

Heat pumps are steadily gaining popularity in Poland. Air-to-air heat pumps are almost a standard especially for detached houses. Their integration with solar panels is also becoming more common, so they can be considered green energy. There is no doubt that they are indispensable to satisfy the heat demand in any larger area considered in aggregate. In Chrzanów county it is estimated that there are currently 44 995 residential properties. The number of family houses can be estimated at around 3717 [20]. As mentioned in the county characteristics, most flats and houses are connected to the central heating network. It will require not only modification in terms of fuel source giving heat, but also a change in design. Thus, it can be concluded that there is definitely a potential and a need for heat pumps to cover the heat demand. However, it must be remembered that this is an electrical appliance, so their use must ultimately be covered in the energy balance.

4.2 Energy consumption analysis

The data and their analysis in the context of energy consumption in Chrzanów county was provided for the purpose of this study. The data were taken from the document ”Assumptions for Territorial Plan of Fair Transformation of Western Małopolska” prepared by the Marshal's Office of the Małopolska Region [19]. The document itself was developed as part of the EU LIFE integrated project ”Implementation of Air Quality Plan for Małopolska Region - Małopolska in a healthy atmosphere” [23]. This is a EU project whose main objective is to effectively use available EU and national funds aimed at improving air quality in Małopolska voivodeship. Thus, within the framework of this section, the energy consumption values presented for each sector are not the result of independent research, but only the processing of the data provided.

As mentioned in the main assumptions, the analysis consists of 3 sectors: Economy, Buildings, Agriculture and forestry. The economy is largely based on large companies connected with heavy industry, mining, energy and manufacturing. A majority of the economic entities in Małopolska operate in the wholesale and retail trade segment, such as repair of motor vehicles, and in the construction sector. These are mostly micro and small companies, most often run by individual persons, serving the local market. Buildings are mainly understood as the municipal and household sector. These include residential and commercial buildings as well as public utilities. Thus, the subject of this sector is the energy efficiency of buildings with high energy standards. Agriculture and forestry are all kinds of agricultural and cultivation processes, the use of machinery, animal husbandry, irrigation, heating and cooling processes [19]. This sector also has a huge impact on greenhouse gas emissions. For industrial processes, this problem is obvious, but unfortunately it is often underestimated in agriculture.

In addition to the sectoral breakdown, analysis also lists the fuel types used by the sector plus heat and electricity as additional energy demand values. Thus, these are: solid fossil fuels, oil and petroleum products, natural gas, renewables and biofuels, others fuel, heat and electricity. As the aim is to create an energy self-sufficient district based on sustainable, ecological sources ”renewables and biofuels” are not taken into account since they already meet these criteria and don’t have to be replaced. The consumption values of the other energy carriers are treated as energy demand to be met by the green alternative presented in terawatt hours (TWh) in table 4.6.

Table 4.6: Final annual energy consumption of the county from non-renewable sources in TWh

<table>
<tr><td>Specification</td><td>Solid fossil fuels</td><td colspan="2">Oil and petroleum products</td><td>Natural gas</td></tr>
<tr><td>Economy</td><td>0.126</td><td colspan="2">0.023</td><td>0.254</td></tr>
<tr><td>Buildings</td><td>0.216</td><td colspan="2">0.000</td><td>0.248</td></tr>
<tr><td>Agriculture & forestry</td><td>0.012</td><td colspan="2">0.026</td><td>0.000</td></tr>
<tr><td>Total fuels cons. (TWh)</td><td>0.354</td><td colspan="2">0.049</td><td>0.501</td></tr>
<tr><td>Specification</td><td>Other fuels</td><td>Heat</td><td>Electricity</td><td>Total sector cons. (TWh)</td></tr>
<tr><td>Economy</td><td>0.006</td><td>0.029</td><td>0.206</td><td>0.644</td></tr>
<tr><td>Buildings</td><td>0.027</td><td>0.070</td><td>0.258</td><td>0.819</td></tr>
<tr><td>Agriculture & forestry</td><td>0.003</td><td>0.000</td><td>0.005</td><td>0.046</td></tr>
<tr><td>Total fuels cons. (TWh)</td><td>0.036</td><td>0.099</td><td>0.470</td><td>1.509</td></tr>
</table>

4.3 Energy balance model approach

The goal of the energy balance model is to meet the district’s energy needs through alternative energy sources to divest itself of fossil fuels and gas. The approach that was proposed was to analyse each of the identified sectors separately in order to better match alternative energy sources to the specifics of the sector. It was also attempted to ensure that the proposed alternative could cover 100% of the demand of its assigned type of fuel, heat or electricity. The model proposes that the level of diversification of sources is reasonable and consistent with the RES potential of the county. This means that the RES proposals were chosen in such a way that the transition of the region is as simple as possible to realize not only in theory but also potentially in practice. Why? Diversifying energy options is obviously very important. However, it must be remembered that the introduction of each new source has consequences in terms of new investments, new technologies, balancing, control and storage of incoming energy to the system. Therefore, it increases its level of complexity and consequently, its investment and operational costs. Hence, the model was designed to include the necessary components leading to a successful transition.

A flowchart showing the process on which the model is based is presented in figure 4.1. A key aspect in developing the model was of course that the values unified to TWh should coincide, but a second very important aspect was ”utilisation”, i.e. identifying for what purpose the energy from a given fuel is used. This approach allowed a better tailoring of the dedicated green alternative and thus a more appropriate technology to be proposed. The technology proposal is the final step of the model and should be considered as a suggested solution that was selected as far as it is possible and within the knowledge of the actual purposes for which energy is consumed in the particular sector. The model results in each sector were described and interpreted accordingly. The description of individual technologies is in addition to the model, but is an essential part of the overall concept of a potential energy cluster.

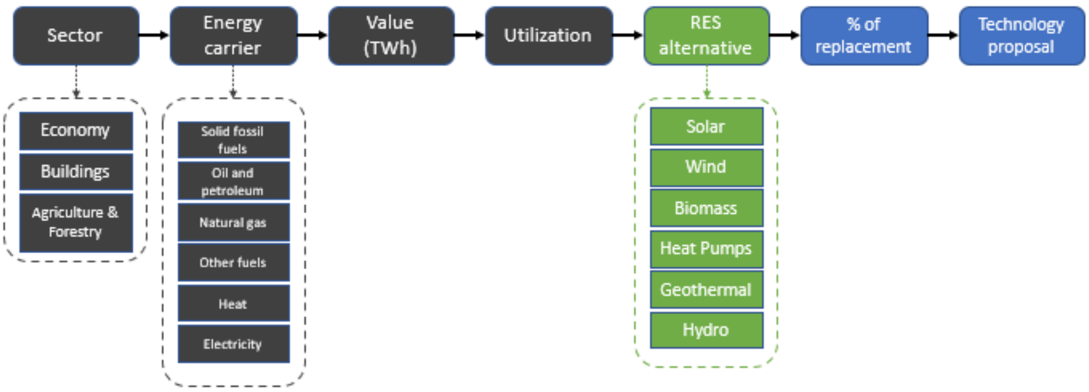

Figure 4.1: Flowchart of energy model development

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To fully illustrate the energy model development procedure, it is useful to analyse the individual steps shown in figure 4.1. For the purposes of the concept, the county's consumption was divided into the 3 sectors described earlier. Based on the data that was provided to the author for the purpose of the paper, the consumption of each energy carrier by each sector was known. All the carriers were also listed on the flowchart. Knowing the value (TWh) that the consumption of each carrier brings, it was then necessary to identify what this energy is used for. This was referred to in the model as "utilization." The next step was to match an appropriate renewable energy source that can meet the requirements of the sector possibly at 100%. The selection of appropriate RES alternatives and the energy balance, as well as the analysis of data on the district's energy potential, was done independently and is an original part of the presented concept.

At the stage of energy balancing, the first major problem was identified. Based on the collected data on RES potential in the county and energy consumption, it was found that under the reference scenarios [21] used to determine the RES potential, the values do not balance. This means that there is simply not enough energy to achieve energy self-sufficiency. The solution to this problem is to assume that Poland, under pressure from current energy trends, will decide to abolish the current 10H rule for wind power. At the time when this concept was developed, there were intensive discussions on lifting the rule. This is absolutely essential, not only for this concept, but also for the entire energy transition of the country. Therefore, taking into account the time horizon of the scenario described in the data source publication, the liberalisation of the wind energy law in Poland was adopted. As a consequence, work continued for the sake of further development of the concept based on the EU-Wide low restriction scenario, with the capacity factor between 20% and 25% as a optimal conditions for considered wind turbines operation.

4.4 Energy model results

The procedure outlined above resulted in an energy model balancing consumption with RES energy potential for each considered sector.

Table 4.7: Energy balance model - Economy

Energy carrier	Used value (TWh)	Utilization	RES alternative	% of replacement
Solid fossil fuels	0.126	Heating	Biomass	100%
Oil and petroleum products	0.023	Electricity	Wind	100%
Natural gas	0.254	Heating	Wind	100%
Others fuel	0.006	Heating	Biomass	100%
Heat	0.029	Heating	Biomass	100%
Electricity	0.206	Electricity	Solar	100%

In the economic sector, energy is used to produce heat or electricity. Solid fuels were replaced by biomass as an alternative heat source, which can be successfully burned in boilers and supply the generated heat to production processes. The same is true for other fuels and for heat itself. Oil and other petroleum products that are used to produce electricity have been replaced by wind energy, while the remaining electricity needs could be covered by solar energy in the form of local micro-grids created for the plants or could be supplied from a local distribution system that receives wind and solar energy. Gas, which is also needed to produce heat, was replaced by wind energy. In this case, the entire change would go further and would require electrification of the heat generation processes.

Table 4.8: Energy balance model - Buildings

Energy carrier	Used value (TWh)	Utilization	RES alternative	% of replacement
Solid fossil fuels	0.216	Heating	Biomass	100.00%
Oil and petroleum products	0.000	-	-	-
Natural gas	0.248	Heating	Solar	70.00%
		Cooking	Solar	30.00%
Others fuel	0.027	Heating	Biomass	100.00%
Heat	0.070	Heating	Heat pumps	100.00%
Electricity	0.258	Electricity	Solar	100.00%

For buildings and the municipal and household sector, most of the energy is for heat production. In this sector, heat is mainly understood as the heating of building space and domestic water. Installations using fossil and other fuels were replaced by biomass in the form of low-temperature district heating and cooling (DHC) networks, which can successfully convert burning biomass directly and warm domestic water or lead to central heating systems, described in more detail in the section on technological proposals. Electricity was covered entirely by photovoltaic panels, which have by far the greatest potential in the study region. The heat itself has been treated as space heating, so it can be safely replaced by heat pumps. The energy needed to power them would also come from PV panels, so the energy expenditure from the pumps was subtracted from the solar pool. Gas is an interesting case here. Its purpose is divided between heating spaces mainly by gas boilers, and gas used for cooking. In this case, electrification of both these branches is required. In the case of heat, electrification would consist of modernising heating appliances and replacing them with electric heaters, heat pumps and other appropriate technologies, while for cooking a modification is needed from gas cookers to electric ones and to induction hobs. The transformation of this sector would also include a number of upgrades to current buildings to increase their energy efficiency such as proper insulation.

Table 4.9: Energy balance model - Agriculture and forestry

Energy carrier	Used value (TWh)	Utilization	RES alternative	% of replacement
Solid fossil fuels	0.012	Heating	Biomass	100%
Oil and petroleum products	0.026	Electricity	Solar	100%
Natural gas	0.000	-	-	-
Others fuel	0.003	Heating	Biomass	100%
Heat	0.000	-	-	
Electricity	0.005	Elctricity	Solar	100%

Modernising the agricultural sector is primarily about replacing the non-renewable energy carriers needed to produce heat in agricultural and crop processes. Here, too, biomass would play a key role and should be used naturally in this sector, as it is mainly produced by it. This would fit in perfectly with the idea of a circular economy [1]. Combustion of agricultural and forest biomass is already widely practised in Europe and worldwide. The demand for electricity could easily be met by photovoltaic power in the form of for example local installations. Energy from oil and fuel products should be distinguished here, as transformation in this aspect would mainly require electrification of agricultural equipment.

Table 4.10: RES potential utilization - summary

RES source	Total RES potential (TWh)	Potential used (TWh)	Potential left (TWh)
Solar power	0.972	0.717	0.185
Wind power	0.313	0.277	0.036
Biomass	0.431	0.419	0.012

The summary in Table 4.10 shows the final balance of renewable potential, utilization, and potential energy stock. The energy needed for heat pumps has been subtracted from the balance described above and is therefore also included in the summary. It can therefore be seen that with the right assumptions, RES can successfully replace the current state of use of non-renewable energy sources. It should be remembered that these are only estimations, which should be directly confronted with the data provided by the county in case of an actual project and transformation of the region. Thus, it can be seen that solar, wind and biomass were utilized. Geothermal and hydropower were dropped mainly because of the inability to assess their actual potential and the fact that they would introduce additional complications into the actual project feasibility study. The theoretical energy balance can therefore be considered feasible, and consequently it can be concluded that the transition of the region into an energy self-sufficient cluster is possible in a broader time horizon.

Table 4.11: Percentage coverage of energy carriers by individual RES

Energy carrier	Total value (TWh)	% converted by RES
Solid fossil fuels	0.354	100% Biomass
Oil and petroleum products	0.049	100% Wind
Natural gas	0.501	50.6% Wind
		40.4% Solar
Others fuel	0.036	100% Biomass
Heat	0.099	29.4% Biomass
		70.6% Heat pumps / Solar
Electricity	0.470	100% Solar

Additionally, table 4.11 provides a summary of the previously described approach to the model itself. It can be seen that the renewable alternatives were selected so as to diversify the substitution of the different energy carriers as little as possible. This approach significantly reduces the complexity of the entire transition and allows for better planning of the modernisation process of individual sectors along with the fuels that are used within them.

4.5 Technology proposal

Since the whole concept is quite innovative, the aim of this part is to present individual technologies which can be also considered as innovative. These are solutions that are not introduced especially in Poland on a large scale, but which would be necessary to carry out a successful transformation of the Chrzanów county. This means that this section is not about a detailed specification of solar panels or wind turbines, but rather focuses on broadly described system solutions responsible for energy production, energy management or storage.

4.5.1 Low-temperature DHC networks

DHC stands for "District heating and cooling". In Poland district heating satisfies 34% of total heat demand [24]. It is at a mature stage and is widely used. However, the partially outdated infrastructure and heavy reliance on coal and heat-only boilers call for renovations. The technological solution proposed in the concept is the 4th generation DH (4GDH) also known as low-temperature DH (LTDH) [25]. Today, 4th generation DH is still considered as an innovative system to replace the existing 3rd generation DH. LTDH reduces the amount of energy lost in converting and transporting energy to buildings. It enables renewable and waste energy sources to be used for heating and cooling, such as solar thermal collectors, biomass-fired heating plants and large heat pumps. It is one of the most cost-efficient technology solutions for achieving 100% renewable and emission-free energy systems on a community scale. Referring directly to the model developed, for the purposes of the concept, the use of primarily biomass in the municipal sector and heat pumps is highly recommended. The transformation of the current fossil fuelled district heating system which is based on district heating knots that supply energy to homes has particular potential. The current system could be successfully converted to use biomass as fuel, but it would require greater effort since Central European countries have more inefficient DH systems designed for higher temperatures supplying an inefficient building stock [25]. The operating temperatures of district heating networks must be then lowered to facilitate the integration of sustainable heat sources. In traditional district heating systems, district heating networks operate at 60-90°C, with heat generated in centralised production distributed to end users. The advent of fourth-generation (30-60°C) heating and cooling systems makes integrating RES easier, and even requires it in many cases [24]. RES-based heating and thermal technologies operate more efficiently when the district heating network operates at a lower temperature so decentralised production facilities and waste heat recovery would replace large central fossil fuel power generation and district heating units, and district heating infrastructure would be used to supply locally generated heat to buildings. With decentralised heat production and distribution, individual solutions are often expected to reduce heat losses associated with distribution because heat will be produced closer to consumption points and transported at lower temperatures. Furthermore, less dependence on imported fossil fuels will contribute to a more secure heat supply. By integrating individual heat pumps at building level, low temperature networks can also provide bidirectional heating and cooling using the same pipes. Nonetheless, such series of modernisation would be quiet challenging from technical point of view.

Apart from this technical barrier there are also some political and regulatory ones. District heating and cooling is affected by numerous laws and policies, at EU, national and local levels. Plus, political action and decarbonization targets tend to focus mainly on the electricity sector. However, given the advantages and disadvantages, it is definitely worth taking steps to implement such systems. Moreover, its implementation when building an energy self-sufficient cluster is simply necessary. By integrating RES into district heating networks, cities have the opportunity to achieve a variety of sustainability objectives, such as addressing local air pollution and mitigating climate change, creating jobs and promoting energy security, as well as building future-proof energy infrastructure, thus making urban areas more liveable. Copenhagen and Vienna are already undergoing this process, with the city's district heating networks delivering increasingly low-carbon heat to residents. LDHC networks have the potential to provide a viable source of low-carbon heat, while simultaneously reducing primary energy consumption. In Chrzanów County, integrating waste heat and additional biomass with the LDHC networks would reduce primary energy consumption and provide a viable source of low-carbon heat. With RES and heat pumps integrated, DHC networks could provide grid balancing services and integrate variable renewable electricity into the electricity grid [25]. This is very important because in the case of energy-neutral areas, energy management resembles a closed circuit, which must be carefully balanced so that no shortages or excessive surpluses of energy occur.

4.5.2 Power to Heat technology - electroheating

This paragraph is indirectly linked to the LTDH sinc e.g. heat pumps mentioned earlier are included in both LTDH and power-to-heat (P2H) [13] categories. However, we have previously focused on heat generation mainly from biomass and renewable fuels. This section is about the conversion of electricity to heat. It takes place in several elements of this concept, as presented in the energy model summary. These devices typically use grid electricity, largely generated from coal, so their use does not necessarily contribute to the decarbonisation of the Polish energy sector. Therefore, the proposed solutions are assumed to use energy generated from the renewable sources designated in the model, namely wind and solar. These are devices from the ”green Power to Heat” (gP2H) category [13]. There are currently a few basic technologies used in gP2H projects to convert electricity to heat [13].

The first of these are resistance heaters. These are large-scale resistance heaters commonly used to heat domestic hot water. They can be flow-through devices or mounted inside a heat accumulator. Resistance heaters work together with hot water storage tanks (so-called storage heaters, boilers). For home heating, a suggested solution could be storage heaters. These devices can draw cheap electricity during periods of renewable energy overproduction to charge and discharge, giving off heat during the rest of the day. Air circulates inside the cooker, which is heated and then blown into the room through slots.

Another option is electric resistance boilers, which work on the same principle as electric water heaters, but are designed for use in installations from a few kilowatts up to a maximum of 5 MW. Whereas electrode electric boilers are more suitable for larger scale projects. The advantage of this type of device is that they show almost zero electricity consumption when operating in the standby phase.Medium-voltage grid-connected electric district heating boilers in P2H technology should ideally be combined with seasonal heat storage to achieve adequate efficiency in the overall system [13].

Obviously, it is also impossible not to mention heat pumps. This is the most mature technology of the mentioned. Depending on the choice of heat source, one may distinguish between air-to-air, water-to-water and ground heat pumps. The latter are generally not recommended in the case of the concept being developed, however, it is possible to set up such an installation on one's own. In order to achieve a 40% share of RES in district heating in 2030, the demand in district heating systems is expected to be an additional 670 MW of power, and in single-family houses and housing several times more - 5.3 GW [13].

Therefore, there is still a huge potential for development of this industry and their use in the described concept can also be qualified as necessary.

4.5.3 Microgrids

The advantage of renewable energy sources is, of course, that they are zero-emission and have no negative impact on the environment. However, the biggest challenge is that they require much more sophisticated methods of controlling and managing the energy they produce. This is what microgrids (MGs) are for, and with the current technological requirements they are absolutely essential. In the case of an energy self-sufficient area, they play an even more important role, because on such a system would be based the ”command centre” responsible for the appropriate distribution of electricity, coming mainly from solar and wind energy. A precise definition is given by the Microgrids Exchange Group: ”A microgrid is a group of interconnected load and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to eneable both grid-connected and island-modes of operation” [26]. For ENDs, we are talking about the second mode. Microgrids that are off-grid by definition operate in the isolated mode, where they are assigned to remote locations and do not have access to macrogrids, where large Distributed Energy Resources (DER) are being integrated more quickly [26].

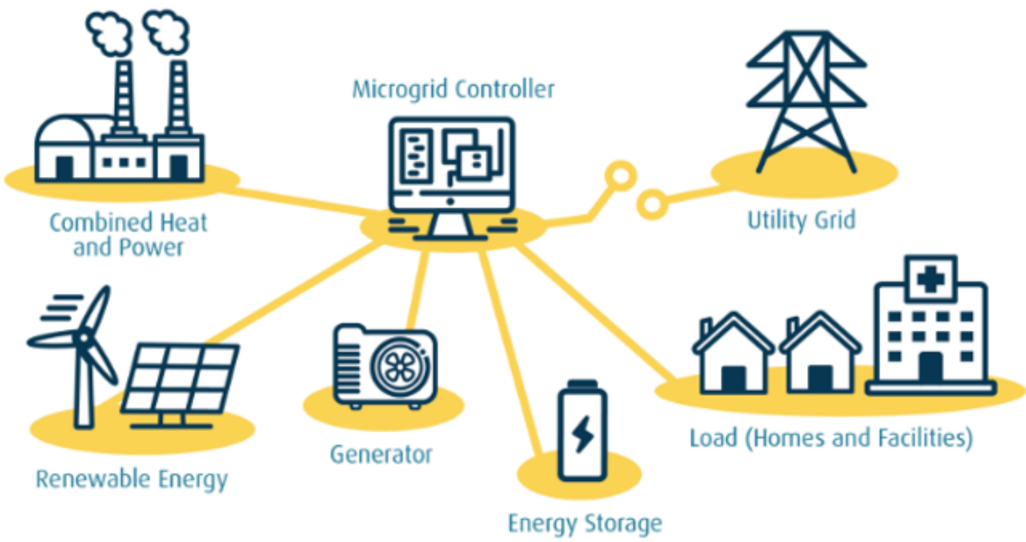

Figure 4.2: Sample microgrid diagram [27]

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Microgrids are a fairly well-known technology, but they become much more demanding in relation to the concept being studied, as the challenges posed by this technology become even more nefarious. The first is control.

MG control is the only significant feature that differentiates them from simple distribution lines with distributed energy resources. Therefore, the control mechanism is usually multi-level in order to provide energy security. There is primary, secondary and tertiary control level shown on the figure 4.3.

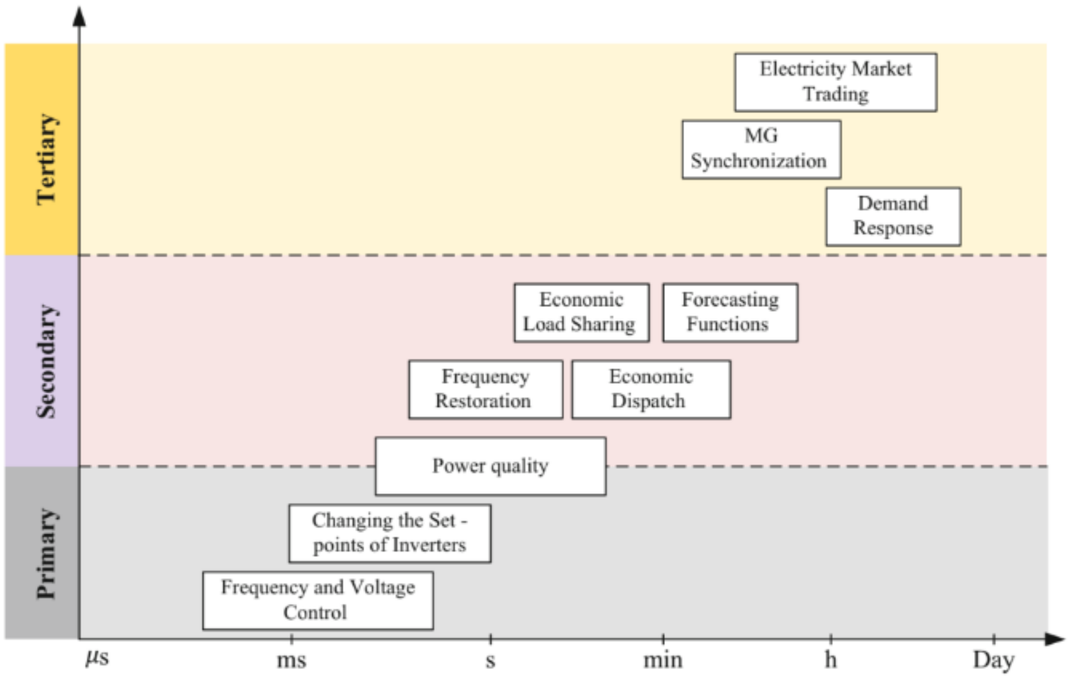

Figure 4.3: Microgrid control levels and their roles [26]

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Another issue to deal with is stability. However, this is where microgrids work at their best. RES are associated with uncontrollable, intermittent and sometimes even random decrease or increase in power generation. A huge effort has been put into research on the stability of grid-connected MGs and islanded MG. Especially for the integration of RES with storage devices. When a MG operates in disconnected mode, so off-grid, it must maintain its own support of voltage and frequency which practically means to balance power generation and load. Luckily, in MGs, there are no such a long transmission lines which often causes limitation of transmission of power between loads and generator by voltage instability [26]. Nonetheless, it is difficult to imagine that one central management centre could meet the control needs of an entire energy cluster. Therefore, for the purposes of this concept, the suggested solution are a so-called ”networked microgrid clusters” (NMCs) [26]. It is a system consisted of two or more microgrids with the ability to exchange energy with each other. The exact architecture of such a system is beyond the scope of this work, however, its idea can be brought closer. In NMCs, power can flow between one MG to another or to distribution system, while the topology of the network are changeable.

While the challenges with this solution are very similar to the general case of microgrids, this solution has a number of advantages [26]:

- **Utilization of DERs** - From the principle utilisation of DERs is more accessible in microgrids networks. Hence, power from wind and solar resources, which are exploited to the maximum in this concept can be easily connected to the multiple microgrids and feed the intended consumers. It can reduce the total system operating costs. Additionally distributed microgrids network vastly reduce uncertainty factor of RES. Moreover, combining it with energy storage system could smooth the power generation and reduce the peak load and facilitates demand response on time.

- **Overall cost reduction** - A study conducted by Los Almos National Laboratory shows that the NMGs solution reduces at least 10% of costs in contrary to traditional distribution network mode [26].
- **Improvement of ancillary services** - smart directioning of power by keeping a balance between supply and demand helps the system to return to normal operational mode when faults in ancillary services occur. These services include regulation, spinning reserve, supplemental reserve, voltage regulation, black-start and others. What is more, it is a forward-looking solution, because if the number of electric cars on the market increases (which it undoubtedly will), this will increase the demand for such services, as electric cars are, in a way, carriers of stored electricity.
- **Improvement of power system resilience** - generally the resiliency of power system is one of the most important features. Distribution of power from RES between microgrids in NMC system increases resilience but also lowers investment costs. Furthermore, as the system resilience is inversely related to the loss parameter, the resilience of NMG networks is higher than that of traditional networks [26]. Where the loss parameter is known as the loss of power network persistence and inability to perform a quick recovery and restoration to the normal operation state after low-frequency high-impact incidents.
- **Improvement of system reliability** - In general terms, electricity system reliability refers to the issue of service interruptions and supply losses. In many cases it is defined as a target to be achieved in terms of indicators directly related to the customer. NMCs improve this feature by making it easier to transmit energy between them, which reduces the risk of supply interruptions during a blackout.

These technological solutions aim to bring the final appearance of a energy self-sufficient region closer. In the case of project implementation, it is assessed that the implementation of the above mentioned solutions is necessary for county's successful energy transition. The detailed architecture is beyond the scope of this work, but without any technological proposals, the concept could be considered incomplete. The implementation of individual elements could undoubtedly provide material for subsequent scientific and engineering dissertations. On the other hand, the research carried out certainly provides a direction for further activities aimed at the transition of the studied county, which is one of the main objectives and assumptions of this paper.

Chapter 5

Community level - Energy community model and social perspective

5.1 Energy community model

An energy self-sufficient area is not only about the balance of energy consumed and produced. It is, above all, a place where people live and where many stakeholders have their interests represented. The idea of completely changing the current state of matters may be welcome to some and unacceptable to others. There are a huge number of innovative projects and initiatives that have not come to life simply because they were socially unacceptable. Therefore, the aim of this thesis and more specifically of this chapter is to outline concrete administrative, management and social solutions, which will make it much easier for the county's stakeholders to deal with the new energy reality.

The structure of this chapter is divided into two larger issues which are the management structure of the cluster and the role of society and local authorities in the energy transition of the region. With a particular focus on the potential opportunities and benefits for the local community in the Chrzanów county. Why are these two issues linked? Because in the case of projects like the building of smart, eco-friendly neighbourhoods, estates or regions, the residents are directly involved with them. This is mainly due to the legal design of residential and energy communities. The dominant ones in Poland are housing associations. They are non-profit cooperatives that can offer benefits to tenants in social housing, although they cannot be involved in decision-making. They have the characteristics of a legal entity and can take out loans and undertake projects [15]. Projects can be implemented by changing tenants' rents. It must be set up by at least 10 individuals or a minimum of three legal entities.

The second popular solution is housing communities, very common in Chrzanów county. They are created by law when the first apartment is separated. It is an association of owners of apartments in a given property. Tenants, as members of a housing community, have certain rights and obligations, but most importantly they have more say in decisions made about the buildings in which they own premises.

However ”Energy Community” is not only residents and homeowners. In the context of this work and this project, the term ”Energy Community” is understood as a collection of key stakeholders whose engagement is required to successfully deliver the energy transformation of the county. Each needs an individual approach, which is why it is important to identify stakeholders in advance so that the new system takes into account the interests and role of each of them. Based on Polish housing policy and the structure of the energy system, within the project, the following stakeholders were identified:

- **Local authorities of Chrzanów county** - the tasks of the county as defined from above in the act on county government are carried out by the ”County Administrative Service”, which consists of organisational units. These include departments, offices and individual independent positions. The organisation of the work of the entire district office is carried out by the district governor. Their competences include, among others, taking care of water supply, disposal and treatment of municipal wastewater, maintenance of cleanliness and order and sanitation, landfill and disposal of municipal waste, supply of electricity and heat and gas; municipal housing, matters of public education; matters of public order and security of citizens; matters of health protection. In addition, the local county authorities comprise the County Board, which adopts resolutions, and the County Council, which elects and dismisses the Board.
- **Residents and local community** - these are residents of the towns and municipalities located in the district. People living in county-owned and owned housing, single-family home occupants. These are people who use public infrastructure such as offices, schools, kindergartens, hospitals. In the project scope, they are primarily concerned with a constant supply of electricity and heat to ensure their living comfort and safety.
- **Małopolska Marshal's Office and other higher institutions** - are the provincial authorities and higher authorities, such as the national government, whose input is also essential for the county's energy transition to succeed. They are, in fact, the first entities on the way to obtaining for example, EU funding, and they have top-down legislative power, so they can facilitate or hinder the transition primarily from a legal and legislative point of view.
- **Distribution system operator (DSO)** - power company engaged in the distribution of electricity, responsible for the flow of electricity in the distribution system, the security of this system in the short and long term, the maintenance and repair of distribution networks, as well as their integration with other electricity systems. For the Chrzanów county the distribution system operator is Tauron Polska Energia S.A. Tauron is a major player in the Polish market and a state-owned company. It is a very important stakeholder who may find such a transformation a challenge, but also an opportunity for development. Hence, what is required is an initiative on the part of entities responsible for the transition of the district and an offer to cooperate with the distributor under new conditions.
- **District heating supplier** - Veolia Południe Sp. z o.o. is a heat provider for Chrzanów county. Its core business is the production and distribution of heat for central heating, domestic hot water and process heat. The Veolia Term Group owns more than 30 district heating systems and 3 combined

heat and power plants. It is simply a service provider, so there is the potential for further cooperation or a change of provider if the need arises.

Knowing the main stakeholders, it is therefore possible to move on to an administrative and management model for the cluster and to find a place for each of them within it. Based on a research and gathered experience, it was attempted to create a unique solutions that take into account the characteristics of involved entities.

5.1.1 Energy community model overview

This part of the project mainly concerns the model, which was independently designed by the author specifically for the development of the concept that is the subject of this work. However, individual components may be based on solutions that already exist or that are recommended in the literature. In such a case, this is appropriately indicated in the paper. The model brings together the business aspect of the whole project and the management structure with a breakdown of the roles of individuals and their responsibilities. Furthermore, it takes into account the broader spectrum of the concept by involving the entities directly related to the district, but also supporting institutions which were considered useful for the concept of an innovative district.

The model is strongly linked to the current municipal characteristics of the district. This means that it incorporates municipal concepts and solutions specific to Poland. These may differ from what the same solutions look like in other countries. Within the description of the model, an attempt was made to illustrate them, but it is assumed that the person familiar with the concept is to some extent familiar with municipal and household sector solutions in Poland.

The idea is to present an overall model scheme and then to introduce the individual components sequentially. Energy community and management model is presented on the figure 5.1.

As can be seen in the diagram, the model consists of three modules. The first of these is called the "Management level". It contains entities, which are understood to be institutions, legal bodies, companies or authorities. Generally speaking, these are the entities responsible for cluster decision-making. A detailed description of the individual stakeholders in this module and how they cooperate is described in the section dedicated to them. The second module is the "Solution Development Team". It contains entities defined as specific individuals holding specific functions, or as a team composed of specialists with dedicated tasks. Essentially, their overall objective is to address the technological challenges of the county energy transition as well as monitoring and maintenance the system. A detailed description of the roles and their scope of work is also given in the section about this module. The third component of the model is a section that can be called advisory. It consists of the Marshal's Office of the Malopolska Region, which is undoubtedly strongly linked to the Chrzanów county. Nonetheless, in the model it has an advisory function mainly in the field of business consulting, fundraising or mediation with the county residents. The second entity is the "Scientific Environment". This name was given for the purpose of the concept and is understood as a mainly technical environment, which could provide advice on technology or data analysis and collection. Often in such projects, the academic environment plays such a role, which is why AGH UST is also proposed here, as it is one of the best, technical universities in the country, which is also closest to Chrzanów county. The entire model was inspired by the Agile management technique [28], but was modified to suit the needs of the project.

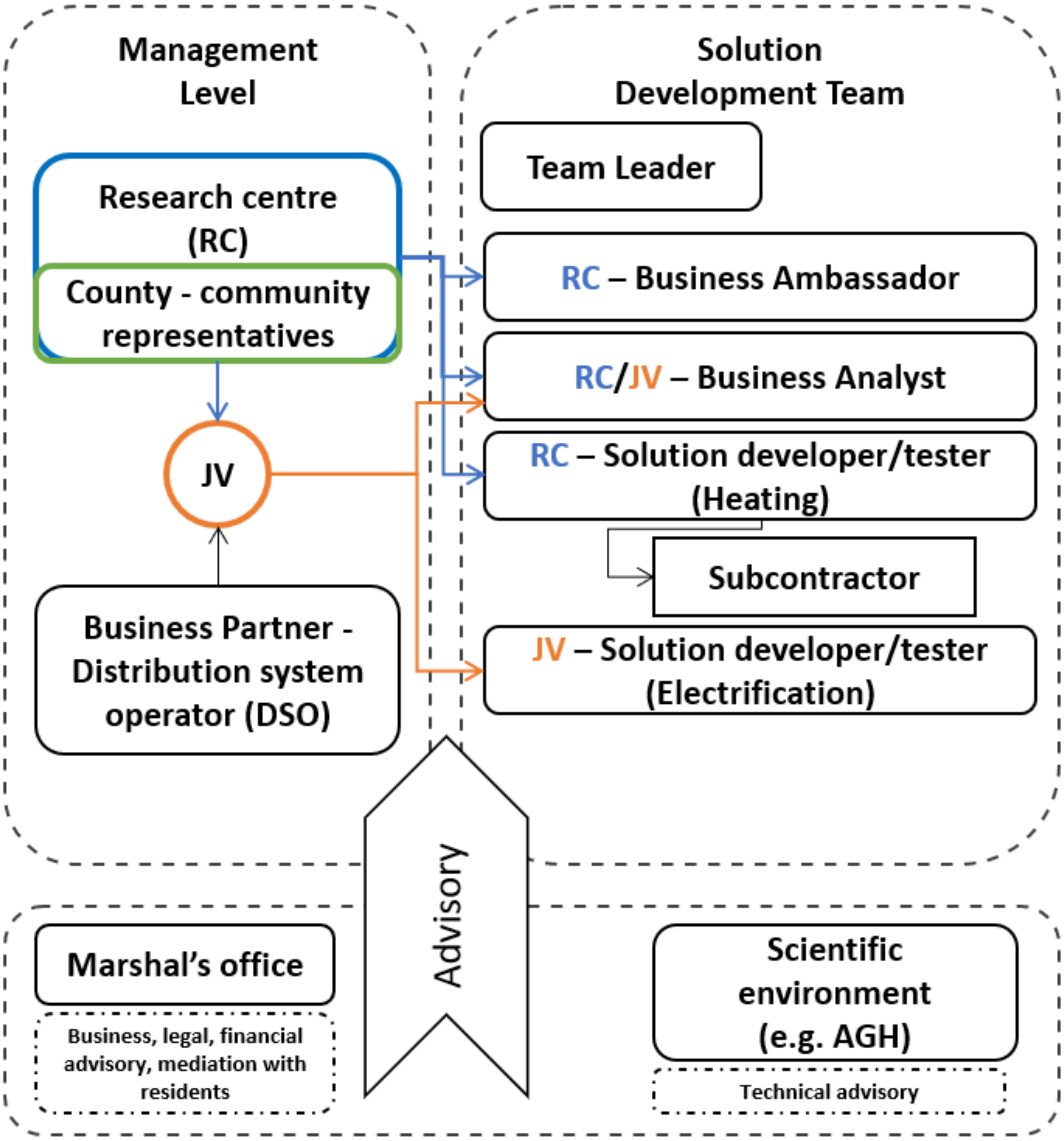

Figure 5.1: Energy community and management model diagram

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5.1.2 Energy community model - Management Level

"Management level" in the view of the whole concept is by far its most important part. This is because it brings together cluster administration, business case, community role and overall decision-making scheme. Therefore it is a multi-layer module that needs to be addressed step by step to be well understood. Hence, the proposed approach is to systematically introduce the different players shown at this level and characterise their roles, justify their presence and describe their interactions with each other.

An energy self-sufficient area, or cluster, can be considered as a separate entity that needs a dedicated coordinator due to its specific nature of functioning. The coordinator is responsible for the development, mobilisation and management of relationships between cluster members and for providing specialised services to members. These specialised services usually relate to energy trading, mediation of contracts between producers and consumers, organising distribution, representing the cluster and managing its development [15]. Based on the accumulated experience of cluster formation in Poland and around the world [15], it is suggested that a dedicated coordinator, often specifically created to manage the cluster, should be identified instead of, for example, an existing, large municipal enterprise. Thus, in the case of this concept, this is what was decided to do. For the broad cluster management described above, it was decided to establish a Research Center that would bring together and employ specialists from the world of technology, law and business, who would have decision-making power in the development of Chrzanów county as an energy self-sufficient area.

The diagram shows that the Research Center includes ”County - community representatives” block. Such a scheme is intended to show that local authorities would also have a vote on the development of the district. As it was outlined, the idea of an energy cluster is one of the best ways to get the local community involved in the country’s energy transition. However, it carries implications. Everything must be done to make the people living in the cluster area, feel taken care of and included in the whole process. This is the only way to gain their trust and count on their involvement, which is absolutely essential. The tasks of those on the local authorities’ side who would be members of the Research Center would therefore be to represent the interests of county residents, mediate between them and other members of the management level, develop methods of informing and educating local communities, and maintain relations and direct contact with the authorities of the Malopolska voivodeship.

A third, significant stakeholder found at the Management level is the distribution system operator (DSO). In the diagram, it is represented as a business partner, for good reason. The DSO in the case of Chrzanow County is the previously mentioned Tauron Polska Energia S.A. It is a huge player in the Polish energy market operating in 7 voivodeships. Its activities include electricity distribution, renewable and conventional power generation, sales, coal mining and broadly servicing its customers through its subsidiary companies and capital groups. In a word, it would be hard to imagine completely abandoning cooperation with a company that has the financial resources, experience and know-how in energy projects. Therefore, the model proposes to invite Tauron to work with the county as a business partner and form a joint venture for the energy cluster project. This is an uncommon solution and rarely seen in Poland. This requires the ability to create a company by the county as well as by Tauron. While the procedure itself is not unusual for the second one, it is not a popular solution for the county. Nevertheless, it is possible as long as the creation of the company is in accordance with Article 4 of the Law on County Self-Government. According to it, the company must serve to carry out public tasks of both municipality and county nature within the scope specified in the law [29]. Transformation of the district into a cluster can be described as taking care of the supply of electricity and heat, environmental and inhabitant's health protection (by, for example, reducing emissions) and even as preventing unemployment. In conclusion, there are a number of arguments why, from a legal perspective, the county can set up a company. The question remains: what is the justification for setting up a joint venture? Like any business solution, this brings with it potential challenges but also advantages. As for the benefits, such a solution has many arguments in favour. The main pros are:

- It is broadly suitable for larger projects with a high investment value and so there is the possibility of benchmark
- JV ensures a clear division of responsibilities
- Mitigation of the risk of a breakdown in the preparatory phase of the project (for example due to lack of funds)
- It guarantees time for the community to identify sources of funding for their share of the project
- Makes it easier to inform the local community about the progress of the project and to hold public consultations (the county, as co-owner, has the right to know what is happening in the project and to inform the inhabitants)
- Possibility of taking out a loan
- County maintains control over resources
- Potential investors would be more reassured having an experienced partner on board
- Design, construction and maintenance can be handed over to a business partner for implementation

Despite all these advantages, the main reason is the aforementioned opportunity to involve Tauron as a business partner, which would primarily provide funds and know-how in the field of renewable energy technologies and microgrids, mentioned in the previous chapter. It is even now possible to apply to Tauron for the construction of microgrids managing photovoltaic installations. This subject is certainly not unfamiliar to them. Therefore JV between the Chrzanów county and Tauron Polska Energia S.A. would perform as a kind of special purpose vehicle which would be responsible for energy self-sufficient county electrification and electric grid management. Tauron, in turn, would benefit in particular from having the prestige and a new area for business development as the first company of its kind in Poland to be involved directly or through a subsidiary in the construction of an energy cluster. In addition, it would gain a permanent business partner with whom he would share clear objectives and be given the opportunity to co-distribute EU and State funds in the implementation of the project. Additionally, given the lifespan of the installation, the operating characteristics of the cluster and the way the micro-installation is operated, it would also have a guaranteed, long-term business relationship and a structured income within its part of the company.

Unfortunately, such a solution also has its drawbacks and challenges. Primary among these is the capital contribution to the company by the county. The capital contribution itself, in the form of funds, could be problematic; fortunately, capital in this case can also be understood as land and residential buildings - generally the area for the construction of renewable energy installations. However, here we return to the topic of housing associations and housing communities. In order to deposit the required capital into the JV company, the owners of the company (in this case, the county in general) would have to persuade people who own land and own flats to make their properties available to them. For privately owned flats, this would be, for example, the roofs of the buildings where the flat is located in order to install the photovoltaic panels. This is unfortunately more difficult than it sounds. There are a number of potential benefits of the county becoming an energy cluster, which are addressed later in the paper. However, they are often quite distant. It would therefore be necessary to first of all compile a list of owner-occupied housing within housing associations and housing communities in order to assess the capital held. Then do the same with the land within the county. Finally, it would be necessary to think of a way to properly address the residents with the idea of forming a company in order to convince them to make their properties available. This is definitely feasible, nonetheless not everybody might be willing to participate in this undertaking. It might occur that the initial capital is not as high as estimated initially due to lower percentage of people contributed. This introduces quite high volatility at the early stage of the project, therefore this particular issue was described in such details, in order to be well understood by anyone who gets familiar with this concept.

Despite the unconventional approach to the ”Management level” of the model, the above solutions have their justification. They are a combination of past good practice (as in the case of the research center as coordinating entity) as well as innovative solutions (as in the case of the joint venture). Thus, it is highly recommended as an integral part of the developed concept of an energy self-sufficient county.

5.1.3 Energy community model - Solution Development Team

”Solution Development Team” (SDT) is a model layer strongly inspired by Agile Management method [28], however it was modified in order to be well tailored to project requirements. Presented roles inside this module are meant to be either single persons who holds specific roles and responsibilities or a group of people who forms a teams and shares a specified objective to provide a technical solution needed for the cluster to operate safely and effectively. It is intended that the people working would answer to the research Center and optionally, depending on their competences, to the management of the joint venture. In summary, this is a strictly task team, which is required to report its work to the management level and thus to the district authority. This guarantees, above all, transparency towards not only the management bodies but especially the local communities. Outlining the individual roles included in this module will certainly give an idea of the overall proposed model [28]:

- **Team Leader** - is a single-person role, which is responsible for ensuring team functions as a whole and meet stated objectives. By design, this is a person who is focused on the smooth functioning of all team members and sub-team representatives and may or may not assist them in their tasks. Works closely with team to plan and coordinate all aspects of product delivery at the detailed level.

He also empowers the STD members and manages the working environment for evolving the solution. This role is not representative of any of the elements that constitute the ”Management Level”. It is a mix of manager and team leader, but with a particular focus on providing high-level leadership to Solution Development Team.

- **Business Ambassador** - is a key business representative within SDT. This is also intended to be a single-person role that provides a significant input into creation and prioritisation of requirements. It is responsible for day-to-day communication between project and business. Within the concept, this is a person from the Research Center, as the Research Center is the superior body responsible for the entire operation of the cluster in terms of the safe provision of energy (electricity and heat). The term ”business” in this case is understood to mean the interests of the stakeholder whose proper operation is paramount. Thus, such a person is main decision-maker to ensure evolving solution is fit-for-purpose to meet business need and to benefit the entire cluster and therefore the county.
- **Business Analyst** - these would be probably two people representing interest of each entities separately - Research center and joint venture company. This role is mainly focused on facilitating relationship between business and technical roles, ensuring accurate, appropriate day-to-day decisions about the evolving solutions in accordance with requirements defined and ensuring that business needs are properly analysed and correctly reflected in solutions development process. This role combines both technical and business case understanding but is not an intermediary between Business Ambassador and the rest of the team.
- **Solution developer/tester (Electrification)** - is intended to be the technical team with a representative person at the forefront. This team’s objective is to interpret business requirements and translate them into a deployable solution within the broad electrification of the cluster. The team as well as its members would come from the JV company which in practical terms would mean that they would be recruited by Tauron and would rely on its experience and know-how.
- **Solution developer/tester (Heating)** - has the same objectives as the case described above but mainly concerning the district heating sector. The team would report to the Research Center, but the delivery of the required, technical solutions itself would be done in cooperation with a subcontractor. This could be the county’ s current heat supply partner, but given the necessary modifications to the system primarily in terms of the heat generation sources used, it cannot be excluded that the supplier of these services could change.

5.1.4 Energy community model - Advisory

Given the complexity of the county’s transformation into an energy cluster, it is difficult to expect that all decision-making processes related to legal, financial, technical and social aspects will take place inside the county authorities. For this reason, additional stakeholders were included in the concept, which are intended to serve in an advisory role, but which would work closely with the units established within the county. This cooperation is proposed to take place mainly with the Research Center and the county authorities, depending on the scope of operations.

The first advisory component of the system should be the Marshal's Office. The Marshal's Office could get involved and assist municipalities and the county in assessing options and steps to engage local governments in the production and distribution of clean energy and other elements of the energy system. Furthermore, the Marshal's Office could also be involved in developing and implementing demonstration initiatives. Such support would demonstrate regional and local commitment to energy transition and could set an example for the whole country.

Examples of specific activities were developed, for instance, in the development of the report "Coalition for a Clean Tomorrow" aimed at assessing the potential involvement of local authorities and communities in the development of energy clusters in the Małopolskie Voivodeship [15]. The role of the Marshal's Office is repeatedly highlighted there. A few suggested solutions possible to implement in the case of the Chrzanów County concept developed in this study are as follows:

- Promotion of coordination, knowledge sharing, effective use of public resources and skills, and economies of scale for public participants, the Marshal's Office may map and prepare an inventory of existing and potential initiatives in western Malopolska (or the entire province).
- Furthermore, the preparation of a map and inventory can enable strategic analysis and framing of green energy development opportunities at the provincial level. This strategic framing would allow for a greater awareness of the opportunity among regional politicians, potential investors and Distribution System Operators (DSO). This context would allow an overview of the potential collective contribution of green energy initiatives to socio-economic transformation and development.
- The Marshal's Office could promote the coordination of local government contact with potential investors and DSOs in order to optimise the potential benefits and constancy of the municipalities' and districts' experience in dealing with these entities. This could minimise the risk of many fragmented contacts between private and public actors private and public and strengthen the collective position of public entities.
- Primarily the Marshal's Office may use its existing internal capacities or procure external specialist support to order to provide legal, financial, economic and technical.
- In addition to specialised support, it is possible to develop standardised materials on potential production and distribution models of clean energy by the local government (pros and cons) and good practices. These materials can be supplemented with a workshop programme.
- What is more, partnership with higher authority level would be necessary - cooperation with the Ministry of Development on the non-emission transformation of the heating equipment sector, the aim of which will be the development of zero-emission and low emission technologies for the supply of buildings in energy and the transformation of Polish manufacturers of heating devices into solid fuels into manufacturers of RES installations [2].

- Manufacturers of RES equipment could receive support through national and regional programs, including funds from the National Center for Research and Development. With a special focus on supporting Polish manufacturers of coal and biomass heating equipment in their transition to the production of RES installations and biomass boilers with higher emissions requirements. [2].

As a second advisory body, within the concept, the scientific environment is proposed. It is very common in such projects to reach out for academic knowledge and people resources. Hence, it is suggested to use the support of, in this case, a university. It would be AGH University of Science as one of the best technical universities in Poland, located in the capital of the Malopolska voivodship, Krakow. The team established for the development of the energy cluster would be employed on a salaried basis at the university and their task would be to advise on technological and IT solutions within the project scope.

To summarise the whole model described above and all its elements, the solutions presented are obviously a series of proposals, but they have been created and arranged in such a way as to form a coherent unity. It covers the administrative structure, considers the legal and business aspects and even presents the role-based cluster management model in detail. It is therefore considered that, in this respect, the paper provides a comprehensive picture of the concept in terms of organising work of the district.

5.2 County energy transition from a community perspective

Within the scope of the project "community" is understood as local stakeholders such as residents, county infrastructure day-to-day users and local authorities. All of them are facing different type challenges during energy transition process. However, they are all equally important to overcome in order to begin and successfully complete the county's transformation into an energy self-sufficient district.

5.2.1 Social and legal challenges in the face of county transition

The multi-level nature of the county's energy transition is repeatedly mentioned throughout this thesis. The aim of this section is to take a closer look at the challenges that face local authorities as well as end-users in this matter. In the energy transition, the key role is played by the end-users as they are the stakeholders for whom this transition is primarily being held, who will make decisions and act based on their motives and social-value orientations [5]. Thus, it is the job of those in power and with the capacity to do so, to facilitate guiding the main users through the transition process by identifying and developing a plan to overcome the main social and legislative obstacles. A number of current and potential issues related to this topic are outlined below:

- Studies have shown that cluster strategies are often partial, uncommitted, and primarily focused on the benefits of cheap energy rather than the broader socio-economic benefits. In addition, strategies need to be linked to other energy system objectives, like improving the environment, enhancing energy efficiency, and managing demand. The research highlights the lack of detailed conceptual justifications for local energy projects [15].

- Some local authorities lack the knowledge of how to deal with the social challenges of the mining transition. Local authorities are often not prepared to take on new responsibilities and propose effective policies to support economic activity in their municipality. Especially in smaller municipalities, this situation is unfortunately common [18].

- As a result of the imbalances in the energy system that it causes, studies indicate that the cluster faces financial liabilities, and it does not have access to a settlement system like an housing associations. It is time-consuming, costly, and bureaucratic to negotiate access to electricity in Europe [15].

- Lack of investment areas in the municipalities; in particular, there is a lack of developed, functionally integrated and well-connected investment areas. This makes it difficult to attract investors and inhibits the development of entrepreneurship. In addition, the dominance of traditional industry over companies investing in new technologies is still visible in the region of Malopolska and Chrzanów County [18].

- The Western Małopolska region (where Chrzanów county is located) is highly industrialised, especially around the mining municipalities. The economy of these municipalities is largely based on the mining industry and thus guarantees a huge number of jobs. A large part of Polish society is unaware of the changes taking place (especially in Europe) in the energy sector. For this reason, there is often fear of losing jobs and earnings, which in turn generates aversion and lack of trust towards projects such as the one that is the subject of this work.

- Moreover, for over 100 years, the coal industry has “always” provided jobs, often for entire families. In these traditional coal mining areas, a certain social status is attached to these jobs, which has contributed to the creation of a cultural identity with a strong ethos of work [18].

- The installation of renewable energy systems itself requires not only technical or engineering effort, but often the simple consent of the end users. This is not always so easy and often requires a clear presentation of the real benefits.

- The transition process itself is almost always long and is often associated with unexpected problems that arise on an ongoing basis. Therefore, there is a demand for reliable and specialised staff to be hired, often in locations that are less attractive to live in, and who are additionally willing to sign a long-term contract and live on site.

- On legislative matters, recent research work and commentaries indicate that the members of energy clusters and the clusters themselves are elements of a very complex legal and regulatory structure, which makes it very difficult to understand the mutual correlations and use the know-how. The key elements of this structure are the Polish Energy Law, the Renewable Energy Sources (RES) Act, the Public Procurement Act and the Local Government Units Act. In the RES Act, which is the basis for the operation of clusters, the provisions are very concise and require interpretation [15].

- The diversity in organisation and lack of legal personality of energy clusters makes it difficult to compare and learn from other forms of local energy production and consumption such as energy associations. The preparation and signing of a partnership agreement between cluster members is fairly straightforward, the challenge is the interpretation and application of rules and regulations.

5.2.2 Potential benefits and public incentives

For most of the concept described, there was a lot of mention of technical, legal, organisational, administrative or social challenges. But let's not forget that this whole project, this whole transition of the county into an energy cluster, is not just a test of ambition for local authorities or engineers. First and foremost, its primary objective is generally to improve the standard of living of the district's residents and to increase the energy security of the district, but also it is safe to say that of the entire country. It is natural that people are afraid of change. It's natural that people don't need to know everything and see the bigger picture right away. Thus, the key role of those who win elections, those who take responsibility for their cities and the people who live there, and those who have the privilege of being educated and aware of the global climate situation, is to do everything possible to show as many benefits as possible and create as many incentives as possible for people to be eager for changes that are essentially good for them. The aim of this section is to present a range of instruments and activities to encourage local communities to take a real part in the energy transition process in Chrzanów County. Because, as it has been mentioned many times before, all hands on board are necessary for such a transformation to be fully successful. The literature and the examples described therein indicate that although local energy projects do not require the community and local entrepreneurs to be stakeholders (members), the involvement of local organisations, businesses and skilled and knowledgeable individuals can be beneficial [15]. These benefits can be linked to four broad intersecting categories: developing distributed, cleaner, cheaper energy for consumers (not just public entities); promoting energy security and efficiency; stimulating local economic and social development; creating consensus for broader community transformation. Therefore, referring to these categories, below are a number of good initiatives and positive arguments supporting the idea of an energy self-sufficient county in social perspective.

- Local participation in clean energy can be encouraged by the possibility of achieving better value and lower prices for local consumers and residents. As a result, consumers can better manage their electricity spending because of better quality and a more reliable energy supplier, lower electricity bills or more stable and predictable electricity costs [15].
- The development of local energy solutions can also be encouraged by the potential for income generation. The revenue generation potential and associated risks will depend on the operational model chosen by the local administration and community, while appropriate revenue estimation is one of the most effective methods for dialogue.
- Another benefit is an increase in the value of the property financed by external measures. e.g. insulating the house with county money or installing PV as part of a transition programme [15].

- The participation of local authorities and communities in green energy projects can also be motivated by their potential to create jobs during the construction or operation and maintenance phase.
- Additionally, such projects guarantee future employment and opportunities for young people especially from smaller towns or counties.
- As it was mentioned, this is a region strongly based on mining-related professions. Such people have qualifications (e.g. engineering, metalworking, welding) and skills (e.g. for construction work) that could give them the opportunity to gain an employment outside the mining sector, which will systematically fade over time [18].

In addition to material and livelihood matters such as earnings, income-generating potential or jobs, it is very important to simply work with people and care about their awareness. Here are some examples of how something like this can be done:

- First of all intensive educational and information campaigns and actions should be carried out aimed at the general public. Their goal should be both to show the implications of climate change and its impact on the lives of residents, as well as to shape the right attitudes, actions and choices. A set of sample topics has already been proposed in the "Regional Climate action and Energy Plan" developed by Marshal's Office of the Malopolska Region, and it is believed to fit perfectly with the scope of the project. Suggested topics of the educational campaign are [2]:
  1. climate change, its effects and the need to take action to combat it,
  2. installations of renewable energy sources, improvement of energy efficiency of buildings and energy-efficient construction,
  3. reduction of energy and water consumption, minimization of waste generation,
  4. the needs and principles of the circular economy,
  5. reducing the negative effects of intensive agriculture, protecting natural resources.
- Another simple option is to organise events and maintain communication in local communities. Increasing the ecological awareness of residents is necessary to gain social acceptance for the planned activities and to obtain the necessary level of social involvement in activities.
- Training and certification of installers, designers and architects in RES installations. Creation of a training and certification program for installers of low-carbon heating devices and RES installations for residential existing and new buildings, installation warehouses, retail inspections, construction supervision inspections, as well as technical schools. As a result of the activities carried out, a list of certified installers of RES installations in Małopolska could be created [2]. For example, in Fleuraye, France, there is a positive energy district where construction professionals and specialised trainers are put together in contact with one another so that they can acquire the sharp technical bases induced by passive-haus buildings [5].

- Involving the local community in decision-making can increase public legitimacy and reduce potential opposition to clean energy projects. An interesting way to do so was introduced in Limerick in Ireland. There is a PED (+CityxChange project) where local authorities use ”Citizen Observatory” system. This is a digital platform for increased citizen understanding, ownership and active participation including interactive mapping which will be put in place, enabling a 2- way dialogue regarding the aims, goals, motivations and ambitions of the communities with the urban authorities [5].
- A more traditional approach like collecting surveys in an online format can also be effective and would make residents feel that their voice matters, as long as the survey structure and questions are well-designed.

In summary, a lot of positive things can result from the creation of an energy cluster from the Chrzanów county. Everything really depends on the development of the plan and the execution of the adopted assumptions. After reviewing the challenges as well as the potential benefits of the transformation, it can be deduced that it is very important to achieve as many synergies as possible between end users, business and local authorities of the county. The listed initiatives are primarily designed to enable these synergies and can inspire possible social actions if the concept is implemented. Thus, within the framework of the concept being developed, it is highly recommended that the listed arguments be taken into account and should be treated as an indivisible part of the entire concept of transformation of the county.

Chapter 6

Financial level - Costs assessment and funding

6.1 Investment and maintenance costs assessment

Renewable energy projects are now so popular that their investment characteristics are fairly well known. They are characterised by high investment costs (CAPEX), but relatively low operating costs (OPEX). Energy clusters and especially self-sufficient clusters are unfortunately not that well known, but as they by definition consist of RES installations, it is possible to estimate (with a high tolerance) the costs, especially of investment. Thus, the main purpose of this section is to give an approximation of the expected expenses associated with the construction of a clean, green energy installation, according to the energy model proposed at an earlier stage of concept development. A significant part of the costs in such cases is covered by state and EU funds, but this topic will be covered in the next section of this chapter.

At this stage, some assumptions were made regarding this part of the model. Due to limited data availability and current geo-political and economic uncertainties, it is extremely difficult to rely on forecasts of macroeconomic indicator and commodity prices. Even the World Bank itself does not undertake long-term, annual forecasts. For this reason, at the financial level of the concept, calculations of indicators such as IRR, NPV, or EBITDA were not attempted and are considered beyond the scope of this work. The calculations were limited to estimating investment and operating costs in order to give a baseline so that it is known what is the order of magnitude of the funds required for the transformation of the county.

The project distinguishes 4 types of RES installations: Wind, solar, biomass and heat pumps. CAPEX and OPEX were estimated for each of them. The values were converted into euros based on the exchange rate forecast by the Polish Ministry of Finance. Moreover the OPEX estimations were based on the recent inflation forecast provided also by Polish Ministry of Finance in the document: ”Guidance on the use of uniform macroeconomic indicators as a basis for estimating the financial impact of proposed acts. Update - April 2022” [30] The OPEX base year is 2021, due to the availability of data on the costs of RES installations, hence 2022 is taken as the potential first year of realisation. Taking into account the average lifespan of the installations, i.e. 25 years, the investment cost projections therefore reach 2047.

6.1.1 Wind installations - cost estimations

On the basis of the "Polenergia" Group's report [31] on its financial results for 2021, an estimate was made of the financial outlay that could be expected to be incurred if the construction of the energy cluster were to go ahead. The installed capacity was taken from the energy model of the district concept, while the baseline data series is presented in the table respectively.

Table 6.1: Wind farm - CAPEX estimation

Required wind farm capacity (TWh)	0.313
Required wind farm capacity (MW)	86.8
Construction cost per MW (M EUR)	1.48
Project CAPEX (M EUR)	**128.1**

Table 6.2: Wind farm - OPEX estimation for the base year (2021)

Required wind farm capacity (TWh)	0.313
Required wind farm capacity (MW)	86.8
OPEX per year per MW (thou.EUR/MW/year)	44.1
Project OPEX for base year 2021 (M EUR)	**3.82**

Table 6.3: Wind farm - OPEX forecast

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Project OPEX (M EUR)	3.95	4.07	4.18	4.28	4.39	4.50	4.61	4.73	4.85	4.97	5.09	5.22	5.35

Year	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047
Project OPEX (M EUR)	5.48	5.62	5.76	5.90	6.05	6.20	6.36	6.52	6.68	6.85	7.02	7.19	7.37

Data obtained from a report by the Polenergia Group shows that for a wind installation of annual power production equal to 1 MW, the investment cost is approximately €1.48 million. Considering that wind energy capacity could reach 0.3125 TWh, the CAPEX of a wind installation in the county was estimated at €128 million, since a 86.8 MW wind warm would be needed. For operating costs, the cost was estimated also based on the "Polenergia" Group's report at €44.05 thousand per year, meaning that for maintenance and other operational activities, the OPEX in the base year would be €3.82 million [31] OPEX for the subsequent years of operation of the plant from 2022 onwards is shown in Table 6.3

6.1.2 Solar installations - cost estimation

For the solar energy potential in the county, it is assumed that these will most likely be photovoltaic panel installations. The energy model shows the total potential solar PV capacity in the county, which would consist of ground-mounted solar PV farms and domestic installations, which are customarily mounted on the roofs of users' homes. However, at the stage of estimating installation costs, such approach is unacceptable, mainly due to the scaling effect of photovoltaic farms, which significantly reduces the investment costs per MW compared to a domestic installation. On the other hand, the operating costs for a single installation on the roof of a house with a capacity of a few kW are negligible in a project perspective, so no prediction was made for them. For this reason, the solar part of the project was divided into ground-mounted installations, i.e. photovoltaic farms, and roof-mounted installations. The data for the individual potential values of the generated power were also developed on the basis of the ENSPRESO dataset, following the methodology described for the energy model.

Table 6.4: Solar ground installations - CAPEX estimation

Required installation capacity (TWh)	0.797
Required installation capacity (MWp)	797
Construction cost per MWp (M EUR)	0.45
Project CAPEX (M EUR)	**360.01**

Table 6.5: Solar ground installations - OPEX estimation for the base year (2021)

Required installation capacity (TWh)	0.797
Required installation capacity (MW)	221.47
OPEX per year per MW (thou.EUR/MW/year)	15.42
Project OPEX for base year 2021 (M EUR)	**3.41**

Table 6.6: Solar ground installation - OPEX forecast

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Project OPEX (M EUR)	3.53	3.63	3.73	3.82	3.92	4.02	4.12	4.22	4.33	4.44	4.55	4.66	4.78

Year	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047
Project OPEX (M EUR)	4.90	5.02	5.14	5.27	5.40	5.54	5.68	5.82	5.97	6.11	6.27	6.42	6.58

Table 6.7: Solar roof installations - CAPEX estimation

Required wind farm capacity (TWh)	0.175
Required wind farm capacity (MW)	48.58
Construction cost per MW (M EUR)	0.73
Project CAPEX (M EUR)	**35.31**

Based on a research [32], it was determined that for large-scale PV farms the cost per MWp is €0.45 million. Assuming according to the solar potential of the county, the achievable capacity would be 0.797 TWh which means that the CAPEX of the installation would be €360 million. This is by clearly the largest amount of those appearing in this part of the model. However, solar energy has by far the largest potential in the county and accounts for more than half of the county's annual energy needs. For rooftop installations, the energy potential was 0.175 TWh. The capacity of such installations is often given in kW, so the investment cost per kW was also taken to be approximately €727. The total CAPEX was therefore estimated at €35 million. It is worth noting here the operating costs, which in the base year were estimated at €3.41 million. This is marginally less than for wind farms, despite more than twice the power generated. This is justified because photovoltaic farms have extremely low operating costs compared to other RES installations. It can therefore be deduced that investment in this green energy source is beneficial for the optimisation of energy systems, especially in energy clusters.

6.1.3 Biomass installations - cost estimation

Biomass installations are problematic when it comes to assessing their costs because of their diversity. Both feedstock and the way it is combusted and converted into energy can vary widely. The concept presented here allows for different types of biomass from agriculture, forestry and waste, but for the purposes of this section, it was decided to standardise these technologies to one which, according to the concept, would have the greatest utilisation potential. Furthermore, it is stated as a matter of principle to anticipate a "worst case scenario" for any kind of estimation. Therefore, according to this approach, the most expensive option for biomass boilers for district heating was taken as such a scenario [13].

Table 6.8: Biomass installations - CAPEX estimation

Required installation capacity (TWh)	0.431
Required installation capacity (MW)	119.68
Construction cost per MW (M EUR)	0.64
Project CAPEX (M EUR)	**76.45**

Table 6.9: Biomass installations - OPEX estimation for the base year (2021)

Required installation capacity (TWh)	0.431
Required installation capacity (MW)	119.68
OPEX per year per MW (thou.EUR/MW/year)	35.24
Project OPEX for base year 2021 (M EUR)	**4.22**

Table 6.10: Biomass installations - OPEX forecast

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Project OPEX (M EUR)	4.36	4.49	4.61	4.72	4.84	4.96	5.09	5.21	5.34	5.48	5.62	5.76	5.90

Year	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047
Project OPEX (M EUR)	6.05	6.20	6.35	6.51	6.68	6.84	7.01	7.19	7.37	7.55	7.74	7.93	8.13

The estimated averaged capital cost ratios for biomass boilers was €0.64 million per MW. Thus, with a potential of 0.431 TWh, the CAPEX of biomass projects was estimated at €76.5 million. In contrast, the OPEX, which for the base year was €4.22 million, may seem exceptionally high compared to the previous two renewables. Nevertheless, it should be remembered that biomass plays a huge role in the concept described, especially in district heating, so the annual demand for biomass is enormous. In addition, such installations have not yet achieved the same economies of scale as photovoltaics, which significantly increases annual operating costs.

6.1.4 Heat pumps - costs estimation

The costs of installing heat pumps were estimated based on the same source as for biomass [13]. It is a fairly common technology for both air-to-air or air-to-water systems. It is often associated with split house installations or larger sanitary installations. These are therefore systems that supply heat to individual residential units.

Table 6.11: Heat pumps installations - CAPEX estimation

Required installation capacity (TWh)	0.07
Required installation capacity (MW)	19.38
Construction cost per MW (M EUR)	0.77
Project CAPEX (M EUR)	**14.94**

Table 6.12: Heat pumps installations - OPEX estimation for the base year (2021)

Required installation capacity (TWh)	0.07
Required installation capacity (MW)	19.38
OPEX per year per MW (thou.EUR/MW/year)	77.09
Project OPEX for base year 2021 (M EUR)	**1.49**

Table 6.13: Heat pumps installations - OPEX forecast

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Project OPEX (M EUR)	1.54	1.59	1.63	1.67	1.72	1.76	1.80	1.85	1.89	1.94	1.99	2.04	2.09

Year	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047
Project OPEX (M EUR)	2.14	2.20	2.25	2.31	2.36	2.42	2.48	2.55	2.61	2.68	2.74	2.81	2.88

Despite the standardised technology, the investment cost for 1 MW is quite high compared for example to biomass - €0.77 million. Using an assumption according to the energy model, where the capacity delivered by heat pumps is 0.07 TWh, the CAPEX of the project is €14.94 million. The annual OPEX per MW was estimated at 77.09 MW, so operating costs for the base year would be approximately €1.49 million as presented in table 6.12 The investment cost forecast is shown in Table 6.13. It can be seen that the annual cost is indeed the lowest of all the proposed technologies, but it is still relatively high for the amount of energy supplied. This is due to the relatively low energy efficiency of the installation and the lack of achieving the previously mentioned economies of scale, which are difficult to achieve with many single household systems.

6.1.5 Project CAPEX summary

Summing up, the total CAPEX including the renewable energy technologies used in the concept was estimated at €614.8 million. Of course, in reality, investment costs also spread out over time depending on the development and implementation plan of the project. Moreover, the pace at which individual investments are realised is often dependent on the pace at which the relevant funds are raised. This means that both investment and operating costs will fluctuate over the years as macroeconomic indicators dependent on the global geopolitical situation change. There is no real reason to summarise operating costs, given the lack of a schedule for implementing the concept. It is highly unlikely, in fact impossible, that all of these installations would be built together at one point in time. This is inconsistent with previous assumptions and contrary to the definition of conducting an energy transition on any scale. It would only make sense to estimate the total operating costs of the district energy system once an appropriate project time horizon has been developed and the implementation of its individual parts has been planned in detail.

Table 6.14: Project CAPEX summary

Specification	CAPEX (M EUR)
Wind installations	128.12
Solar installations	395.32
Biomass installations	76.45
Heat pumps	14.94
Total	**614.83**

6.2 Potential sources of funding

Poland is a member of the European Union, which is the main promoter of initiatives to deal with the negative effects of climate change. One of the main consequences of membership is that it is required to adapt to EU policy, which largely involves changes in the energy sector. There is no doubt that this is one of the most money-worthy sectors. This was demonstrated even by the analysis of this project at a financial level. The CAPEX was estimated to be around €614 million and we are talking just about a county transition. Fortunately, behind these ambitious plans there is also funding to support national energy restructuring projects. However, the national government has a huge role to play here, with the task of applying for and obtaining such funds, as well as managing and redirecting them appropriately to suitable investments. Their task is also to distribute the funds among the voivodeships. Here again, the same task arises, but this time at the level of voivodeships and local governments - to develop restructuring plans and obtain funds for their implementation. So from an administrative point of view, it is one big, multi-level competition between local authorities. That being said, how has the Małopolska region, which includes our Chrzanów county, performed in it so far?

In January 2021, an allocation of €247 million was planned for Western Małopolska from the Fair Transition Fund (pl. *Fundusz Sprawiedliwej Transformacji*). Meanwhile, this is not the only support. It is estimated that additional funds are expected to flow from the National and Regional Operational Programmes (KPO, RPO), as well as from Pillar II and Pillar III of the Fair Transition Mechanism (pl. *Mechanizm Sprawiedliwej Transformacji*. The absorption potential of the area is estimated to be around PLN 3 billion (€660 million) by 2030. Of this, approximately PLN 340 million (€ 75 million) relates to projects ready for implementation [19].

From a country perspective, on the basis of the already mentioned document describing Poland's energy policy until 2040, it is known that the quoted amount of the national energy transformation by that time is PLN 1 600 billion (€352 billion) [14]. Accordingly: "Investments in the fuel and energy sectors will involve financial resources of approximately PLN 867-890 billion (€191-€196 billion). The projected outlays in the electricity generation sector will reach ca. PLN 320-342 billion (€70-€75 billion), of which approx. 80% will be earmarked for emission-free capacity, i.e. RES and nuclear energy" [14]. The consequence of such dramatic changes in the energy field could be a temporary increase in energy costs for end users. This is why it is so important to obtain funds not only for the construction or restructuring of the national energy infrastructure itself, but also for the mitigation of price shocks for consumers and the fight against energy poverty. Besides, the national energy transition is spread out over time. According to the Climate Ministry's plans, around PLN 260 billion (€57 billion) of EU and national funds will be allocated for this purpose until 2030.

The list of financial instruments dedicated for this purpose is set out below. For programmes and instruments created under Polish national policy, the titles were translated and their Polish original name was also provided for clarification [14]:

- Cohesion Policy (pl. *Polityki Spójności*): approx. €17 billion,
- Instrument for Reconstruction and Resilience (pl. *Instrument na rzecz Odbudowy i Zwiększania Odporności*): approx. €21.5 billion,
- Fair Transformation Fund (pl. *Funduszu na rzecz Sprawiedliwej Transformacji*): allocation for Poland of approx. €3.5 billion,
- ReactEU: approx. €0.4 billion
- Other instruments: approx. €4.4 billion
- new instruments like the Modernisation Fund and a national special-purpose fund fuelled by funds from the sale of CO_2 emission allowances, i.e. the Energy Transformation Fund: above €10.5 billion.

As mentioned, each region of the country has to apply separately for a given share of the funds indicated above. This is why the role of local authorities is so important to create programmes and initiatives that have a realistic plan and feasible target. The concept of an energy self-sufficient county fits into most of the objectives for which funds are raised regionally. The Regional Climate action and Energy Plan [2] cited many times in this work provides a set of programmes written to realise the goals of sustainable energy development in the Małopolska territory. Funds obtained from these programmes could support the realisation of the concept of Chrzanów County as an energy cluster. The main purpose of this list, however, is to show that the much-needed money for this concept can indeed be obtained if the assumptions and plan of the concept are well presented as a coherent proposal.

- Program LIFE: €15.5 million - For implementation of the Regional Energy and Climate Action Plan,
- Regional Operational Programme of the Malopolska Region for the years 2021-2027: no data available regarding the amount - For energy and environmental activities,
- Clean Air Programme: €1.8 billion - For improving the energy efficiency of single-family buildings,
- Program Stop Smog: €55 million - For improving the energy efficiency of buildings for people affected by energy poverty

- Thermo-modernization relief: €440 million - For energy efficiency and renewable energy improvement measures,
- My Current Program: €22 million - For purchase and installation of photovoltaic panels on single-family buildings,
- Own resources of counties and communes: no specific data available regarding the amount - Activities in the field of air protection, energy efficiency and renewable energy sources

Chapter 7

Work to be done - What to do to make the concept a reality

Within the study, the scope of the concept was outlined in detail. The final form of the concept was presented at a technical, administrative, management and financial level. However, a lot of work still needs to be done in order to make the transition of Chrzanów County into the most innovative energy region in the country even theoretically possible. This short chapter is intended to indicate some basic points that should be on the agenda of both local and regional authorities as well as those responsible for the national, sustainable transformation of the energy sector in Poland. Since, as highlighted throughout this thesis, multi-level involvement is needed to implement such a concept, starting with government structures and finishing with end-users.

The first point is action at the national level in terms of legislation and regulations concerning both energy clusters as legal entities and the general operation of RES in Poland. First and foremost is the simplification of the legal structure that would facilitate the construction of energy clusters across Poland. Their organisational diversity and lack of legal personality makes it difficult to compare and learn from other forms of local energy production and consumption. The main problems at the moment are the lack of clear guidelines for cooperation with Distribution System Operators. DSOs are usually required to sign contracts for the distribution of electricity generated under the RES Act. Yet, the research findings indicate that there are no other provisions for this kind of cooperation [15]. A proposal to partially solve this problem is to enter into a close cooperation between the county and the DSO in the form of a joint venture, described at the ”Community level”. However, is it quite easy to imagine that this unusual solution might encounter administrative difficulties. Here, the Polish government should play a key role to facilitate these innovative solutions by legal simplification of such processes and empowering local authorities to make necessary decisions. Fortunately, an update to the RES Act has been announced, which addresses the topic of energy clusters. According to it, the basic mechanism of preference for energy clusters will include exemption from the RES fee, cogeneration fee, excise duty and obligations related to certificates of origin in relation to electricity generated from RES by members of the energy cluster and consumed by members of the energy cluster for each hour of the settlement period. Reduction of distribution rates has a significant impact on the profitability of the energy cluster and therefore the whole project.

Furthermore, remaining on the subject of administrative and legal problems, it is essential to open up the potential of renewable energy sources in Poland as much as possible. In the context of this work, this mostly includes the lifting of the previously mentioned 10H rule [10], which, as it is worth recalling, blocks the possibility of a county to achieve energy self-sufficiency. The changes should also apply to heating and cooling. Regulations concerning guarantees of origin, generation and grid connection of heat from alternative sources such as the low-temperature fourth-generation [24] system proposed in the concept should be adapted and simplified accordingly. Without such action at national scale, it does not matter how much local and municipal authorities will be mobilised to come up with new clean energy projects. Confusing procedures will cause huge delays in the implementation plan and consequently massive costs, which most counties and communities cannot afford with an already expensive undertaking like the regional energy transition. Therefore, the first most important assumption is undoubtedly the mobilisation of the government in this regard.

The next major and very concrete step is to establish a timeline for the county' s transition to an energy self-sufficient district. As mentioned in the fundamental assumptions of this study, setting such a timetable goes beyond its scope. By design, the concept presents a final picture of the Chrzanów County with proposed solutions. However, the importance of proper planning of the implementation of the presented concept cannot be neglected in this paper. Without a proper strategy and the people who are responsible for it, even the best concept has no chance to be realised in the real world.

The greatest challenge identified during the development of this concept is to properly synchronise actions on exactly the same 3 levels on which the whole concept was built - technical, community and financial. Assuming that a decision is taken to create a self-sustainable energy cluster in the Chrzanów county, the basic, first challenge would be to gather the right people who are able to create such a strategy. Their task would be to develop a detailed timeline that would include:

- the establishment of a central management unit,
- the development of a timetable for community measures - probably starting with a public consultation
- synchronisation of the whole project with the funds already held and potentially held and a long-term fundraising strategy.

In addition, all these elements must comply with top-down legislation in the country. Only once you have established a solid base and a development strategy is it possible to think about the next steps, which are closer to the concept itself. For the technical level, these are matters such as a strategy for obtaining data on energy acquisition and consumption, research on adequate technological solutions, identifying suitable technological partners. For the community level, these could be conducting community consultations, surveying stakeholders, developing a community education strategy, developing a strategy for interviewing representatives of housing cooperatives and housing communities. At the financial level, they could be researching potential investors, business partners and a strategy for attracting them. Also necessary would be a preliminary financial analysis of the project and the selection of a partner dedicated to identifying risks and synergies.

Please note that up to this point, we have been talking all along about developing strategies for individual actions and not about implementing them. This shows how multi-stage this project is and how carefully the implementation of such projects should be approached. This is still a very general approach and is worth noting that. Meanwhile, there are many other tasks such as creating the right personnel for the mentioned assignments. Nonetheless, with the development of more specific strategies for each level, it is possible to proceed to the actual selection of partners, the collective development of solutions and strategies for their implementation and finally, to the implementation itself. All these stages must be specifically scheduled, of course, taking into account a certain tolerance. This is undoubtedly a massive business and logistic challenge that only a dedicated personnel can manage.

Within the framework of the work, it was decided to detail at this stage two specific steps that should be taken for the eventual implementation of the concept into operation. The first is to collect actual data on the energy potential of renewable energy sources in the county. The concept uses a database that itself had a number of assumptions, and the values given were based on parameters obtained for Małopolskie Voivodeship. This therefore gives some insight into the feasibility of the district's energy transition, however, in the case of actual implementation of the concept, these are not data on which to rely. Hence, it is crucial to develop a method of collecting data on the RES potential in the district and to actually collect it, analyze it and draw further conclusions. This is one of the most important steps at an advanced technical level, as it determines further decisions on investments in individual technologies and thus the entire energy infrastructure of the new system.

The second highlighted task is local community surveying. As emphasized in the section on community aspects, the lack of acceptance of end users, who are ultimately the main stakeholders of the entire project, can lead to the suspension of its implementation at practically every stage. Therefore, it is crucial to develop a long-term strategy for building relations with the district's residents, which should be based primarily on making them aware of what the purpose of the district's transformation into a cluster is, what its projected process is, and how the transition will affect their quality of life. It is very important to collect and respond to concerns that arise at every stage of the project. Especially in the case of representatives of housing associations and housing communities, because their involvement and acceptance are key in obtaining private infrastructure to create a better integrated energy system.

The above outlines the broad assignments that in the context of this work should be undertaken to create an energy self-sufficient county, but their exact description is not included as an integral part of the concept. These are, of course, suggestions, but after an extensive study of the problems of implementing energy systems based on RES, their inclusion in the study was considered as essential.

Chapter 8

Study summary and conclusions

8.1 Study summary

The present paper develops the concept of an energy self-sufficient district based on distributed renewable energy generation. The subject of the study was a clearly defined area, which was the Chrzanów county. The subject of the study was a well-defined area, i.e. the county of Chrzanów. The foundation for undertaking such a project was the European Union's energy policy of conducting energy transition and the ambitious plan to achieve climate neutrality among the member countries [1]. Within the scope of the work, the current state of Polish energy mix and the current condition of Chrzanów district was thoroughly analysed. Moreover the study introduces the topics of energy-neutral regions and energy clusters and the challenges to be overcome in order to achieve an energy transition on a regional scale.

After familiarising with the broad issues of developing and implementing self-sufficient energy districts based on clean energy, a number of assumptions were made, according to which further work continued. The core assumption was, that during the course of concept building, it might turn out that such a transition in the district was simply not possible. Second important assumption was that the specific solutions which are proposed within this paper are tailored to the Chrzanów county, which means, they are not fully universal, although they may be used in the case of similar projects.

In order to develop a comprehensive concept that takes into account the complexity of the problem, it was decided to divide it into three levels - technical, community and financial.

As part of the technical level, the region's renewable energy potentials were examined based on the EU-28 wide, open dataset for energy models on renewable energy potentials - ENSPRESO [21]. The data obtained were compared with the current consumption of energy carriers in the district and the demand mainly for electricity and heat. Analysis of obtained results made it possible to develop an energy model for the county within the following 3 sectors: economy, construction, agriculture and forestry. The objective of the model was to adjust the achievable energy from RES in such a way as to eliminate coal and gas from the district energy balance for the 3 sectors. Unfortunately, it was found that with the current policy and law blocking the potential of wind energy in Poland, it is impossible to make a successful transition for the region. Therefore, from now on, it was assumed for the sake of further study that the current regulations would be lifted in line with European Union policy. As a result, it was feasible to develop a model that meets the imposed requirements. In addition, several innovative technological solutions were proposed that would be ideally applicable to the deployment of the modified district's energy infrastructure.

Within the social level, a unique administrative model was developed. Its task is to improve the cooperation of local authorities with the distribution system operator and also to provide a management structure for the district from the energy standpoint and its development strategy. The developed model of the energy community takes into account the current legal aspects but also, it is intended to include the local community as much as possible in the whole process, since the success of the entire project depends tremendously on it. Therefore, a number of additional initiatives were listed that can be taken to ensure the best possible comfort for all stakeholders involved in the county's transformation starting with the local authorities and ending with the final users.

The final level objective was to estimate the investment and operating costs of the project. The calculations were based on the installations and their sizes proposed at the technical level. As expected, the cost of such a project is substantial. Thus, research was done on potential sources of financing for the county' transition based on the energy policy of Poland and the European Union.

By combining these 3 described levels, the concept of an energy self-sufficient Chrzanów county was obtained, which addresses many of the challenges arising in the project of transforming the it into a more climate sustainable district.

In addition, going beyond the concept model, several steps were suggested at the national and regional scale through which implementation of the developed concept would be possible.

The entire developed concept as well as its individual elements can be treated as a basis for further energy self-sufficient districts studies as well as be even an inspiration of an actual model implementation.

8.2 Final conclusions

The measures taken and analyses carried out within the framework of this work allowed the author to formulate the following conclusions:

- An energy cluster in the form of an energy self-sufficient area is currently a very complicated entity in terms of technical, economic, legal and social aspects.
- The Polish government assumed the creation of 300 energy clusters by the end of 2030. To meet this goal, it should definitely simplify the current system of national cluster certification and create clear guidelines on, in particular, cooperation with distribution system operators.
- Despite its complexity, building an energy self-sufficient county is one of the best ways to involve citizens at every community level.

- Currently, Chrzanów County is heavily dependent on coal. This primarily concerns the structure of the energy system, but not only. A sizable part of the population has coal-based jobs, which poses a major challenge in terms of its elimination.
- The transformation of Chrzanow County into an energy self-sufficient district based on RES is possible provided that legislation limiting the potential of wind energy in Poland is abolished.
- The largest energy potential in the analyzed county has solar energy (0.972 TWh/year), which, with proper utilization, could cover the entire county's electricity needs.
- The energy carriers used for heat production could mostly be covered by the potential from agricultural, forestry and waste biomass (0.431 TWh/year).
- As part of the region's transition, it would be necessary to electrify housing and the agricultural sector, as well as increase the energy efficiency of buildings by, for example, properly insulation.
- It is a vary good practise to have specially identified coordinating unit within the cluster structures, which would responsible for the development, mobilisation and management of relationships between cluster members and for providing specialised services to them.
- Support from the voivodeship Marshal's Office in legal, financial, coordination of contacts with potential investors and mediation between stakeholders is essential for this project.
- Lack of public acceptance can result in the suspension of a project at almost any stage of its implementation, which is why it is so important to undertake a number of social initiatives targeting end users.
- The construction of energy renewable self-sufficient district requires a great investment. However, it is a very effective way to facilitate the energy transition and contribute to climate neutrality through energy efficiency and net zero energy balance [5].

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Preparation of the concept and model of an energy self-sufficient region based on distributed generation in the Chrzanów district - Poland

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