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Local factors and green transition–what drives investments in low-carbon economy in Poland?

Aldona Standar [a], Agnieszka Kozera [a,*], Łukasz Satoła [b]

[a] Poznań University of Life Sciences, Faculty of Economics, Wojska Polskiego 28, 60-374 Poznań, Poland
[b] University of Agriculture in Kraków, Faculty of Agriculture and Economics, al. Mickiewicza 21, 31-120 Kraków, Poland

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ABSTRACT

The main objective of the study is to identify the main socio-economic, environmental and financial determinants of local investments supporting the development of a low-carbon economy in macro-regions in Poland in the EU financial perspectives 2007–2013 and 2014–2020. These conditions play a significant role in business practice, influencing efficiency of investment processes and effectiveness of actions towards low-carbon economy. The empirical research aimed to answer the following research questions: What is the role of municipalities and their subordinate units in the implementation of investments in developing a low-carbon economy in individual macro-regions of Poland? Did the experience of beneficiaries in absorbing EU funds for the development of a low-carbon economy in the 2007–2013 financial perspective translate into higher absorption of these funds in the next 2014–2020 financial perspective? Empirical research was conducted based on data from the Ministry of Development and Investment, Statistics Poland's Local Data Bank and the Ministry of Finance in Poland. The analysis showed that the high investment activity of local authorities in the first of the financial perspectives under review translated into even higher activity in the next one, with the degree of concentration in 2014–2020 no longer as high as before in individual macro-regions. The development of a low-carbon economy in macro-regions depends on a number of socio-economic (e.g., population density, net migration balance, and the number of business entities per 10,000 inhabitants), environmental factors (per capita water consumption in cubic meters), and financial factors (operating surplus and own revenue-generating potential per capita). These factors vary depending on the specifics of each macro-region, which can influence the unique approach to low-carbon economy development in individual areas. Research results have significant implications for the regional policy and management practices for EU funds. They suggest the necessity to develop support instruments for municipalities with lesser investment activity, increasing availability of training programs for local government employees, as well as promoting good practices at the local and regional levels.

1. Introduction

In Europe, many regions are still highly dependent on fossil fuels. After China and the United States, the European Union (EU) is the third largest emitter of greenhouse gases (GHG) [1]. The European Union has therefore set itself the ambitious long-term goal of achieving climate neutrality by 2050. Therefore, as part of the European Green Deal, Europe aims to become the first continent to be able to remove by 2050 as much CO_2 emissions as it produces. Moreover, the European Parliament has adopted a target to reduce GHG emissions to at least 55 % by 2030. This puts the EU in the role of global climate change leader. To achieve climate neutrality, the Central European regions in particular must therefore transform their energy system. An important direction for changing the economic model of these regions is therefore the low-carbon transition, which is a response to the problem of depletion of natural resources, increased pollution, climate change, as well as a panacea for the energy crisis in the EU exacerbated by Russia's invasion of Ukraine [2,3]. A low-carbon economy is an economy with low CO_2 emissions into the atmosphere [4]. It is based on a low-carbon society that lives and works in low-carbon buildings, uses low-carbon private and public transport and lives in cities or rural areas where emissions are lower [5]. This economy leads to more efficient consumption or production of energy and materials [6,7]. Waste is disposed of or recovered using methods that minimise greenhouse gas emissions [8,9]. The low-

* Corresponding author.
E-mail address: agnieszka.kozera@up.poznan.pl (A. Kozera).

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carbon economy is linked to sustainable development because it is associated with its criteria (e.g. reducing greenhouse gas emissions or increasing the share of renewable energy) [10].

The ambitious reduction targets of the EU climate and energy policy in the period up to 2030 are a challenge for the Polish economy and will require significant financial outlays, especially in regions with the highest GHG emissions. Poland is one of the larger GHG emitters in the EU, which is mainly due to its dependence on coal as the main energy source. For example, in Poland, more than half of GHGs are produced annually in only three regions, i.e. in Śląskie, Mazowieckie and Łódzkie Voivodeships [11]. To this end, investments are needed to support the energy transition towards climate neutrality, tailored to the specific characteristics of individual regions and macro-regions of Poland. This is because many factors influence the low-carbon economy in macro-regions. These include both external and internal elements, such as government policies, the availability of natural resources, the level of technological and social development and civic involvement. Among the internal determinants of the analysed phenomenon, socio-economic, financial and environmental factors can be distinguished [12]. Each of these factors may differ depending on the specifics of the macro-region, which should influence the unique approach to low-carbon economy development in individual areas. However, there is a cognitive gap in this area. This study contributes by identifying the drivers of green investment by municipalities, and furthermore provides an answer in terms of their variation across macro-regions differing in the structure of the local economy, the financial condition of local and territorial authorities and other social and environmental determinants.

Despite the progress made locally in terms of environmental protection, emissions continue to increase globally. Hence, all measures to reduce destructive environmental impacts and limit resource consumption are permanently topical. Decision-makers at the national level design desirable courses of action for the public and private sectors to ensure their favourable environmental impact. In the European Union, the regions are the basic level for implementing Community policies. For this reason, it is important to know the extent and structure of investments aimed at developing a low-carbon economy at regional level. Local authority entities are among the most important groups of actors implementing low-carbon economy measures. They use both their own budgetary resources and, to a relatively large extent, obtain financial support available through the implementation of European Union programmes. For this reason, an analysis of their activities illustrates in a measurable way the level of progress of regions in implementing a low-carbon economy. Due to the importance of this issue, research into local and territorial authority climate change policies is becoming increasingly common [13–15].

The main objective of this research is to identify the main socio-economic, environmental and financial determinants of local investments supporting the development of a low-carbon economy in macro-regions in Poland in the 2007–2013 and 2014–2020 EU financial perspectives. The empirical research aimed to answer the following research questions: What is the role of municipalities and their subordinate units in the implementation of investments in developing a low-carbon economy in individual macro-regions of Poland? Did the experience of beneficiaries in absorbing EU funds for the development of a low-carbon economy in the 2007–2013 financial perspective translate into higher absorption of these funds in the next 2014–2020 financial perspective?

2. Research materials and methods

The territorial scope of the study covered Poland as one of the largest beneficiaries of EU funds. The analyses were carried out in macro-regional terms, the so-called NUTS 1 classification. According to the EUROSTAT classification, there are seven such NUTS groups of voivodeships, these are: South-Western, Northern, Eastern, North-Western, Central, Southern and Mazowieckie Voivodeship [16]. On a macro-regional basis, the number and value of EU funds obtained for the low-carbon economy are presented, both by all (public and private) beneficiaries and by municipal authorities alone, as the basic local government units in Poland. In addition to data on the acquisition of EU funding in absolute terms, indicators based on population and area were used. Information on projects was obtained from the databases of the ministry responsible for their implementation. Currently, it is the Ministry of Funds and Regional Policy [17,18]. From databases covering tens of thousands of projects, those in the Low Carbon Economy Area were distinguished. The detailed structure of investments within this area was analysed based on the so-called priority theme (2007–2013) or support area (2014–2020). In total, information was collected on ongoing projects under two EU financial perspectives 2007–2013 and 2014–2020. The 2007–2013 perspective is the first one in which Poland has fully participated since joining the European Union in 2004. In turn, according to the n + 3 rule, projects under the 2014–2020 perspective were implemented and settled until the end of 2023. Although the analysis in this paper covers solely projects co-financed from EU funds, it needs to be stressed that these funds are the most important source of financing for investments in low-carbon economy. In Polish public statistics there are no comprehensive data concerning all enterprises implemented by local government units in this respect. On the other hand, the Local Data Bank of Statistics Poland (GUS) [19] and the databases of the Ministry of Finance [20] were used to collect the necessary data to identify the socio-economic, financial and environmental determinants for obtaining these funds. The data quoted in the text were converted according to the National Bank of Poland's average exchange rate [21].

Achieving the stated objective required research in two stages. In the first stage, an analysis of the diversity of the level and structure of investment in the low-carbon economy was carried out. The number of EU low-carbon projects and their value in absolute and relative terms were presented. The structure of low-carbon investments was also shown. The analysis employed selected methods of descriptive statistics. Due to the presumption of a significant increase in the activity of the analysed local and territorial authorities in the 2014–2020 perspective compared to the years 2007–2013, statistical significance was checked with the Student's paired sample *t*-test. Adoption of Student's t-test for dependent samples results from the characteristics of the analysed data. Student's t-test for dependent samples is particularly suitable when we analyze the same entities in different time points, which makes it possible to eliminate the effect of differences between the entities and instead focus solely on temporal changes. Moreover, this test is characterized by high sensitivity, which facilitates detection of even slight, but statistically significant differences in investigated values of investment activity of local government units [22].

In the second stage of the research, logistic regression was used to identify the main socio-economic, financial and environmental determinants of local investments supporting the development of a low-carbon economy in macro-regions in Poland in the 2007–2013 and 2014–2020 EU financial perspectives. Logistic regression was selected as a method of analysis, since the investigated dependent variable is binary in character (a municipality received or did not receive co-financing for low-carbon projects). Alternative approaches, such as e.g. linear regression, would not be suitable, since they do not meet assumptions for the explained variable, which is not continuous. Logistic regression is widely used in economic studies and public policy in order to model probability of specific investment decisions, which underlines its suitability for the analysed problem. The model construction was conducted in 5 steps, as shown in Table 1. In the conducted analysis, aimed at identifying the main determinants of investment activities of municipalities in the area of low-carbon economy co-financed from EU funds, eight logistic models were constructed (seven for individual macro-regions and one for total value for Poland). Logistic regression is used when the dependent variable has a dichotomous character, i.e. taking two values – 0 and 1 (where 1 means the presence of a given

Table 1
Steps of logistic modeling for analyzing determinants of municipal low-carbon investment activities in macro-regions of Poland.

Step		Description	Details and calculation formulas
1	Data preparation	Data from municipalities were collected and categorized based on whether they implemented low-carbon projects.	$y_i = \begin{cases} 0 \text{ municipalities not implementing EU projects related to the development of a low-carbon economy} \\ 1 \text{ municipalities implementing EU projects related to the development of a low-carbon economy} \end{cases}$
2	Variable Selection	Explanatory variables included socio-economic, financial, and environmental determinants.	About 50 variables were taken into account, and the model included variables that were not correlated with each other.
3	Model Estimation	Use of the logistics function	$f(z) = \frac{e^z}{1+e^z}$ $P(y_i = 1/X) = \frac{e^{\beta_0+\beta_1 x_1+\ldots+\beta_K x_K}}{1+e^{\beta_0+\beta_1 x_1+\ldots+\beta_K x_K}}$ where: y_i – ith $(i = 1, \ldots, n)$ observation on a dichotomous explanatory variable that assumes a value of 1 or 0, $k = 1, 2, \ldots, K$, $X_{i1}, \ldots, X_{iK}$ – explanatory variables (socio-economic, financial and environmental determinants, respectively), $P\left(y_i = {}^{1}/_{X}\right)$ – the probability that the variable Y would assume a value equal to 1 for the values of the explanatory variables $X = [X_{ik}, \ldots, X_{iK}]$, $\beta_o, \beta_1, \ldots, \beta_K$ – structural parameters of the model.
4	Interpretation of parameters	Estimated odds ratios	$\psi = e^{\beta_o+\beta_1 x_1+\ldots+\beta_K X_K}$ where: $e^{\beta_k} > 1$, it is considered that the factor described by the variable X_k stimulates the probability of a given phenomenon, with a stable influence of the other variables included in the model, $e^{\beta_k} < 1$, it is considered that the factor described by the variable X_k has a limiting influence the probability of a given phenomenon, with a stable influence of the other variables included in the model.
5	Significance testing	Statistical significance of variables	Wald test and *chi*-squared statistics.

Source: own study based on [23–26].

characteristic, while 0 means the absence of a given characteristic) [23]. The local government units analysed – municipalities in each macro-region – were therefore divided into two disjoint classes (Table 1). This method is used in modeling the probability of an analysed unit (e.g. a municipality) in a certain condition ($Y = 1$, i.e. e.g. implementing projects related to the development of a low-carbon economy), and allows the identification of statistically significant factors influencing this probability. Logistic regression allows the calculation of the probability of this event (the so-called probability of success) [24].

Approximately 50 different variables, representing socio-economic, financial and environmental determinants, were considered in the study. Their selection was based on substantive and statistical criteria. With regard to the first criterion, a literature review and studies by other authors were taken into account [27], as well as the research experience of the authors [28]. Considering the second criterion, the degree to which the variables were correlated with each other was taken into account. The study eliminated variables that were highly correlated with each other. Logistic regression was selected as a method of analysis, since the investigated dependent variable is binary in character (a commune received or did not receive co-financing for low-carbon projects). Alternative approaches, such as e.g. linear regression, would not be suitable, since they do not meet assumptions for the explained variable, which is not continuous. Logistic regression is widely used in economic studies and public policy in order to model probability of specific investment decisions, which underlines its suitability for the analysed problem.

The logistic regression model is a generalised linear model (GLM) using logit as the binding function. The sign of the parameter next to the variable X_k determines the direction of the variable's effect on Y. A positive sign indicates that as X_k increases, the probability that $Y = 1$ increases. Negative values, on the other hand, indicate a decrease in the probability that $Y = 1$. In order to interpret the values of the model parameters, the so-called odds ratios are estimated [25] (see Table 1). The e^{β_k} expression constitutes a relative change in the probability of an event occurring as a result of a factor described by the X_k variable, assuming the stability of the remaining variables included in the model. This value is interpreted by comparing it with value 1 and expressing the difference as a percentage [26]. The accuracy of the logit model is evaluated by means of *chi*-squared statistics and the so-called pseudo-R^2 measures. The statistical significance of variables is verified based on the Wald test. In addition, the predictive ability of the models is assessed. For this purpose, a measure of the predictive ability of the model determined from the relevance table (overall model relevance) is used [23].

3. Literature review

3.1. Theoretical foundations for low-carbon economy and its effect on regional development of EU countries

Factors promoting the transition to low-carbon economy are connected with the awareness that human activity is the primarily responsible for greenhouse gas emissions. They are formed mainly in the combustion of fossil fuels. For years high-emission energy sources have driven economic growth, but they also had a negative effect on the environment. It was found that in the long run a lack of restrictions for the negative environmental impact will also have a strong negative influence on the economy [29]. According to the conducted calculations, high costs of transition towards low-carbon economy were supposed to be lower than costs and risks resulting from the absence of actions mitigating the consequences of climate change [30].

The successive reports of the Intergovernmental Panel of Climate Change [31] that have been released indicate a growing awareness of anthropogenic sources of climate change. They also show the negative effects of global warming not only on the environment, but also on society and the economy. Stern [30], for example, points out that climate change could reduce GDP by up to 20 % per year. It should therefore be borne in mind that ethical considerations, the protection of health and life, issues of intergenerational justice [32] and even economic considerations are arguments for the need to reduce anthropopressure [33]. In order to effectively counteract them, extensive multi-state cooperation is required. This awareness translates to varying degrees into specific initiatives and measures in different countries all over the globe.

The European Union is at the forefront of international efforts to

counter the effects of climate change. In the process of electricity and heat generation, the EU's energy and climate policy is geared towards a gradual shift away from fossil fuels, particularly coal [34,35]. In this transition process, the aim is to develop a low-carbon economy, with zero emissions as a long-term goal [36]. Furthermore, the transformation of the economy towards low emissions is intended to reduce environmental pollution and also to become a driver of innovation as a consequence of developing cutting-edge, resource-efficient technologies. Many authors signal that, in the absence of a shift in economic models regarding the extent and use of natural resources, the economies of the world's countries will be increasingly exposed to the negative effects of climate change [37–39]. The belief that measures are needed to reduce the vulnerability of the economy to climate change is becoming more widespread even while taking into account the inherent uncertainty that is associated with long-term projections. It is also estimated that GDP value losses will be recorded by regions that export their resources without taking sufficient economic transition measures to reduce emissions [40].

The reasons for implementing a low-carbon economy are many. Although renewable and clean energy accounts for an increasing share of Europe's energy demand, it is still, and in particular in Poland, dependent on fossil fuels. The burning of such fuels in turn pollutes the environment, damages human health, and affects fauna and flora through climate change [41].

The European Community has set ambitious climate and energy targets in recent decades, aiming to increase the share of renewables in the overall energy mix and to save energy through conservation and efficiency measures. In addition, Russia's invasion of Ukraine has highlighted how dependent Europe is on energy imports – Russia is the EU's largest supplier of imported energy. Fluctuating energy prices from 2022 onwards have made it necessary to step up efforts to accelerate the transition to more reliable and affordable renewable energy sources [42]. Implementing a low-carbon economy is expected to provide multiple benefits affecting the economy, people and the environment. Promoting energy and resource efficiency is expected to increase the cost-effectiveness and competitiveness of industry and services.

Economies of the EU countries are struggling with growing problems related to the loss of competitiveness on international markets [43]. To an increasing degree this results from high manufacturing costs, generating by growing energy prices [44]. The application of low-carbon solutions is to reduce energy production costs, thanks to which it will eventually be cheaper for both entrepreneurs and consumers [45]. Investing in renewable energy development is expected to create new jobs [46]. A low-carbon economy stimulates innovation leading to new techniques, products or markets [8]. The transition to a low-carbon economy will simultaneously improve quality of life, increase the offer available to consumers and the enforcement of their rights, and ultimately reduce energy bills [47,48].

3.2. *The role of local authority entities in the development of a low-carbon economy*

Low-carbon economy's implementation is a complex process that requires the involvement of many actors at different levels (e.g. governments and public institutions, the private sector, NGOs, civil society). Within the public sector, mention can be made first of all of the national governments creating policies, laws and regulations for a low-carbon economy, setting GHG reduction targets and introducing appropriate support programmes. In addition to these, one should also point to local authorities implementing local sustainability initiatives such as public transport programmes, cycling infrastructure development, retrofitting of municipal buildings and support for local renewable energy sources [49]. Municipalities have the greatest potential to operate in this respect, since their competences cover local affairs. Moreover, as it is indicated by results of other studies benefits from the implementation of low-carbon sources are found at the local level [50].

In Poland, local authority entities at the basic level are municipalities. They are responsible for the implementation of the largest part of public tasks. They perform public tasks and services within the framework of carrying out the municipal economy understood as satisfying the current needs of the inhabitants of the local government community through the provision of generally available services. The scope of public tasks of municipalities in addition to the basic ones, covering e.g. water supply, sewage disposal, municipal waste management, is expanding [51–53]. Nowadays, it is also increasingly being extended to the provision of electricity, heat and gas, among other things [54]. The implementation of these tasks is carried out on a continuous basis, hence its high environmental importance and the odds of reducing negative impacts if there is a conversion to a low-carbon economy [55]. What is more, investment in the development of a low-carbon economy has the potential to become a way for local authority entities to reduce energy costs which have been rapidly increasing in recent years. In carrying out day-to-day tasks, municipalities and their organisational units use a variety of energy carriers and, as a consequence, their prices largely determine the operating costs of local authorities. Already a few years earlier, anticipating, as it were, the increase in the costs of resource use in the European Union, the transition towards a low-carbon economy was assumed as an important direction in anticipation of the expected increases in energy prices, as well as in limiting the increasing costs of environmental pollution (emission allowances, environmental charges, etc.) [56,57].

Of great importance in the success of the low-carbon economy implementation process are the proper planning of measures and effective monitoring of this implementation. Because many countries have a decentralised model of territorial division and local government units take over responsibility for the implementation of some public tasks, it becomes necessary to ensure a high level of coordination of measures undertaken [58]. The organisational and legal solutions prepared at the national level must, on the one hand, take into account the specifics of regional diversity, while, on the other hand, they should ensure a sufficiently high level of coordination of measures undertaken at the local level to guarantee the fulfilment of the environmental objectives set. However, experience in other countries shows that the effective implementation of national low-carbon policies at the local level yields positive results [59].

To ensure an adequate level of coordination in many countries, public administrations define the desired courses of action in Sustainable Energy Action Plans (SEAPs) [60]. In Poland, this function is performed by Low Emission Economy Plans. These are documents that are adopted by the decision-making bodies of local government units in order to schedule and coordinate low-carbon transition efforts. They are intended to facilitate the achievement of goals such as increasing the share of energy generated from renewable sources in overall energy consumption, reducing final energy consumption and reducing carbon dioxide emissions. In addition to achieving environmental objectives, Low Emission Economy Plans are becoming an important document to benefit from EU structural funds for energy transition [61–63].

In the management of municipalities, the preparation and implementation of measures resulting from Low Emission Economy Plans, in addition to the fulfilment of obligations under environmental law, is evidence of strategic planning. It combines the challenges faced by local government units with the concern for the rational management of environmental resources. However, to successfully implement the projects identified in Low Emission Economy Plans, large investments are required. In the EU, this problem has been recognised and under the Structural Funds and the Cohesion Fund/Equitable Transition Funds, financial support is allocated to public and private entities aiming to meet climate goals.

The investment activities carried out by local and territorial authorities resulting from the developed Low Emission Economy Plans are associated with the need to allocate significant financial resources [64,65]. With insufficient own resources, municipalities are forced to

seek external sources of funding [66]. Due to their nature of subsidies, meaning that no reimbursement is required, programmes available under the EU Structural Funds attract great interest. However, it is worth noting that the availability and extent of support from the Structural Funds is increasingly dependent on municipal investments meeting the targets set out in Low Emission Economy Plans.

The transition towards a low-carbon economy entails relatively high costs, but can also bring specific benefits to municipalities [67]. The relatively greatest potential for positive effects of a low-carbon economy lies in: improving the energy efficiency of municipal buildings and infrastructure elements (e.g. street lighting), modernising district heating systems, reducing the energy consumption of local public transport (e.g. by investing in technologically advanced public transport fleets) and, furthermore, in investing in renewable energy sources [68].

In recent years, local government units in Poland, for various reasons, have increasingly faced a deficit of budget funds. Therefore, they should design their investment policy in such a way as to include such undertakings for the implementation of which external funding can be obtained. It is also worth emphasising that completed investments, despite the fact that they generate high costs in the initial phase, bring benefits to local and territorial authorities in the long term [69]. This is because these savings result from a reduction in the cost of performing municipal tasks due to, for example, reduced material consumption, lower energy prices, more efficient public transport, or reduced losses in the provision of other municipal services (water supply) [70,71]. In this way, the higher investment costs that occur in the first phase make it possible to reduce the costs of providing many utility services by local government units.

3.3. Energy transition in Poland – problems and challenges

In Poland, being one of the greatest coal producers in Europe, the energy industry relied for many years on this energy source, which was connected with its available resources, as well as the economic policy of the People's Republic of Poland (the predecessor of the current Third Polish Republic), which stipulated energy self-sufficiency. In that period large coal-fired power plants were built, such as the Bełchatów or Kozienice Power Plants. At that time pollutant emissions were not monitored, which led to the degradation of the natural environment and considerable air pollution. In the 1990s as a consequence of political transformations the extraction of hard coal was reduced thanks to closure of numerous unprofitable mines, particularly in the Upper Silesia. At the same time first investments in renewable energy sources, such as e.g. wind farms, were initiated. In 1997 Poland signed the Kyoto Protocol and thus declared to reduce carbon dioxide emissions. Another significant step was also connected with Poland's accession to the European Union in 2004, which provided access to considerable funds allocated to support energy transition. This has led to a dynamic development of renewable energy sources, particularly photovoltaics, supported by government programs, such as Mój Prąd [Polish: My Electricity] [72] and Czyste Powietrze [Polish: Clean Air] [73]. At the same time the wind energy sector was being developed, although the so-called Wind Farm Act of 2016 imposing the 10H rule considerably hindered development of new onshore projects. Moreover, the first regulations concerning development of offshore wind farms were introduced, which is essential, because it is estimated that approx. 60 % of Poland's territory have advantageous conditions for the development of such projects [74].

One of the main challenges for energy transition in Poland is connected with high investment costs. It is estimated that by 2040 Poland will need min. 1.6 trillion Polish zlotys (PLN) or 376.5 billion EUR for investments in renewable energy sources, nuclear energy sector and modernization of transmission grids [75]. A key sources of financing in this case is provided by EU funds, including those from the Just Transition Fund and involvement of the private sector. Despite numerous investments, in 2023 still approx. 60 % electricity in Poland came from fossil fuels [76]. Poland remains the largest coal producer in the European Union, accounting for almost 97 % its extraction in the EU and ranks second in that of lignite (19 %) [77].

In 2023 Poland considerably accelerated actions towards diversification in the supply of energy sources. The Russian invasion of Ukraine in 2022 contributed to an energy crisis and caused changes in the structure of imports of raw materials. Russia ceased to be the main energy supplier (except for LPG), which forced Poland to search for alternative suppliers. However, this process led to increased costs of energy imports, while Poland's dependence on foreign suppliers continues to be high, reaching 43 % [74]. For this reason Poland is developing nuclear power engineering as a key element in its strategy of becoming independent of fossil fuels. The Polish nuclear power program is a strategic government document constituting a roadmap for the construction of the first Polish nuclear power plant [78]. Nuclear power plants planned to be constructed in cooperation with the USA, South Korea and France are to provide a stable low-carbon energy source. Thus, the growing demand for electricity requires not replacement of high-emission energy generation facilities, but also considerable increase in the potential for generation of low-carbon energy in the nearest future.

The Report on Energy transition in Poland (2024) indicates a disparity in the course of this process. Progress is evident particularly in the electric energy sector, while in the other sectors of the economy it remains limited. These delays result in the necessity to purchase emissions allowances from countries, which more effectively implement their decarbonization goals [79].

Energy transition does not affect only technology and economy, but it also has significant social consequences. Closure of mines and coal-fired power plants triggers concerns over job losses, particularly in regions strongly dependent on the extractive industry, such as Upper Silesia or the eastern part of the Wielkopolska region. The last hard coal mine in Poland is to close down in 2049, which is protested against by its employees and local communities [80]. In order to mitigate social costs of energy transition, it is essential to implement just transition through financial support, vocational retraining and development of new sectors of the economy. Authorities also have to persuade the public to see benefits resulting from the transition to renewable energy sources and to promote environmental awareness.

A significant challenge is also posed by the modernization of the electrical grid, which in its present form is not adapted to the dynamic development of distributed energy sources, such as photovoltaic and wind farms [75]. The obsolete grid infrastructure hinders efficient management of energy flow and causes numerous problems with connecting new installations to the grid. Additionally, instability of legal regulations and lengthy administrative procedures constitute a significant obstacle for investors. The Act on renewable energy sources was amended as late as 2023, introducing changes facilitating development of onshore wind power facilities thanks to the liberalization of the 10H rule [81].

Poland signed the Paris Accords and declared to reduce greenhouse gas emissions. However, it is a challenge to attain the goals of cutting down emissions by 2030 and 2050, primarily due to the predominance of fossil fuels in the energy mix, which makes Poland a country with some of the highest emissions in the EU. Secondly, due to the low implementation of energy storage technology it is difficult to stabilize the grid at a high share of renewable energy sources. Thirdly, this is caused by a lack of a definite strategy leading to climate neutrality, whereas many EU countries have already defined specific deadlines for coal phase-out. Compared to countries of western Europe, Poland lags behind with respect to implementation of climate policies.

Energy transition is a key process shaping the future of the economy and the society. Similarly to other European countries, Poland is moving towards a sustainable and low-carbon economy; however, the rate and character of these changes differ considerably depending on the region. Each macro-region faces unique challenges resulting from its economic

structure, natural resources, as well as local policies and development strategies. While Silesia needs to tackle problems of restructuration of the coal sector, Pomerania is dynamically developing wind power infrastructure and the Wielkopolska region is investing in hydrogen technologies. In tur, eastern regions of Poland promote renewable energy sources supporting agriculture and local communities. Paths to energy transition in individual regions are determined by various socio-economic and environmental factors.

Energy transition in Poland is a multifaceted process, requiring coordinated actions in technological, economic, social, legal and political spheres. Despite many challenges, Poland has a potential to phase out high-emission energy generation technologies and implement state-of-the-art, sustainable energy generation solutions. A key role in this respect is played by stable legal regulations, education programs, investments in infrastructure, as well as international cooperation, facilitating an efficient and just transition in the energy sector.

4. Empirical research results

4.1. Variation in the level and structure of local investment co-financed from EU funds in the low-carbon economy

Poland became an EU Member State in 2004. Since then, it has been able to influence the formation of development and cohesion policies at the national and EU levels. Already in the 2007–2013 financial perspective, the first in which Poland fully participated, the low-carbon economy was recognised as an area of intervention. At that time, 2023 projects were implemented, amounting to EUR 1.8 billion (Table 2). Three macro-regions were characterized by the highest activity of beneficiaries: Eastern, Mazowieckie voivodeship and Southern macro-regions. The degree of concentration of acquired EU subsidies in terms of the number and value of projects in these three areas was enormous and amounted to 76 % and 67 %, respectively. The results for the Eastern macro-region were influenced primarily by the attitude of beneficiaries from the Lubelskie and Podkarpackie voivodeships, including the very active attitude of municipal authorities. Their projects accounted for nearly half of the support obtained there (Fig. 1).

It is worth emphasising that the result of the Mazowieckie voivodeship was influenced by only one voivodeship, as it is the only one in this macro-region. This is because it is the largest in terms of both number and area, and includes the capital city of Warsaw. Interestingly, local and territorial authority beneficiaries were the least active there (Fig. 1).

In the Southern macro-region, on the other hand, the beneficiaries of EU funds in the Śląskie voivodeship paid particular attention to low-carbon economy projects. The activity of municipalities there was at an average level. Surprisingly few measures for this type of economy were undertaken in the North-Western macro-region, despite the location of one of the voivodeships, Zachodniopomorskie, by the sea. In total, in this financial perspective, Polish municipalities were a party to every third contract signed for EU funding, obtaining ¼ of the value of the subsidies (Table 2).

Under the 2014–2020 financial perspective, there have been intensified efforts to implement a low-carbon economy. Public as well as private entities implemented as many as 8445 projects amounting to EUR 16.71 billion. The increase in activity was immense, as much as fourfold in terms of the number of projects and almost tenfold in terms of their value. This perspective also saw the emergence of 70 nationwide measures (Table. 2).

Comparing the results of macro-regions in both perspectives, the high activity in the first perspective translated into even higher activity in the next one, although the degree of concentration was not as high as before. Taking into account the number of projects, beneficiaries from the Eastern, Northern and Southern macro-regions dominated, implementing a total of 66 % of them. On the other hand, taking into account the value of measures undertaken, the Southern, Mazowieckie voivodeship and Northern macro-regions stood out positively, collectively concentrating 55 % of the value of EU subsidies. Once again, the success of beneficiaries from the Eastern macro-region was influenced by the particularly high mobilisation of beneficiaries from the Lubelskie voivodeship, again primarily local and local and territorial authorities from this voivodeship. In turn, in the Mazowieckie voivodeship macro-region, the number of projects was the lowest of all the macro-regions, but their average value was the highest. This means that the capital city Warsaw and the other beneficiaries implemented the most capital-intensive projects (on average it was EUR 6.3 million) Entities from the Northern macro-region, due to its partly coastal location, should also be interested in measures aimed at a low-carbon economy. In fact, the Pomorskie voivodeship, located by the sea, was an area of particular interest in the implementation of these projects, which, compared to the previous perspective, increased as much as 22-fold. It is worth noting that beneficiaries from the other coastal voivodeship, Zachodniopomorskie, which together with Wielkopolskie voivodeship are part of the

Table 2
Number and level of implemented projects co-financed from EU funds in the field of low-carbon economy by macro-regions in Poland with a particular focus on beneficiaries – municipal authorities in the 2007–2013 and 2014–2020 financial perspectives.

Macro-region	Perspective	South-Western	Northern	Eastern	North-Western	Central	Southern	Mazowieckie voivodeship	Total [a)]
Number of projects	2007–2013	122	166	717	17	164	413	424	2023
	2014–2020	694	1709	2363	866	794	1489	460	8445
	2007–2020	816	1875	3080	883	958	1902	884	10,468
Total value of projects (EUR million)	2007–2013	201.0	131.4	376.8	118.0	141.0	351.6	496.8	1816.6
	2014–2020	1494.3	2808.7	2358.7	2242.7	1237.3	3374.0	2932.3	16,707.0
	2007–2020	1695.3	2940.1	2735.6	2360.7	1378.2	3725.6	3429.1	18,523.6
Percentage of projects implemented by municipalities (%)	2007–2013	50.82	39.16	45.8	23.5	22.6	31.0	12.7	33.5
	2014–2020	40.49	38.27	44.9	49.9	60.2	66.8	64.6	49.7
	2007–2020	42.03	38.35	45.1	49.4	53.8	59.0	39.7	46.6
Percentage of the value of projects implemented by municipalities (%)	2007–2013	14.37	38.16	50.0	0.4	21.1	31.3	7.6	24.5
	2014–2020	41.41	49.38	59.5	50.53	68.1	42.6	71.4	53.4
	2007–2020	38.32	48.9	58.2	48.12	63.4	41.5	62.5	50.6
Value of projects implemented by municipalities per 10 thousand inhabitants (EUR million)	2007–2013	15.5	30.6	229.6	0.8	45.4	48.9	37.1	407.8
	2014–2020	213.1	416.4	1032.2	325.8	516.4	436.7	320.3	3260.8
	2007–2020	228.6	447.0	1261.7	326.6	561.8	485.5	357.3	3668.6
Value of projects per 100 km^2 of area (EUR million)	2007–2013	26.1	62.9	291.1	0.4	42.5	173.0	47.9	644.1
	2014–2020	608.7	2346.4	1693.9	929.6	1046.4	1886.2	1569.6	10,080.7
	2007–2020	634.8	2409.3	1985.0	930.0	1089.0	2059.3	1617.5	10,724.8

Source: author's own study based on: Polish Ministry of Development and Economic Investment [83].

[a] In the 2014–2020 financial perspective, an additional 70 projects worth more than EUR 0.3 billion were implemented, which were nationwide and not assigned to any macro-region.

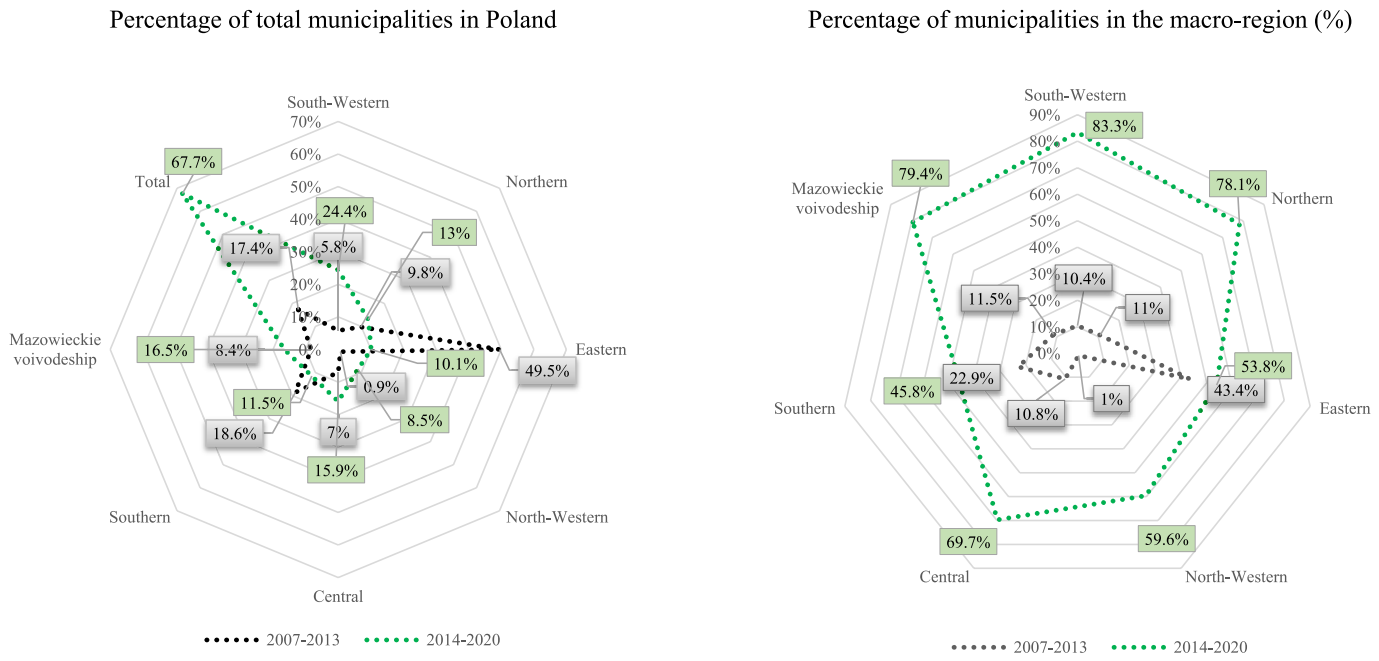

Fig. 1. Percentage of municipalities implementing investments co-financed from EU funds in the field of low-carbon economy by macro-region in Poland in the 2007–2013 and 2014–2020 financial perspectives. Source: author's own study based on: Polish Ministry of Development and Economic Investment [83].

North-Western macro-region, also contributed to obtaining enormous EU subsidies. Also in this macro-region, there was a vast, almost 20-fold increase in activities (measured by the value of projects implemented) (Table 2).

The contribution of municipal authorities to the implementation of the low-carbon economy was large. In the 2014–2020 financial perspective, nearly one in every two projects and one in every two zlotys was obtained by municipalities for this purpose. These are significantly higher participation rates than in the previous perspective. While in 2007–2013 the highest activity of municipal authorities in terms of the number of projects was observed for the South-Western and Eastern macro-regions (51 % and 46 %, respectively), and in terms of value for the Eastern and Northern macro-regions (50 % and 30 %, respectively), this was different in the next perspective. Indeed, between 2014 and 2020, >60 % of projects were implemented by local and territorial authorities in the Central, Southern and Mazowieckie Voivodeship macro-regions. In turn, taking into account their value, the low-carbon economy projects implemented by municipalities in the Mazowieckie voivodeship and Central macro-regions definitely stand out. About 70 % of all grants were obtained there thanks to municipalities (Fig. 1).

The aforementioned increase in the activity of municipalities in terms of obtaining EU funds for the low-carbon economy in 2014–2020, compared to 2007–2013, was large enough to provide a basis for checking the significance of this phenomenon. Considering all four criteria included in Table 3 in absolute terms (number and value of projects) and in relative terms (converting funds obtained per capita and per unit of area), statistically significant changes were confirmed using Student's paired sample *t*-test. This means that Polish municipalities have become a much more effective beneficiary in the next perspective. Also, the data cited in Table 2 and Fig. 1 indicate that the transition of the Polish economy to a change in energy sources would not have been possible without so much interest in these ventures by the analysed entities. The results of this test aggregated to the examined macro-regions also indicate significantly increased activity in the implementation of investments in the low-carbon economy.

Table 4 indicates the directions of spending of EU funds in the low-carbon economy. The areas of support have changed and expanded from 12 to 16 in 2014–2020 compared to 2007–2013. The choice of

Table 3
T-test for paired samples of characteristics of the implementation by Polish municipalities of investments co-financed from EU funds in the field of low-carbon economy in the years 2007–2013 and 2014–2020.

Macro-region	Indicator	Average for 2007–2013	Average for 2014–2020	*t*	*p*
Total value for Poland	a	0.3	1.7	−30.9	0.00
	b	179,794.6	3,598,412.6	−4.7	0.00
	c	167,970.8	1,315,452.2	−29.7	0.00
	d	260,026.0	4,069,721.8	−12.3	0.00
South-Western	a	1.2	1.7	−9.1	0.00
	b	2,614,162.1	16,001, 074.9	−2.0	0.04
	c	1,035,947.6	1,401,473.6	−9.2	0.00
	d	2,686,161.5	7,352,877.5	−4.5	0.00
Central	a	1.7	1.5	−17.5	0.00
	b	3,145,021.1	14, 759,302.8	−3.3	0.00
	c	1,922,808.9	2,761,459.4	−11.5	0.00
	d	3,907,972.2	15,291,587.0	−3.9	0.00
Southern	a	2.9	4.0	−12.4	0.00
	b	4,288,306.0	15,806,652.2	−4.6	0.00
	c	1,306,304.4	1,905,416.6	−11.1	0.00
	d	5,631,337.0	12,944,671.0	−7.6	0.00
North-Western	a	1.0	1.9	−10.9	0.00
	b	2,804,402.1	18,771,169.3	−2.9	0.00
	c	800,204.1	1,403,001.7	−11.1	0.00
	d	2,300,567.8	9,156,847.8	−4.9	0.00
Northern	a	1.7	2.1	−13.7	0.00
	b	3,773,355.3	18,614,976.5	−3.8	0.00
	c	1,128,954.1	1,480,943.0	−13.2	0.00
	d	6,383,167.0	20,582,011.6	−5.8	0.00
Mazowieckie voivodeship	a	0.9	1.2	−11.6	0.00
	b	6,944,115.2	92,142,363.6	−1.3	0.02
	c	1,079,154.5	1,786,211.3	−9.3	0.00
	d	5,208,252.5	24,327,310.4	−3.6	0.00
Eastern	a	2.2	1.8	−16.1	0.00
	b	2,977,462.7	14,634,205.4	−3.8	0.00
	c	2,197,371.7	2,300,016.5	−14.8	0.00
	d	3,594,482.9	12,751,973.7	−5.1	0.00

Legend: a – Number of projects, b – Total value of projects in EUR million, c – Value of projects in EUR per 10 thousand inhabitants, d – Value of projects in EUR million per 100 km^2 of area.
Source: author's own study based on: Polish Ministry of Development and Economic Investment [83].

Table 4
Structure of implemented projects co-financed from EU funds in the field of low-carbon economy by priority theme in Poland in 2007–2020.

Priority theme	Total projects		Projects implemented by municipalities	
	Number (%)	Value (%)	Number (%)	Value (%)
2007–2013				
06 Assistance to SMEs for the promotion of environmentally-friendly products and production processes (introduction of effective environment managing system, adoption and use of […] technologies	9.11	4.92	0.00	0.00
24 Cycle tracks	3.12	1.57	5.75	3.98
33 Electricity	2.10	0.72	0.15	0.10
34 Electricity (TEN-E networks)	0.15	0.81	0.00	0.00
39 Renewable energy: wind	1.75	22.65	0.15	0.00
40 Renewable energy: solar	21.25	16.02	30.83	38.27
41 Renewable energy: biomass	1.75	4.29	0.88	1.67
42 Renewable energy: hydroelectric, geothermal and other	3.12	2.12	3.10	3.61
43 Energy efficiency, cogeneration, energy management	48.88	22.00	49.41	35.59
47 Air quality	2.39	1.99	3.24	3.17
48 Integrated prevention and pollution control system	0.54	12.95	0.00	0.00
52 Promotion of clean urban transport	5.85	9.95	6.49	13.61
Total	100.00	100.00	100.00	100.00
2014–2020				
005 Electricity (storage and transmission)	1.02	4.46	0.07	0.02
009 Renewable energy: wind	0.12	0.15	0.05	0.02
010 Renewable energy: solar	28.38	9.00	21.24	9.13
011 Renewable energy: from biomass	0.72	0.76	0.26	0.05
012 Other Renewable Energy (including hydroelectric, geothermal and marine) and Integration of Renewable Energy (including storage, conversion of electricity to gas, as well as infrastructure)	1.86	1.13	0.50	0.12
013 Energy efficiency renovation of public infrastructure, demonstration projects and supporting measures	34.47	17.67	49.54	18.55
014 Energy efficiency renovation of existing residential buildings, demonstration projects and supporting measures	7.47	3.29	5.17	1.86
015 Intelligent Energy Distribution Systems at medium and low voltage levels (including smart grids and ICT systems)	0.38	1.21	0.00	0.00
016 High efficiency co-generation and district heating	4.65	8.81	2.55	0.64
043 Clean urban transport infrastructure and promotion (including equipment and rolling stock)	6.20	43.77	10.38	61.83
044 Intelligent transport systems (including the introduction of demand management, tolling systems, IT monitoring, control and information systems)	0.18	0.96	0.33	1.71
068 Energy efficiency and demonstration projects in SMEs and supporting measures	7.26	1.88	0.00	0.00
069 Support to environmentally-friendly production processes and resource efficiency in SMEs	0.64	0.08	0.00	0.00
070 Promotion of energy efficiency in large enterprises	0.21	0.63	0.00	0.00
083 Air quality measures	3.60	3.39	4.98	1.66
090 Cycle tracks and footpaths	2.83	2.82	4.93	4.42
Total	100.00	100.00	100.00	100.00

Source: author's own study based on: Polish Ministry of Development and Economic Investment [83].

direction is based on the individual needs of beneficiaries, but also on climatic and environmental determinants. Coastal areas predispose to the development of wind energy, the sunnier western part of Poland for solar energy, and areas used for agricultural purposes – for biomass energy. Urban municipalities, especially the largest cities, given their well-developed public transport and air pollution problems – for measures to develop clean urban transport and improve air quality [82].

Between 2007 and 2013, the main priority theme of low-carbon economy spending by both private and public entities (including municipalities) was to improve energy efficiency. More than a thousand projects of this type were implemented for a total amount of EUR 0.4 billion. The second most significant direction of investment was renewable solar energy, which attracted much more interest among municipalities than other entities. In total, there were 436 investments representing EUR 0.3 billion. The third most popular priority was clean urban transport, with projects not only implemented by municipalities, but also by associations of municipalities (it is difficult to identify the main beneficiary in such cases), or other levels of territorial authorities. Those 120 projects cost a total of EUR 186 million. For the business sector, there was a special priority devoted to the promotion of environmentally friendly products and processes, with public entities, including municipalities, also benefitting from the measure for the construction of cycle tracks. Other priorities were of marginal interest to potential beneficiaries.

In the next EU financial perspective, the main focus on the low-carbon economy did not change much. One in three projects concerned the renovation of public infrastructure. A total of EUR 3.0 billion was spent on this purpose (18 %). Solar energy continued to be the second direction of investment. Within this priority, 2397 (as much as 29 % of all) projects were implemented, amounting to EUR 1.5 billion (9 %). However, the largest share of EU funds was allocated to measures for clean urban transport infrastructure, whose main beneficiaries were municipalities, municipal companies subordinate to them and associations of these municipalities. On average, such a project cost over EUR 12.7 million, and a total of as much as EUR 5.4 billion was spent on this priority.

4.2. Identification of socio-economic, financial and environmental determinants of local investments supporting the development of a low-carbon economy in Polish macro-regions

The process of obtaining EU projects supporting the development of a low-carbon economy by local government units and their subordinate entities is a derivative of a number of determinants. They can vary from region to region, due to the varying levels of socio-economic development in the regions and the different needs for a low-carbon economy [84]. In order to identify them, logit models were estimated for each

macro-region and Poland (seven models in total), illustrating the impact of socio-economic, financial and environmental factors on the investment activity of the analysed entities in terms of obtaining low-carbon economy projects co-financed from EU funds. The empirical data depicting the determinants of investment activity of municipalities and their subordinate entities in each macro-region in terms of supporting a low-carbon economy were mainly from 2021. A total of nearly 40 different variables were considered in the study, including 19 variables depicting the socio-economic situation, 10 variables depicting the financial situation and 9 environmental variables. Ultimately, only those models that included statistically significant variables have been discussed. The results of the estimated logit models were presented in Table 5. The estimated models presented a good fit to the empirical data and high statistical significance of the parameters found at the explanatory variables.

Taking into account the total number of municipalities and their subordinate units in Poland, socio-economic, financial and environmental determinants turned out to be among the factors determining their investment activity in supporting the development of a low-carbon economy co-financed from EU funds (in total in the two analysed financial perspectives). The increasing value of indicators such as population density, demographic dependency ratio or migration balance contributed to an increase in the odds (probability) that the entities in question would obtain and implement projects in the area of low-carbon economy development. The high demographic potential of local government units did not determine higher investment activity of these entities. Economic and financial determinants, in turn, stimulated the discussed phenomenon. An increase in the number of business entities per 10 thousand population resulted in an increase in the probability of the discussed investment activity of local authorities. The situation was similar with regard to the financial determinants of this activity. An increase in the level of operating surplus and own revenue potential per capita increased the chances of the territorial unit to obtain and implement projects co-financed from EU funds in the area of low-carbon economy. Operating surplus is an indicator reflecting the financial situation of the territorial authority entity, its ability to repay instalments on loans, borrowings or bonds issued and its ability to finance investments itself. The higher the value of the operating surplus, the greater the territorial authority entity's capacity to implement new asset projects, either directly by allocating this amount to investments or indirectly by repaying previously incurred liabilities for investment purposes. Consequently, an upward trend in this indicator, or at least its relative stabilisation over time in the case of numerous investments realized by the local authorities, is a positive phenomenon.

The empirical research significant variation in the main determinants of investment activity of municipal authorities in individual macro-regions in terms of obtaining projects related to the development of a low-carbon economy and co-financed from EU funds. Municipalities in the Eastern Region were in the lead in obtaining EU funds per 100 ha of area to support the development of a low-carbon economy. A number of important determinants of this activity were also noted in this region. The study showed that a higher population density, migration balance or a higher proportion of businesses employing >49 people translated into a lower probability of municipalities obtaining and implementing low-carbon economy projects. On the other hand, an increase in such indicators as the percentage of unemployed people, demographic dependency ratio, bed places per 10 thousand population and the percentage of developed and urbanised land (%) translated into an increase in the probability of the discussed investment activity of the analysed entities in the Eastern macro-region. The voivodeships comprising the Eastern macro-region are still among the relatively less developed ones. However, the authorities of these regions pay attention to social and economic benefits resulting from undertaking investments, e.g., in the field of green energy. Therefore, investments in building a low-carbon economy can translate into a revival of the region (e.g. through an increase in the number of jobs), and as a result, an increase in revenue to the budget of a local authority entity (due to an increase in the tax basis of individuals and businesses). As a result of high investment activity of local authorities in the discussed macro-region, there is a gradual shift from an economy based on low labour costs to one based on knowledge. This should reduce the outflow of young, educated people, due to the creation of prospects in the high-tech industry (see Table 5).

The Southern macro-region – consisting of the Śląskie and Małopolskie Voivodeships, has a high level of industrialisation and urbanisation of the area, as well as a high level of environmental pollution. The needs for the development of a low-carbon economy in this macro-region are therefore high. In the case of this macro-region, population density, the number of business entities per 10 thousand population and the percentage of farms of 15 ha or more proved to be important factors in investment activity. An increase in the value of these indicators increased the probability of obtaining and implementing low-carbon economy projects. This means that the size of the territorial unit and its level of socio-economic development significantly influenced the fact of obtaining EU funding for the development of a low-carbon economy.

Empirical research showed that an increasing value of the explanatory variable – the percentage of councillors with a higher level of education – increased the probability of the analysed entities obtaining projects co-financed from EU funds in the area of the low-carbon economy in the North-Western macro-region, while this probability decreased in the Northern macro-region. The possibilities promoting the development of the municipality depend on the activity of the municipal authorities in obtaining funds for development, and the basis for success can be a qualified workforce. In the Northern macro-region, in contrast to the Eastern macro-region, an increase in the value of the change in population per 1 thousand inhabitants and in the demographic dependency ratio translated into lower odds of obtaining and implementing projects for the development of a low-carbon economy. The analysed phenomenon was also adversely affected by such determinants as the level of unemployment and the high number of people working on farms per 100 people of working age.

The situation was different for local authorities in the North-Western Region. In the case of this macro-region, as many as two of the three voivodeships forming the macro-region in question are located directly by the sea. This is an attractive macro-region in terms of tourism and residences. The analysis showed that significant factors influencing the activity of local authorities in the discussed macro-region were the migration balance per 1000 population and the number of bed places per 10,000 population. Higher values of these indicators translated into a higher probability of low-carbon investments co-financed from EU funds. Municipalities serving tourist and residential functions take care of air quality, including through the development of environmentally friendly energy.

In the South-Western macro-region, among the financial factors, the share of operating surplus in current revenues (%) also had a stimulating effect on the phenomenon in question. An increase in the value of this indicator, as well as in the amount of operating surplus per capita, may indicate increasing opportunities for the local authority entity to realise new investments. The average usable floor area of residential premises per capita also had a stimulating effect on the phenomenon in question.

Municipal authorities and their subordinate units from the Mazovian voivodeship macro-region are also a significant beneficiary of EU funds for the implementation of investments in the area of low-carbon economy. Stimulating for the analysed phenomenon in the macro-region in question were such factors as a higher percentage of economic entities employing 49 persons and more, and development potential in relation to property expenditure and capital repayments (%). On the other hand, an increase in the value of indicators illustrating the number of businesses per 10 thousand population and the share of developed and urbanised land in the total area (%) of local authorities resulted in a lower probability of the realization of the discussed investments. It should be emphasised here that there is a very high internal

Table 5
Results of parameter estimation for logit models of investment activity determinants for local authorities and their subordinate units in macro-regions of Poland co-financed from EU funds in the 2007–2013 and 2014–2020 financial perspectives [a),b)].

Macro-region (number of municipalities in the model)	Explanatory (independent) variables	Coefficient	Std. error	*Odds ratio*	*p*-values	Relevance[c)]
South-Western ($n = 184$)	Natural persons conducting business activity per 10 thousand inhabitants	−0.003	0.001	0.997	0.006	***
	Average usable floor area of residential premises per capita	0.140	0.050	1.150	0.005	***
	Share of operating surplus in current revenues (%)	0.076	0.034	1.079	0.027	**
	Share of property expenditure in total expenditure (%)	−0.068	0.024	0.934	0.004	***
Northern ($n = 198$)	Population change per 1000 inhabitants	−0.018	0.004	0.982	0.0000	***
	Demographic dependency ratio	−0.194	0.059	0.824	0.0010	***
	Percentage of councillors with higher education (%)	−0.035	0.012	0.966	0.0026	***
	Unemployment rate (%)	−0.160	0.075	0.852	0.0333	**
	People employed on farms per 100 persons of working age	−0.029	0.017	0.971	0.0933	*
Eastern ($n = 98$)	Population density (persons per km^2)	−0.075	0.026	0.928	0.004	***
	Population change per 1000 inhabitants	0.121	0.033	1.129	0.000	***
	Demographic dependency ratio	0.830	0.251	2.294	0.001	***
	Migration balance per 1000 population (median for 2013–2021)	−0.535	0.221	0.586	0.015	**
	Share of entities employing >49 persons (%)	−0.427	0.181	0.653	0.018	**
	Average usable floor area of residential premises per capita (in m^2)	−0.354	0.174	0.702	0.042	**
	Unemployment rate (%)	0.593	0.209	1.810	0.004	***
	Bed places per 10 thousand population	0.002	0.001	1.002	0.069	*
	Share of operating surplus in current revenues (%)	−0.387	0.115	0.679	0.001	***
	Percentage of total revenue remaining after the end of the financial year (%)	0.119	0.040	1.126	0.003	***
	Level of own revenues per capita (in PLN)	−0.002	0.001	0.998	0.012	**
	Level of revenues from income tax per capita (in PLN)	0.006	0.002	1.006	0.003	***
	Share of developed and urbanised land in total area (%)	1.363	0.489	3.909	0.005	***
	Share of ecological sites in total area (%)	−3.669	2.135	0.026	0.086	*
	Water consumption per capita in m^3	−0.062	0.026	0.940	0.017	**
North-Western ($n = 388$)	Migration balance per 1000 population (median for 2013–2021)	0.062	0.022	1.064	0.006	***
	Percentage of councillors with higher education (%)	0.017	0.008	1.017	0.028	**
	Residential premises per 1000 inhabitants	0.009	0.003	1.009	0.003	***
	Bed places per 10 thousand population	0.000	0.000	0.999	0.032	**
	Share of operating surplus in current revenues (%)	−0.064	0.026	0.938	0.014	**
Central ($n = 118$)	Population density (persons per km^2)	0.039	0.011	1.040	0.000	***
	Share of entities employing >49 persons (%)	−0.246	0.085	0.782	0.004	***
	Unemployment rate (%)	−0.392	0.140	0.675	0.005	***
	Share of property expenditure in total expenditure (%)	0.116	0.042	1.123	0.006	***
	Development potential in relation to property expenditure and capital repayments (%)	0.006	0.002	1.006	0.010	**
	Forest cover (%)	0.046	0.016	1.047	0.004	***
Southern ($n = 136$)	Population density (persons per km^2)	0.006	0.002	1.006	0.005	***
	Businesses per 10 thousand population	0.003	0.001	1.003	0.006	***
	Share of agricultural holdings of 15 ha and more in the total number of agricultural holdings (%)	0.067	0.028	1.069	0.018	**
Mazowieckie voivodeship ($n = 268$)	Businesses per 10 thousand population	−0.002	0.001	0.998	0.018	**
	Percentage of businesses employing 49 persons or more (%)	0.137	0.055	1.147	0.013	**
	Development potential in relation to property expenditure and capital repayments (%)	0.003	0.001	1.003	0.017	**
	Land under water (%)	0.121	0.071	1.128	0.088	*
	Share of developed and urbanised land in total area (%)	−0.091	0.029	0.913	0.002	***
Poland ($n = 1478$)	Population density (persons per km^2)	−0.002	0.000	0.998	0.000	***
	Demographic dependency ratio	−0.047	0.019	0.954	0.012	**
	Migration balance per 1000 population (median for 2013–2021)	−0.038	0.017	0.963	0.024	**
	Businesses per 10 thousand population	0.001	0.000	1.001	0.044	**
	Foundations and associations per 10 thousand inhabitants	0.009	0.005	1.009	0.071	*
	Percentage of councillors with higher education (%)	−0.013	0.004	0.988	0.001	***
	Average usable floor area of residential premises per capita (in m^2)	−0.063	0.020	0.939	0.002	***
	Residential premises per 10 thousand population	0.003	0.002	1.003	0.072	*
	Share of unemployed people (%)	−0.090	0.024	0.913	0.000	***
	Share of agricultural holdings of 15 ha and more in the total number of agricultural holdings (%)	0.017	0.005	1.017	0.000	***
	Share of property expenditure in total expenditure (%)	−0.036	0.008	0.965	0.000	***
	Operating surplus per capita (in PLN)	0.001	0.000	1.001	0.042	**
	Level of own revenues per capita (in PLN)	0.002	0.001	1.002	0.096	*
	Level of revenues from income tax per capita (in PLN)	0.001	0.000	1.001	0.026	**

Source: author's own calculations using *Gretl* software based on Polish Ministry of Development and Economic Investment [83].

[a] The models were built based on balanced samples for individual macro-regions and Poland (municipalities which obtained at least 1 RES project co-financed from EU funds in the analysed period (1) and municipalities which did not show investment activity in this field (0) were taken into account).

[b] Collective test of model coefficients (number of accurate predictions): South-Western – $\chi^2 = 22.03$, $p = 0.000$ (63.0 %), Northern – $\chi^2 = 39.94$, $p = 0.000$ (67.5 %), Eastern – $\chi^2 = 70.44$, $p = 0.000$ (84.7 %), North-Western – $\chi^2 = 70.59$, $p = 0.000$ (68.5 %), Central – $\chi^2 = 39.00$, $p = 0.000$ (73.9 %), Southern – $\chi^2 = 44.25$, $p = 0.000$ (71.5 %), Mazowieckie voivodeship – $\chi^2 = 52.71$, $p = 0.000$ (65.4 %), Poland – $\chi^2 = 218.1$, $p = 0.000$ (65.5 %).

[c] If *p*-value <0.001, it is marked with three asterisks (***), if 0.001 < *p*-value <0.05 – two asterisks (**), and if 0.05 < *p*-value <0.1 – one asterisk (*).

differentiation of the Mazowieckie voivodeship in terms of the level of development, population and development density, which in the capital city and ring-shaped municipalities (rural municipalities with their seats located in separate cities, in adjacent municipalities), is definitely higher than in peripherally located municipalities.

5. Discussion

This study fills a research gap on local authority investment activities in a low-carbon economy. Determinants are much more frequently explored with reference to the business sector and eco-innovation [85–87]. However, it is possible to consider certain factors as universal, applying to the totality of those implementing the investments under analysis. These determinants are usually divided into exogenous (external) and endogenous (internal) ones. Exogenous factors include economic and social progress or environmental regulations at the national, EU or international level [88–90]. Environmental taxes can be an example of such instruments introduced by state or local authorities to protect the environment [91]. The importance of public funding and incentives for the implementation of this type of investment was pointed out by Taghizadeh-Hesary & Yoshino [92], Han [93], Du et al. [94]. Murovec et al. [85], based on a study covering 35 developed and emerging economies, found that green investment is determined by macroeconomic factors and, in addition to economic growth, highlighted the importance of a stable financial system conducive to low interest rates and of high fuel prices and government interventions. The state, too, can stimulate these investments by offering guaranteed loans, reductions in taxes paid or a subsidy system [87]. Shi et al. [95], in turn, based on *R* cluster analysis, proved with regard to Chinese sub-regions that, in addition to economic issues, population change is also important, the increase of which positively influences these investments. Similar conclusions were drawn by Liao & Xunpeng Shi [96]. Their econometric model indicated that there was a positively significant interaction between factors, i.e. social attractiveness, industry structure, population, or regional gross domestic product. Considering the Polish conditions, Milewska and Parlińska [36] point to the importance of excessive complexity of the law in terms of locating investments in RES and frequent legislative changes. Similarly, Ryszko [97] points to barriers in of, i.a., legislation, demand, technology and cooperation.

Analyzing the universal endogenous determinants of environmentally friendly investments, Uddin Bhuiyan et al. [98] proved that social capital, especially the environmentally friendly attitude of managers, is extremely important. Interestingly, Chariri et al. [86] used multivariate and logistic regression analysis in their study demonstrating that the implementation of environmentally friendly investments positively influences the financial performance of the investors. This was therefore a similar finding to the one presented in this study. Referring to Polish municipalities, Milewska and Parlińska [36] point to the low activity of municipalities themselves in environmental undertakings, which is due to the high cost of these investments, from preparing planning documentation to the actual handling of this task. As the authors of a 2018 study note, setting up social energy cooperatives, especially in rural areas predisposed to the use of biomass, could be an opportunity to rationalise costs [99]. Gradziuk and Gradziuk [100], on the other hand, perceive the attitude of local governments to be the opposite, i.e. active. It should be noted that environmental investments are capital-intensive [101] and, in this case, the financial standing of the beneficiary and the possibility to undertake them, are extremely important. Also, a study by Collenbrander et al. [102] demonstrates the special role of finance in the implementation of this type of investment.

Among the internal factors influencing the implementation of the analysed projects, environmentally friendly expectations of the inhabitants can also be distinguished, as well as the awareness of local authorities manifested by the environmental policy implemented in their area [88–90]. The importance of social acceptance is also pointed out by Gradziuk and Gradziuk [100] and Li et al. [103], who further emphasise the role of conducting educational activities.

Every research project has its limitations, as it was stressed by Sovacool et al. [104]. In the case of this study a significant challenge was connected with collecting comprehensive data on investments implemented by the analysed municipalities and the related specific conditions. Available public statistics data, considered to be a reliable source, were used; nevertheless, a limitation here was connected with the relatively small number of indicators available at the lowest tier of the administrative system. Additionally, there is a lack of comprehensive information on all low-carbon investments realized in Poland, as well as their direct impact on the budgets of their beneficiaries.

Considered limitations at the same time indicate potential directions for future research. A valuable supplementation of quantitative analyses could be provided by qualitative studies, facilitating a detailed explanation of selected conditions for investments and an in-depth analysis of the impact of investments on budgets of local government units. It is also worthwhile to consider comparative studies with other EU countries, which would facilitate a deeper understanding of factors determining development of low-carbon economy under diverse socio-economic conditions.

The case of Poland shows the importance of adequate support mechanisms and development strategies in the process of energy transition. For this reason further studies need to focus on a comparative analysis with other EU countries, which would provide more insight into determinants for the development of low-carbon economy within a broader, European context.

6. Conclusions and policy implications

Polish beneficiaries are actively pursuing investments in low-carbon economy. These activities have significantly intensified when comparing absorption rates for projects implemented under the EU financial perspective 2014–2020 compared to 2007–2013. Public entities, as well as their subordinate units, implemented a total of nearly 10,500 projects, of which as many as 80 % in the second perspective. In turn, an analysis of their value reveals that their share was as high as 90 % in 2014–2020. In the first programming period, the degree of concentration of obtained EU subsidies in terms of both the number and value of projects was enormous, with particularly large funds being absorbed in the Eastern, Mazowieckie Voivodeship and Southern macro-regions. In the next perspective, the aforementioned concentration decreased, but the activity of the analysed entities in macro-regions such as Southern, Mazowieckie Voivodeship, Eastern and Northern stood out against the average.

Municipalities were an active beneficiary of the support obtained for the development of a low-carbon economy, as in the period under study they implemented nearly half of the analysed projects, absorbing a total of half of the funding. This means that the transition of the Polish economy towards a change of energy sources would not have been possible without so much interest in these projects on the part of the analysed entities, especially since their activity also improved when comparing both programme periods. Of particular note is the fact that when the value of projects is converted to 10,000 residents, the result improved by as much as 8 times and, taking into account the area, by >16 times. Municipalities in the Eastern macro-region were particularly active in the 2007–2013 period, and in the 2014–2020 period there was also a particularly high absorption in the Eastern macro-region, but also in the Northern, Southern or Central macro-regions. The aforementioned increase in the activity of municipalities in terms of raising EU funds for low-carbon economy was verified with a Student's *t*-test, which confirmed statistically significant changes. With the support they received, private as well as public entities (including municipalities) have mainly increased energy efficiency, worked to develop solar energy and clean urban transportation.

The varying levels of low-carbon projects implemented provided the basis for identifying the determinants of the obtained support. The group

of characteristics that were taken into account included indicators corresponding to the socio-economic, financial and environmental spheres. The largest number of significant characteristics was included in the national model and for the Eastern macro-region, which may be related to the fact that beneficiaries there demonstrated particularly high investment activity in the discussed scope.

Comparing the results for the different models, it should be noted that the development of entrepreneurship, which in turn has a positive impact on the revenue potential of local authorities, especially in terms of tax revenues, is of great importance for investment activity aimed at building a low-carbon economy. Similarly, own revenue and the volume of taxes collected are influenced by demographic potential. The population and its change had a significant impact on the analysed phenomenon, with both positive and negative effects possible. This depends on the specifics of the macro-region and the activity of the individual types of local and territorial authorities. In some of them, the contracting parties were mainly urban municipalities making the largest investments in urban transport. This was particularly the case in the more urbanised macro-regions. In others, such as in the Eastern macro-region, rural local authorities were particularly active. These characteristics in turn, translate into another of the financial determinants examined – the operating surplus, the occurrence of which determines investment opportunities and debt capacity. This capacity is all the more important as low-carbon investments are capital-intensive and therefore often require a financial plan to be prepared, especially by local and territorial authorities with weaker financial positions.

In summary, each of the factors analysed varies depending on the specifics of the macro-region, which may influence the unique approach to low-carbon economy development in individual areas. As noted by Gradziuk & Gradziuk [100], individual municipalities, when choosing how to manage energy, should follow the solutions best suited to their *local conditions, needs and traditions and their vision of the degree of energy self-reliance.* Arguably, this is all the more important as it is the responsibility of the local and territorial authorities to solve environmental problems and, what is more, they have the opportunity to make investments in this area by obtaining subsidies, including from the EU. Local authorities should therefore be supported to step up their efforts to build a low-carbon economy.

Decision-makers need to increase financial support (e.g. by a greater share of such funds in the own contribution from the central budget for EU projects) and simplify procedures so that it is easier for municipalities to acquire funds. This is of particular importance, because at present municipalities are struggling with a crisis resulting from reduced autonomy and inflow of funds. It is also worthwhile to invest in labor force competences. Presently in Poland it is not mandatory for each municipality to have an energy system advisor. However, within the framework of the Energy Advisory Project the National Fund for Environmental Protection and Water Management along with 16 regional partners offer consultancy support for municipalities regarding energy efficiency and renewable energy sources. Among other things, energy advisors provide assistance in the development and implementation of Low-carbon Economy Plans, which may bring tangible benefits to municipalities in terms of reduced energy consumption in public buildings and decreased energy costs. For this reason, despite a lack of the formal requirement to employ an energy advisor cooperation of municipalities with such a specialist may considerably facilitate realization of projects connected by energy efficiency and renewable energy sources. It is also necessary to develop long-term strategies for low-carbon development, which is connected with the above-mentioned Low-carbon Economy Plans. They are not mandatory documents. Cooperation between municipalities and regions needs to be intensified through joint projects and exchange of experiences. It would be worthwhile to establish platforms facilitating communication and sharing good practices.

CRediT authorship contribution statement

Aldona Standar: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Agnieszka Kozera:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Łukasz Satoła:** Writing – review & editing, Writing – original draft, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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