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Conditions Driving Low-Carbon Innovation in a Medium-Sized European Country That Is Catching Up—Case Study of Poland

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Abstract: Studies on the determinants of low-carbon innovations in developed countries already exist. We test here the institutional environment in Poland (science–government–enterprise) as supporters of the technological change in industry towards a low-carbon economy. We will examine as well whether conclusions for well-developed countries are relevant for those catching up. The aim of the article is to assess the systemic nature and durability of the impact of internal and external conditions on the implementation of low-carbon technologies in Polish industry. In order to achieve the goal, two surveys were carried out for the periods 2007–2012 and 2013–2018, on sample sizes of 11,493 enterprises. To verify the hypotheses, a statistical multi-factor logit modelling was used to determine the chances of low-carbon innovations under the influence of various parallel circumstances. The results of this research point to other, often abrupt (unstable) phenomena occurring in the catching-up economy, which are the consequence of a long-term technological gap. The case of Poland shows the lack of cooperation between science, enterprises and the government in stimulating the development of low-carbon technologies, although enterprises do try to implement such technologies on their own in the absence of any external cooperation. Without Research and Development (R&D) support and government subsidies, the attempt to implement low-carbon technology fails. Thus, the institutional framework should distinguish between catching-up and developed countries due to the gaps in technological knowledge, cooperation and institutional barriers.

Keywords: innovations for low-carbon development; low-carbon economy (LCE); low-carbon technology; low-carbon industry; catching up country; Poland



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1. Introduction

The need to mitigate the effects of global warming and the efforts to reduce greenhouse gas emissions require coordination of the policies of individual countries around the world. In developed countries, due to better financial resources and access to knowledge, low-carbon technologies spread without major problems. The results show there a significant reduction in carbon dioxide emissions. In catching-up countries, this process is difficult because these economies have limited access to knowledge and lower R&D investments [1]. However, long-term environmental benefits can offset the economic losses associated with the implementation of low carbon technologies [2]. In developing countries, the situation is made more difficult by the lack of pressure to reduce the energy intensity of production due to the higher competitiveness of their lower labour costs compared to developed countries. According to the data of the European Commission, Poland is one of the countries that since 2010 has ranked low in terms of eco-innovation [3]. This means that few entities implement energy saving technologies [4]. Such circumstances necessitate the creation of mechanisms that will facilitate the transfer of technologies from developed countries and their adaptation to local conditions in catching-up and developing countries. This applies not only to the economic dimension, but also to the social one [5–7]. Properly shaped policy in individual countries or groups of countries requires a diagnosis of the current state

to determine what factors influence decisions about the implementation of low-emission technologies and how they change over time.

The aim of the study is to assess at the level of the national innovation system in Poland the directions, strength and stability of the impact of internal and external conditions on entrepreneurs' decisions to apply innovations resulting in the reduction of low-stack emissions. The authors carried out two such corresponding surveys in the Polish industry in 2007–2012 and 2013–2018 on samples of 5209 and 6284 enterprises. Such numbers of correctly filled out questionnaire forms allowed for analysis at the country level. The article is organized as follows. It begins with a discussion of the global theoretical achievements in the field of determinants of low-carbon innovation. The methodology used in the work is presented right after theoretical background. In the next section, the research results are analyzed in the context of the observations of other scientists. The discussion and implications constitute the most important and are the final part of the article.

2. Literature Review

The reduction of the energy consumption of industry by implementation of new technologies represents an opportunity to achieve climate goals in the form of reducing greenhouse gas emissions by 40% compared to 1990 [8]. Policies are currently being developed to support the implementation of low-carbon innovations, but to be effective, they should take into account the specificity of the local industry [5–7]. Systemic determinants will allow the building of an appropriate policy to support new low-emission solutions.

In the socio-technological approach, several specific characteristics related to low-carbon innovations come to the fore, such as reference [9]:

1. The need for systemic changes.
2. The need for cultural change.
3. The need for a new policy and its instruments.
4. The need to reduce ubiquitous uncertainty.

These points will be discussed in the theoretical and empirical part of the article, together with an indication of the need for their evolutionary inclusion in the design solutions for countries at different levels of development. The systemic theme is of a horizontal nature and concerns all the partial considerations in this article.

International research shows that the propensity to implement low-carbon technologies is determined by the structure of enterprises. This applies to their size and ownership. As the size of the enterprise grows, the chances of implementing low-carbon innovation increase [10–15]. It turns out that large enterprises initially pollute the environment more, but as economies develop, it becomes easier for these entities to adopt stricter environmental regulations [13]. Contradictions arise in respect of the international nature of the activities of enterprises. Most studies indicate that the operation of enterprises on international markets [10,11] or the creation of an enterprise with foreign capital [11] does not affect the implementation of low-carbon solutions. Nevertheless, Costa-Campi, García-Quevedo and Segarra have shown that entities present on the international market can have a greater propensity to introduce pro-environmental innovations [14]. This contradiction can be explained by the fact that energy efficiency has come to be seen as a tool to improve efficiency in the face of international competition from economies with much lower labour costs [12]. It is interesting to note that competitive pressure (but without taking into account international issues) is indicated as a stimulus for the implementation of pro-environmental solutions also in other analyses involving catching-up economies [16,17].

Research in Spain shows that the energy efficiency of companies is largely driven by investments in tangible assets (e.g., purchasing more efficient machinery) or implementing cleaner technologies. However, their implementation relates only to the purchase of fixed assets and does not entail investments in R&D [14,18]. On the one hand, it significantly increases the differences in the level of absorption of low-carbon technologies between developed and catching-up countries [1], to the disadvantage of the latter. On the other hand, the dynamic development of the market for the construction of photovoltaic panels

in China showed that the environmental pressure in developed countries (high demand for pro-environmental solutions) contributed to a sustainable transformation in this area in the Chinese economy [7].

The main motivation for the implementation of low-carbon solutions are financial factors related to cost reduction. They concern lower demand for energy or the threat of its price increase [4,12,16,19–23]. This variable appears as a determinant in both developed and catching-up countries, but the context that accompanies them is different. For example, in Germany [20] and Slovenia [16], it is also important for customers to seek products with better environmental performance [20], while in Spain it was noted that the environmental attributes of innovations are irrelevant to consumers [10]. This means that in developed countries there is greater social awareness of environmental protection against negative factors [24]. High investment costs related to the implementation of energy efficient solutions constitute a significant barrier to this process [25]. Moreover, not all low-carbon technologies translate directly into cost reduction or, if so, it is too low for entrepreneurs. Therefore, public subsidies are required [10,11,21,26,27], especially for small and medium-sized enterprises (SMEs) [12,28]. Politicians have many solutions at their disposal that enable the transformation of technologies from “dirty” to “clean” [29–31]. It is important that these subsidies take into account the specificities of the countries in which they are implemented, as public subsidies from international sources do not increase the likelihood of being eco-innovators, although domestic sources of funding do [11].

The decisions of enterprises related to the implementation of low-carbon technologies are significantly influenced by legal regulations and green market requirements [32]. Such factors constitute the strongest determinants [20,24,33] which play a greater role in catching-up countries [24]. Regulations help to properly allocate internal resources and create their own low-carbon strategies [34] and reduce the technological and regulatory risks associated with investments in renewable energy projects [35]. However, it should be noted that the uncertainty in implementing new environmental protection standards delays the proper development of technical knowledge [36], which simply does not keep up with changing standards over time.

Research on barriers to the implementation of low-carbon innovations is mainly carried out on a group of small and medium-sized enterprises. Analyses indicate that the main limitations indicated by entrepreneurs are economic and information barriers [15,25,37–40], while external factors are perceived as more important than internal ones [38]. Economic barriers refer not only to the lack of self-financing resources, but also to the perception of the conditions for obtaining subsidies for low-carbon innovations as complicated [38]. Despite the importance of external factors, entrepreneurs seem to underestimate internal constraints. It turns out that the hierarchical structure, organizational culture [27,40] or the lack of information about the most energy-consuming aspects of production [23] can significantly limit the implementation of such solutions.

Low-carbon innovation depends on internal and external sources of knowledge [41]. Innovative collaboration [42] and technology diffusion [43–45] are key elements of knowledge capital [46]. Difficulties related to the availability of information on low-carbon technologies necessitate R&D work and entering into cooperative relationships [47]. System problems hinder the rapid development and dissemination of renewable energy technologies and, therefore, require additional attention from decision makers and other national entities interested in accelerating such technologies. Research shows that there is a gap between university and practical knowledge. Relations between the universities and industry are limited, they lack common research strategies [48]. In the process of creating low-carbon innovations, cooperation with suppliers [10,21,49–51], partners [52] and institutions in the field of science [10] plays a special role, which is suggested by the existence of technological interdependencies on knowledge, skills and resources, as well as the need to supplement the internal knowledge base with competences from various domains [53]. Due to the lack of information exchange, many technological problems remain unresolved [54]. The literature review shows that the lack of stable institutions,

both hard and soft, stimulating renewable energy sources, and their poor adaptation to practices in various sectors, are the most important obstacles to the dynamic spread of low-carbon technologies [31]. In catching-up countries, international cooperation is also important, indeed research shows that it increases the likelihood of eco-innovation compared to national cooperation [11].

The review of the literature indicates which determinants may affect the implementation of low-carbon innovations and shows that in the decision-making process of enterprises such factors are taken into account: research and development activity, enterprise size and their capabilities, sources of knowledge about low-carbon technologies, financial and institutional barriers, environmental protection regulations and market turbulence [55]. However, as shown in the literature review, the cited studies do not include all of the aforementioned determinants simultaneously (being isolated studies). On the one hand, the literature presents knowledge of the determinants of the implementation of low-carbon innovations in both developed and catching-up countries, on the other hand, it creates difficulties in assessing the impact of all these factors simultaneously on the national system. In this context, it is the literature that lacks an illustration of the interactions between the aforementioned determinants—strengthening the role of some or limiting others. Therefore, based on the achievements of other researchers, the authors decided to combine these determinants into a systemic approach and include all of them in a study of the implementation of low-carbon innovation at the national level. The analyses will be carried out using the example of a catching-up country, since, as noted by the authors of the study and Del Río, Peñasco and Romero-Jordán [56], middle-income and developing countries are rarely the subject of low-carbon innovation research. Therefore, a research gap appears in the literature on the subject, which consists in the lack of systemic and long-term analyses related to low-carbon innovations in the country's "catching up" industry. This raises the following questions: Do the circumstances surrounding the processes related to the implementation of low-carbon technologies differ from those observed in the most developed countries (which means, will the variables that occurred in developed countries also appear in catching-up countries)? Are the operating conditions of enterprises stable over time? Does the institutional environment of enterprises support technological changes in the industry towards low-stack emissions?

Low-carbon innovations are treated here as new or modified technological solutions (processes and products) applied at enterprises in the last three years, and which contribute to the reduction of low-stack emissions at source of production (direct) or at cooperating entities (indirect)—suppliers of materials and energy factors. This is the definition of low-carbon innovations from the demand side and is consistent with those used in the literature on the subject [9,57].

The aim of the article is to assess the systemic nature and durability of the impact of internal and external conditions on the implementation of low-carbon technologies in Polish industry. The presented arguments led the authors to formulate the following research hypotheses related to the industry of the catching-up country, which is Poland:

Hypothesis 1. *Internal and external conditions stably determine over time Polish industry in implementing new low-carbon technologies in the long term—the nature of the system.*

Hypothesis 2. *The level of available knowledge about technologies and the possibility of finding a scientific and business partner to develop such technologies together favours low-carbon innovation.*

Hypothesis 3. *Low-carbon innovation promotes multi-faceted improvements in the economic efficiency of industrial companies.*

Hypothesis 4. *Low carbon legal regulations permanently determine the technological activity of the industry in this area.*

Hypothesis 5. *Research institutes and innovation support centres have a systemic impact on the low-carbon technological activity of industry in Poland.*

3. Materials and Methods

3.1. Sample

The questionnaire research was conducted in Poland twice in 2007–2012 and 2013–2018 in accordance with the international methodological standards of research on innovations included in the Oslo Manual [58], extended with the authors' own contribution. It was carried out by the employees of the Department of Innovation and Entrepreneurship at the University of Zielona Góra, along with students studying during its implementation, in accordance with the suggestions of Lundvall [59], to involve students in the scientific process at the universities where they study in countries at a lower level of development. In the first round of the study, 5209 correctly completed questionnaires were collected, and in the second, 6284. It should be mentioned at this stage of considerations that the study for the years 2007–2012 did not include support institutions, as it was an early period of their emergence and self-organization. The second study did include all the elements of the so-called triple helix responsible for the national innovation system. The flowchart of the research related to the preparation of the collected material is presented in Figure 1. Apart from this single divergence, all independent variables are repeated in the model estimation process. The number of enterprises that implemented technologies contributing to the reduction of emissions was not large and amounted to 210 entities (4.0%) in the first study and 222 (3.5%) in the second. It can be seen that solutions of this type are not a common phenomenon in Poland.

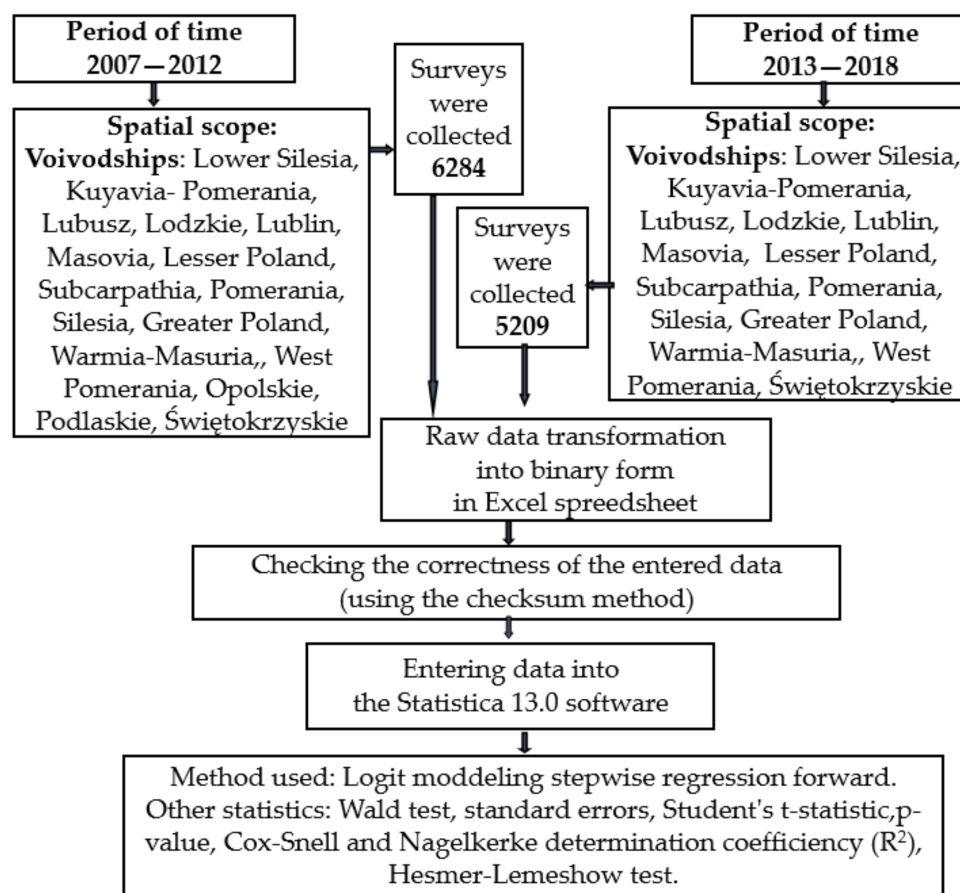


Figure 1. Flowchart of conducted study. Source: Our own study based on the research process.

3.2. Variables

According to the adopted research hypotheses, the dependent variable informs about innovations related to the reduction of low-stack emissions. This can be understood through the prism of two types of solutions used by enterprises. The first are innovative products, and the second are new production technologies. It is important that the effect of their introduction is to reduce the harmfulness of the impact on the natural environment in general and, at the same time, to reduce emissions by limiting the consumption of materials and energy for production (lower material and energy consumption). Six groups were classified as independent variables. The first one concerns the internal attributes of enterprises and these are usually control variables used to show a broader context of the studied phenomena. These include: the size of enterprises (micro, small, medium, large), expenditure on innovation (R&D, purchase of machinery and equipment, new building investments), ownership (domestic, foreign, mixed), technological advancement (low, medium-low, medium-high, high technologies), economic situation (improvement, deterioration, stagnation). The second group of independent variables concerns sectoral conditions. These include cooperation in the field of innovation with suppliers, customers, competitors and within the capital group. They are the first link in the innovation system. The third group of variables represents science. According to the specificity of the country, the study covers cooperation in the field of low-carbon innovations with universities, units of the Polish Academy of Sciences, foreign research institutes and other R&D units. Together, they are responsible for the second pillar of the innovation spiral. The last element of the system are innovation support organizations (included only in the second round of research), i.e., public organizations that support enterprises at various stages of the innovation process. The following units were distinguished here: technology parks and incubators, technology transfer centres, business angels, local and regional loan funds, guarantee funds and training and consulting centres.

Moreover, the conducted analyses include sources of information on new low-carbon technologies, such as: internal sources, suppliers, customers, competitors, units of the Polish Academy of Sciences, R&D units, foreign research centres, universities, conferences and fairs, industry magazines and publications, scientific and technical associations. The group of factors hindering the introduction of new low-carbon technologies includes: lack of own resources, lack of external financing sources, high innovation costs, insufficient personnel qualifications, lack of information about technologies and markets, difficulties in cooperation, dominant position of another enterprise, uncertain demand.

The last element taken into account in the modelling process is the effect achieved by companies as a result of introducing low-carbon solutions. The problem that pertains to them is whether such technologies are isolated or whether they generate added economic value in other areas than just ecology. The following effects are included: increasing the product range, entering new markets, improving quality, improving production flexibility, increasing production capacity, reducing unit labour costs, and meeting regulations and standards. Basic statistics for each variable are presented in Table 1.

All independent and dependent variables accepted for the study are binary (dummy variables). For example, the respondents were not asked about the amount of investment expenditures incurred, but about whether they took place. Thus, there was no need to standardize the variables. It is also worth emphasizing that there are 53 potential independent variables in the first model (no support institutions) and 60 in the second.

Table 1. Descriptive statistics of the variables.

Variable	Period 2007–2012				Period 2013–2018			
	Mean	S.D.	Min.	Max.	Mean	S.D.	Min.	Max.
Medium-sized enterprises	0.22	0.41	0	1	0.17	0.37	0	1
Large enterprises	0.06	0.24	0	1	0.05	0.21	0	1
Enterprises with foreign capital	0.06	0.24	0	1	0.05	0.21	0	1
Revenue dropped down	0.19	0.39	0	1	0.19	0.39	0	1
Revenue–lack of change	0.27	0.45	0	1	0.36	0.48	0	1
R&D	0.36	0.50	0	1	0.34	0.47	0	1
Building investments	0.26	0.44	0	1	0.27	0.44	0	1
Machinery and equipment	0.61	0.51	0	1	0.62	0.49	0	1
New products	0.55	0.50	0	1	0.63	0.50	0	1
New technology	0.48	0.50	0	1	0.48	0.50	0	1
Cooperation with competitor	0.04	0.20	0	1	0.04	0.20	0	1
Cooperation with Polish Academic of Science	0.02	0.12	0	1	0.01	0.11	0	1
Cooperation in the capital group	0.03	0.17	0	1	0.03	0.18	0	1
Technology incubators	x	x	x	x	0.02	0.15	0	1
Scientific and research associations	0.08	0.26	0	1	0.09	0.28	0	1
Foreign R&D centers	0.07	0.25	0	1	0.05	0.21	0	1
Industry magazines and publications	0.30	0.46	0	1	0.28	0.45	0	1
Difficulties in cooperation	0.08	0.27	0	1	0.08	0.28	0	1
Lack of information about new technologies	0.08	0.28	0	1	0.11	0.31	0	1
Improvement in the quality of products	0.57	0.49	0	1	0.59	0.49	0	1
Fulfillment of regulations and standards	0.15	0.36	0	1	0.19	0.39	0	1
Reducing unit labor costs	0.22	0.42	0	1	0.22	0.44	0	1
Improvement production flexibility	0.20	0.40	0	1	0.18	0.38	0	1
Increasing production capacity	0.29	0.40	0	1	0.24	0.43	0	1

Source: own study based on the collected research materials.

3.3. Econometric Methods

Due to the qualitative nature of the dependent variables and the specifics of the research sample, it was decided to use multifactor logit models to test the research hypotheses. Such modelling is used when we operate within a narrow range of responses provided by respondents. The use of classical linear regression then may lead to false results: negative values. Logarithmic modelling, which limits the range of possible values between 0 and 1, comes in handy here. Such modelling has gained its usefulness and popularity in medical science, where the occurrence of the disease is often assessed as present (value 1) or not (value 0). All our dependent variables take the values 0 or 1, true or false (the feature is present or not). Such modelling is based on the conditional probability theory, which takes the following form:

$$P(Y = 1/\chi_1, \chi_2, \dots, \chi_k) = \frac{e^z}{1 + e^z} \quad (1)$$

where P is the probability of adopting the distinguished value (1), provided that specific values of the independent variables are obtained, also called the predicted probability for 1 and which is most often expressed as a linear function:

$$Z = \beta_0 + \sum_{i=1}^k \beta_i \chi_i \quad (2)$$

where:

X_1, X_2, \dots, X_k —independent variables

$\beta_1, \beta_2, \dots, \beta_k$ —model parameters

Logit is the transformation of such a model into the form:

$$\ln\left(\frac{P}{1-P}\right) = Z \quad (3)$$

The coefficients are estimated by the maximum likelihood method, i.e., when looking for the maximum of functions. On the basis of these values, it is possible to infer the magnitude of the influence of the variables on the independent variable. Each parameter is burdened with an error of estimation.

Our research procedure, however, was more sophisticated. Here, forward stepwise regression was used to remove from the equations independent variables, which are strongly correlated (correlation matrix included) and ultimately irrelevant in the estimation process. The Wald test and p -value are used to assess the correctness of the models. The significance of the parameters of the independent variables is checked by use of standard errors, Student's t -distribution and p -value. The measures of fit are the coefficients of determination R^2 —Cox-Snell i R^2 —Nagelkerke typical for logit regression. Additionally, the Hosmer–Lemeshow test was used to assess the proximity of the predicted probabilities (E_g) and the number of expected observations (O_g). This test is applicable to different data subgroups:

$H_0: O_g = E_g$ for all categories,

$H_1: O_g \neq E_g$ for at least one category.

The p -value determined on the basis of the test statistics is compared with the significance level α :

if $p \leq \alpha \Rightarrow$ we reject H_0 accepting H_1 ,

if $p > \alpha \Rightarrow$ there is no reason to reject H_0 .

The expected value of p in this case should be as high as possible so that the H_0 hypothesis cannot be rejected and, consequently, the model is considered well estimated.

The odds ratio is used to present and interpret the study results in the tables. This is a measure specific to logit models. The threshold value of the odds ratio is 1. Above 1, the chances for innovative activity are higher than in the reference group by a certain percentage, and below 1 the chances are lower. The reference variables include: micro and domestic enterprises, low technology and improved market conditions. In the case of the remaining independent variables, referentiality results spontaneously from their specificity. For example, for companies that use R&D activities, the reference group are those not doing it.

4. Results

The presented results are the result of a survey conducted in the Polish industry in two rounds: 2007–2012 and 2012–2017. The national system should not be characterized by radical changes at this time, but rather by their evolutionary nature, a systemic feature. The research results partially confirm this thesis, but not fully. Some of the factors taken into account are important in both rounds of the study, while others occur once, which indicates abrupt changes. This may be due to the shallowness of the system and testify to the emergent nature of low-carbon innovation in Polish industry. This thesis is confirmed

by the percentage of enterprises that declare their introduction: 4.0% in the first round and 3.5% in the second. In such circumstances, decisions about these solutions may fluctuate greatly. In other words, industry in Poland is evolving, but due to the embryonic nature of low-carbon innovations, it is highly variable in some of its parts.

The quality of the model fit for first research period (Table 2) is neither high nor low (R^2 Nagelkerke = 0.26 and R^2 Cox-Snell = 0.07). However, it should be remembered that dummy variables appear on both sides of the equation, which is of great importance for the above measures of fit. At the same time, the model is statistically significant ($p < 0.01$ of the likelihood-ratio test), and therefore the independent variables are statistically significant. The Hosmer–Lemeshow test result shows no significance ($p = 0.56$). It is a desirable situation because it proves the similarity between the observed rates and the predicted probability.

Table 2. Determinants for low-carbon innovations in Poland in 2007–2012, logit function.

Independent Variables	Low-Carbon Innovation (Odds Ratio)
Enterprises Attributes	
Medium-sized enterprises	1.48 (**)
Large enterprises	2.99 (***)
New machinery and equipment	1.50 (**)
Enterprises with partial foreign capital	0.53 (**)
Innovation cooperation	
Polish Academy of Sciences departments	2.24 (**)
Competitor	1.53 (*)
Sources of innovation activity	
Scientific and research associations	1.87 (***)
Foreign R&D centers	1.53 (*)
Effects of innovation activity	
Fulfillment of regulations and standards	3.14 (***)
Reducing unit labor costs	3.10 (***)
Improvement production flexibility	2.49 (***)
Increasing production capacity	2.26 (***)
Constants	0.00 (***)
Reference variables: micro enterprise, domestic enterprise, economic growth	
Sample	5209
chi-square	399.6
R^2 Cox–Snell	0.07
R^2 Nagelkerke	0.26
p -value	0.00
Hosmer Lemeshow test	
chi-square	5.80
p -value	0.56

(***)—statistical significance at 1%, (**)—statistical significance at 5%, (*)—statistical significance at 10%. Source: An own calculation based on questionnaire research.

In the first research period, new solutions for reducing low-stack emissions were introduced mainly in large and medium-sized enterprises, by 199% and 48%, respectively, more often than in the remaining ones. Such solutions required the purchase of new machinery and equipment. Such activities followed a similar course in domestic and foreign-owned enterprises with opportunities twice as high as in those with only partial foreign capital.

It is worth adding here that in the modelling process more internal conditions were adopted, but some of them turned out to be irrelevant, including technological advancement and export activity. The economic situation also did not affect low-carbon innovations, although it does strongly determine the overall technological activity of the industry.

The domestic industry obtained strong support for such solutions as a result of cooperation with units of the Polish Academy of Sciences (odds ratio increase by 124%) and with competitors (more often by 53%), although at the same time the main sources

of knowledge for such innovations were scientific and research associations and foreign scientific institutes. This means that information on such solutions is independent of the cooperating entities, which is necessary for their joint development.

The implementation of new low-carbon solutions is the result of innovative activity in general, but not exclusively. Entrepreneurs decided to implement them as a result of the need to adapt to the legal regulations that enforce such decisions. This reason more than three times as often as others determines such investments than when there is no such need. It is worth mentioning that in the surveyed companies no significant barriers were identified that could inhibit such processes. This proves the imperative of forcing entrepreneurs to make such decisions in 2007–2012, as the research shows they rarely took such actions on their own initiative.

The introduction of low-carbon solutions is also conducive to achieving many economic benefits. In enterprises where such solutions took place, unit labour costs were reduced three times more often than in those where they did not, likewise, production flexibility was improved two and a half times more often, and production capacity was increased to a similar extent. Apart from the internal characteristics of enterprises, which determine the implementation of low-carbon solutions, the scientific environment and competitors are also important. It is worth briefly summarizing that the sources of knowledge about such solutions lie outside the enterprise, and the benefits achieved are much wider than just ecological aspects.

In the second research period, i.e., in 2013–2017, the Polish industrial system underwent a transformation. Some conditions (variables in the model) evolved, while others disappeared, and new ones appeared. This means system stability in some of its parameters and discontinuity in others, which can be explained by the low absolute reference plane and, consequently, abrupt changes.

The quality of the model fit for second research period (Table 3) is higher than before (R^2 Nagelkerke = 0.30 and R^2 Cox–Snell = 0.08). At the same time, the model is statistically significant ($p < 0.01$) and, therefore, the independent variables are again statistically significant. The Hosmer–Lemeshow test result shows no significance ($p = 0.33$), which is desirable.

Low-carbon innovations are still the domain of large and medium-sized enterprises, although the proportions between them have changed. The importance of large ones has decreased and the medium ones have increased, with similar exit odds ratios (twice as often as others). This means an increase in systemic ecological maturity among entrepreneurs (system learning by eco-innovating). A smaller, although still important, role of large entities may result from the high saturation with such technologies and the evolutionary moment of shifting the force of gravity towards medium-sized units has come. Low-carbon innovation is clearly related to the implementation of new production technologies. If a company introduces them, the chances of pro-ecological solutions increase by 68%. New construction investments are a substitute for them. The expansion of the industry goes hand in hand with the reduction of commitment to environmental protection by 27%. Economic stagnation is also not favourable here. This time the business cycle factor is important, and the status quo results in a decrease in interest in low-carbon investments by as much as 36%. The study was completed before the pandemic occurred. It is expected that its economic effects for the discussed processes will be strongly negative.

The cooperation in the field of low-carbon innovations in the second research period changed significantly (system discontinuity). It is now limited to companies belonging to the capital group. In such circumstances, the chances for new ecological solutions increase almost threefold. This can be explained, firstly, by the ease of technology transfer between capital-related entities, and, secondly, by the decreased interest in jointly solving technological problems with both scientific institutions and business partners. Although entrepreneurs indicate difficulties in cooperation on such solutions, at the same time they engage in their independent development or within the capital group. At the same time, the surveyed entities draw attention to the lack of information (knowledge gap) about new low-

carbon technologies. Nevertheless, as in the case of problems with finding a cooperative partner, the lack of available technological knowledge pushes enterprises to implement such investments on their own. Industry magazines and publications are important sources of information on low-carbon technologies and indeed the only significant ones. Moreover, they are publicly available. Unfortunately, scientific institutions do not support these processes. Hence probably the observed problem of limited technological knowledge in this field lies with the lack of access to technological solutions.

Table 3. Determinants for low-carbon innovations in Poland in 2013–2017, logit function.

Independent Variables	Low-Carbon Innovation (Odds Ratio)
Enterprises Attributes	
Medium-sized enterprises	1.90 (***)
Large enterprises	2.00 (***)
Building investments	0.73 (*)
New production technologies	1.68 (***)
Economic stagnation	0.64 (**)
Innovation cooperation	
Enterprises in the capital group	2.63 (***)
Business Support Organizations	
Technology incubators	1.80 (*)
Sources of innovation activity	
Industry magazines and publications	2.34 (***)
Barriers of innovation activity	
Difficulties in cooperation	1.93 (***)
Lack of information about new technologies	1.62 (**)
Effects of innovation activity	
Increasing production capacity	3.79 (***)
Improvement production flexibility	2.19 (***)
Fulfillment of regulations and standards	1.91 (***)
Reducing unit labor costs	1.90 (***)
Improvement in the quality of products	1.91 (***)
Constants	0.00 (***)
Reference variables: micro enterprise, domestic enterprise, economic growth	
Sample	6283
chi-square	526.2
R ² Cox-Snell	0.08
R ² Nagelkerke	0.30
p-value	0.00
Hosmer Lemeshow test	
chi-square	9.14
p-value	0.33

(***)—statistical significance at 1%, (**)—statistical significance at 5%, (*)—statistical significance at 10%. Source: An own calculation based on questionnaire research.

Enterprises cooperating with technology incubators implement new low-carbon solutions 80% more often than those that do not. Perhaps the problem lies in the generative nature of such solutions? This thesis is proved by the fact that entrepreneurs use generally available sources of knowledge, and they have problems with finding cooperative partners, both on the side of research institutions and other enterprises. This all limits the transfer of technology to a narrow group of enterprises linked by capital. Technological incubators accelerate the creation of new technologies by filling the gap, but it is difficult to say whether to a satisfactory degree.

As in the previous survey, companies achieve a wide range of different additional benefits from the introduction of low-carbon solutions, in addition to the obvious impact on the environment. The catalogue of effects from the previous period was repeated and enriched with an additional one, i.e., improvement in the quality of manufactured products. The primary ones include: greater productive capacity and flexibility, reduction of unit

labour costs, but also the need to comply with applicable legal regulations. It is worth adding that the improvement in productive capacity occurs almost four times more often when enterprises implement low-carbon solutions, and twice as often for the improvement in production flexibility.

The achieved effects are stable over time, but their intensity and interactions within groups change. The significance of the command imperative resulting from legal regulations has clearly decreased. Similarly with unit labour costs. The flexibility of production, although in second place, is with a lower odds ratio than in the previous study. Increased opportunities were observed only in the case of increasing productive capacity. Nevertheless, each of the achieved effects occurs at least twice as often in the case of enterprises using low-carbon innovations.

The national industrial system is to some extent evolving in terms of determinants of low-carbon innovation, and in some measure reacting abruptly. This difference in response may be due to the generative state of practical and theoretical knowledge of these technologies. Whether it is a problem of the Polish industry per se or whether it is a broader issue is difficult to unambiguously assess.

Low-carbon innovations are the domain of large and medium-sized enterprises, with the latter growing in importance over time. Systemically important is the financing and implementation of new production technologies related to the low-carbon economy. Enterprises that engage in such activities achieve a number of benefits apart from improving ecological conditions. They increase production capacity, improve production flexibility and reduce unit labour costs. The compulsory regulatory role remains important, but its importance declines over time.

A significant problem in the implementation of low-carbon solutions is the diminishing cooperation of industry with science institutions and business partners (cooperation gap). Potential sources of knowledge about new ecological technologies are far from sufficient (knowledge gap). Although at the same time, despite the existing difficulties, entrepreneurs do. Nevertheless, as in the case of problems with finding a cooperative partner, the lack of available technological knowledge pushes enterprises to implement such investments on their own.

The level of technological advancement of Polish enterprises does not determine the level of low-carbon innovation. The situation is similar in the case of export activities. A significant relationship appeared on the side of the economic situation: if entrepreneurs assume that the economic situation will worsen, they implement low-carbon innovation less often.

5. Discussion

Over the years 2007–2017 in Poland, the national low-carbon innovation system underwent a transformation. The system turned out to be stable in terms of the structure of the size of enterprises and the achieved effects of the implemented new low-carbon technologies. The remaining structural parameters and variables such as cooperation, sources and barriers were discontinuous, which can be explained by the low absolute reference plane and, consequently, abrupt changes.

The structure of enterprises in terms of size steadily determines the national low-carbon innovation system, which is consistent with the results of other studies [11–14,27]. It should be emphasized, however, that in the second period, the influence of medium-sized entities grew in importance, and the influence of large entities lost some impact. This means that the latter have become saturated with technologies and as a result of evolution, medium-sized enterprises have started to absorb a greater number of low-carbon technologies. It remains an open question whether also small entities will start implementing low-carbon solutions in the further evolution. On the one hand, the lack of small enterprises in the group of innovators can be explained by the fact that the intensity of pollution is negatively correlated with the size of the company [60]. Small entities may therefore not feel obligated to implement low-carbon technologies. On the other hand, for

small entities significant barriers are weaker financial resources and greater difficulties related to conducting R&D activity [27]. In this context, it seems necessary to provide effective support to SMEs by making it easier for them to enter into partnerships for more sustainable development [22].

A significant evolution in the field of expenditure on innovative activity has been noticed in the system. In the first period, low-carbon innovations were implemented with the use of new machines and devices, while in the second period they were replaced by the implementation of new production technologies. This phenomenon can be treated with slight optimism, because entrepreneurs invest in new knowledge related to low-carbon technologies (active transfer), and do not stick to the previous knowledge, despite the purchase of less energy-consuming machines and devices (passive transfer). In this context, the problem is that no relationship has been found between R&D and the technologies implemented. On the one hand, catching-up countries are characterized by absorption of low-carbon technologies from developed countries without conducting R&D [61]. On the other hand, entrepreneurs purchase ready-made solutions that cannot be adapted to local conditions (need for “customization”) [62]. This significantly reduces the quality of the implemented low-carbon technologies, because their connection with internal R&D has a significant impact on reducing CO₂ emissions, as shown by the experiences of other countries [63]. In this context, there is a noticeable improvement in the field of low-carbon innovation, but it is not yet possible to speak of a target development direction.

Despite the interest of enterprises in new technologies, in the second research period, the system was additionally limited by building investments. This means that the erected new production halls are built with the use of old technologies that are not based on low-carbon solutions, e.g., installation of photovoltaic panels.

In the course of the evolution of the system, the international thread lost its importance. This is in line with the conclusions of other studies, where it has already been proven that foreign capital has no impact on low-carbon innovation [11]. At the same time, it turned out to be important that the search for new knowledge in foreign research institutes contributed to the improvement of energy efficiency. This means that in this period the transfer of technology from abroad was still important, but it was not carried out by filial branches of foreign entities.

The low-carbon innovation system in Poland is characterized by low knowledge saturation and difficulties in acquiring it. Paradoxically, in the first research period, innovations were implemented in cooperation with PAS (Polish Academy of Sciences) units and competitors, and knowledge about them was sought by foreign research institutes and scientific and research associations. In the second period, the factor of cooperation significantly weakened—it took place only within the capital group, and industry magazines and publications were indicated as sources. At the same time, low-carbon innovations are significantly limited as a result of cooperation problems and a lack of knowledge about new technologies. Taking into account the fact that in both research periods the share of enterprises implementing low-carbon innovations was similar, the system turned in a negative direction. There has been a departure from knowledge generating entities and it has been pointed out that the lack of knowledge and problems in cooperation constitute a significant barrier to low-carbon innovation. At the same time, it is surprising that no difficulties in obtaining financing or the high cost of implementing low-carbon innovations were mentioned. This means that the limitations related to knowledge are much stronger than those related to finances, which is partly in conflict with the research carried out so far. A similar situation as in Poland occurred on the Chinese market [39], while in Germany [25] it was shown that energy efficiency is significantly limited only by cost factors, and in Italy [38] both capital and knowledge-related factors are involved.

The low-carbon innovation system in Poland was characterized by stability in terms of the benefits that these solutions bring to enterprises. The strength of their influence in the first research period was much greater than in the second. The largest decrease occurred in the case of the imperative of meeting regulations and standards. Due to the fact

that regulations play a greater role in catching-up countries [24], the direction of evolution points to the shift of the Polish economy towards a knowledge-based economy.

The main cause of threats to innovative initiatives is insufficient knowledge and hence uncertainty. Other problems include the lack of awareness of the potential economic benefits of implementing low-carbon technologies. The literature on the subject shows that the least significant barriers in developed countries are limited access to outside knowledge and the lack of qualified staff. Moreover, representatives of small and medium-sized enterprises do not perceive the lack of business and scientific partners for cooperation as barriers to the introduction of eco-innovations [64]. The authors' empirical findings indicate that the cooperation of enterprises with science units and business partners diminishes in the capital group. This allows us to conclude that there are no stable links between research units and industry. The lack of information flow and exchange slows down the progress in the field of environmental technologies. It is recommended that the government, through appropriate instruments, supports the transfer of knowledge and promotes cooperation with scientific institutions and business partners.

6. Conclusions

In Poland, as a catching-up country, problems related to the decisions of entrepreneurs to use new low-carbon technologies are often determined by conditions other than those experienced by highly developed countries. They result from the evolution of the system and the level of its maturity. The negative policy dominates here (actions enforced by legal regulations) without the use of positive (incentive) instruments, not to mention parallel changes in the entire systemic and institutional environment of enterprises. The specificity of catching-up countries is also related to the need to dynamically reduce the technology gap as such in relation to other countries, which justifies "silent" political consent to the use of "dirty" technologies. In addition, there is a low level of public awareness, including among politicians, and the lack of responsibility for the long-term consequences of decisions made today. The indicated reasons are responsible for the negative transformation of the determinants of low-carbon technologies between the two rounds of research.

On the one hand, the analyses carried out indicated that there has been a positive trend of shifting the force of gravity from large to medium-sized enterprises (system evolution), but on the other hand, the economy is left to itself. There is a lack of institutional broad system solutions for technological progress in favour of low-stack emissions. The R&D sphere has ceased to support these processes. There are no cooperative partners, which entrepreneurs complain about. The technological knowledge gap is so large that it is impossible to overcome it as a lone company, although enterprises do make such attempts on their own. Technology transfer from R&D units has been suspended. Entrepreneurs in highly developed countries do not face such barriers.

According to the authors, the political actions that should be taken should be related to the two main obstacles that emerged from the analyses: knowledge gaps and difficulties with cooperation (with enterprises and scientific institutes). These actions concern the short and long term. As part of the next programming period for spending European funds in 2021–2027 (short-term perspective), two parallel programs should be created directly and exclusively focused on low-stack emissions for: (a) industry, (b) R&D units. The first one concerns the investment of enterprises in new technologies and cooperation in this area with foreign and domestic R&D units (demand model). The second one (the supply model) should be focused on the cooperation of domestic R&D with foreign scientific institutes and enterprises. Ultimately, domestic R&D should be responsible for the transfer of knowledge about low-carbon technologies from abroad to the domestic industry. Cooperative projects undertaken will launch bottom-up initiatives and as a result of spilling over into the market, the diffusion of such solutions should be accelerated. The intermediary responsible for the transfer of public funds in Poland should be the National Center for Research and Development (Narodowe Centrum Badań i Rozwoju). It is noted in the Polish literature that such an approach would promote the internationalization of domestic companies and attract

projects that benefit from R&D [65]. The proposed recommendations are also consistent with the solutions suggested in the Spanish economy [10,11] and in other less developed countries in Europe [26]. Such solutions concern building political support for the intensification of R&D and establishing cooperation in order to reduce business risk. However, it is important that they are perceived by entrepreneurs as uncomplicated and friendly [38].

In the long term, entrepreneurs should be aware of the benefits of using low-carbon solutions. As shown in this article, they are not limited only to the ecological aspects, but include many more which improve the efficiency and further competitiveness of enterprises. Similar recommendations consist in building a culture of low-carbon technologies appear in the literature [23,27,39].

To sum up, the first of the hypotheses was only partially positively verified, because only a few factors have a stable long-term impact on entrepreneurs' decisions to implement new low-carbon technologies in Poland. The system is emergent and shallow, and consequently reacts strongly and abruptly. The second hypothesis is falsified, because the Polish market lacks sufficient knowledge about low-carbon technologies and, additionally, there are difficulties in finding a partner to jointly develop them, unlike in more developed countries. The third hypothesis has been positively verified. It turns out that low-carbon innovations improve in many areas the economic efficiency of enterprises, contributing to an increase in production capacity, improvement of production flexibility, improvement of product quality and reduction of unit labour costs. It is also true that legal regulations steadily determine low-carbon innovations in Poland (fourth hypothesis), although the impact of this factor has diminished significantly. Innovation support organizations and research institutes affect the implementation of low-carbon technologies in Polish industry only to a small degree (not systemically), if at all. Thus, the fifth hypothesis can be considered false.

To sum up, if the recommendations indicated by the authors are not taken into account or alternative ones are used, the trend of abandoning low-stack emission investments in Poland will continue over the next few years, and this is not a result of the prevailing pandemic, although the latter will further intensify these negative tendencies.

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