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DETERMINANTS OF ENVIRONMENTAL TECHNOLOGY DEVELOPMENT IN TRANSITION REGIONS – CASE OF SILESIA REGION

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Purpose: The primary objective of this paper is to present the results of research conducted to identify factors influencing the development of environmental technologies in regions undergoing transformation.
Design/methodology/approach: To achieve the intended objectives, a study was designed which involved an initial identification of factors related to the development of environmental technologies. These factors were then structured and analyzed by a group of experts involved in the fair transformation process in the Silesian Voivodeship. The factors were categorized into four groups, which were evaluated by entities collaborating with the Specialized Observatory for Environmental Protection Technologies, followed by a ranking process. This resulted in the classification of factors into groups of significance, corresponding to their importance in the development of environmental technologies in transforming regions.
Findings: The main outcome of the analyses indicated that regional (specific) factors are significant for the development of environmental technologies but are not the key factors that would decisively influence this process. Instead, political-legal and economic factors were identified as key.
Research limitations/implications: The study's findings are primarily limited to one region - the Silesian Voivodeship. Therefore, it would be advisable to conduct comparative research in other mining regions, which would allow for the assessment of the same group of factors. Additionally, considering studies in regions where the transformation is not associated with mining but with other economic sectors would help to expand the list of specific factors and verify the other three groups.
Practical implications: The practical significance of the conducted research is linked to the design of legal and economic instruments for the development of environmental technologies. The study confirmed the crucial importance of these groups of factors. Furthermore, the results can be utilized by regional authorities in shaping development policies and fostering collaboration among local stakeholders.
Social implications: The research demonstrated that quality of life and social acceptance play a key role in the development of environmental technologies in transforming regions. This finding should serve as an impetus for planning informational and educational activities during the development and implementation of these solutions.

Originality/value: The article provides insights into factors crucial for planning the development of environmental technologies under the specific conditions created by the socio-economic transformation of a region.
Keywords: Environmental technologies, transforming region, development determinants.
Category of the paper: Research paper.

1. Introduction

Regions demonstrate diverse capabilities in terms of diversification and adaptation to change. This includes their proficiency in initiating new activities, particularly those pertaining to environmental protection and climate change adaptation. There exists significant variance among regions concerning their green specializations and the corresponding readiness to innovate and evolve new environmental technologies (Marra et al., 2017; Perruchas et al., 2019). Hence, comprehending the factors that promote green diversification and propel the development of environmental technologies, tailored to specific regional contexts, is of paramount importance. In light of the global challenges brought forth by climate change and environmental degradation, the concept of green growth has become a critical strategy for sustainable development, especially in regions experiencing transformation. The progression of environmental technologies is vital in these areas, forming the bedrock of socio-economic and environmental-spatial shifts. The Silesian Voivodeship, known as Europe's leading coal-producing region, is presently navigating the imperative of an energy transition, moving away from coal as its primary energy source. This shift is supported by current European policies (REPowerEU Plan, 2022; The European Green Deal, 2019), which intensify efforts towards green transformation (Morton, 2018).

The repercussions of mining and energy sectors on environmental degradation, combined with ongoing climatic changes, highlight the urgency for technological interventions to mitigate the adverse impacts of these activities. These interventions are designed not only for adaptation to changing environmental conditions but also for the revitalization of post-industrial zones for renewed socio-economic purposes. The deployment of environmental technologies is crucial in improving the life quality of the region's residents and in protecting the environment from further harm. However, the evolution of these technologies is intricate. While existing research primarily concentrates on the formal-legal and economic aspects (Hötte, 2020; Lv et al., 2021; Paramati et al., 2022; Söderholm, 2020; Vona, Patriarca, 2011; Zeng et al., 2020), additional studies emphasize the significance of social and environmental factors (Bilal et al., 2021; Feng et al., 2017; Knobloch, Mercure, 2016; Mäler, Vincent, 2003). Newly emerging determinants, especially in regions undergoing energy transformation, call for further investigation and analysis. This article aims to delineate the findings from the identification and assessment of key factors essential for the advancement of environmental technologies in a transforming region, as exemplified by the Silesian Voivodeship.

2. Development of environmental technologies in transition's regions

Green development has emerged as a pivotal force in the global economic restructuring and the enhancement of environmental governance. This phenomenon is extensively documented, as seen in the works of (Dutz, Sharma, 2012; Feng et al., 2017; Zhai et al., 2022), highlighting its growing influence. Governments worldwide are rigorously formulating and implementing astutely designed policy frameworks to shepherd the green economy.

In the context of the European Union, green growth is perceived as an economic progression that is either decoupled from resource utilisation or carbon-neutral in terms of CO_2 emissions. This concept, as elaborated by (Pichler et al., 2021; Vezzoni, 2023), presents a multitude of challenges to member states, spanning sectors such as energy, transport, construction, agriculture, and others. The crux of executing the objectives of the Green Deal lies in innovations, particularly eco-innovations and new technologies (Pichlak, 2017; Sarkar, 2013). These eco-innovations and technological advancements are poised to be sustainable solutions for maintaining competitive advantage and for the genesis of novel, innovative value chains (Szilagyi et al., 2018).

The planned and executed policy of green growth is set to transfigure the economies of numerous regions, especially those traditionally reliant on fossil fuels as their primary energy source. The scholarly literature is replete with instances demonstrating how environmental technologies can emerge in the wake of innovative activities and the amalgamation of environmentally friendly solutions with existing industrial technologies (Van Den Bergh, 2008; Zeppini, Van Den Bergh, 2011). This explains the higher degree of complexity and efficiency characterising technological solutions in regions dominated by traditional industry (Perruchas et al., 2019)). However, without governmental support and societal consensus, developing a green economy in these regions would be unattainable, as transformation is a challenging and often contested process. The economic profile shift, including the integration of ecological solutions in traditionally industrial regions, encounters significant barriers (Droste et al., 2016; Lindberg et al., 2019). However, without the support of authorities and social consensus, the development of a green economy in regions would not be feasible, as transformation is a challenging and frequently contested process. Economic profile alteration (Morton, 2018), including the integration of ecological solutions into the mainstream, encounters significant barriers in regions reliant on traditional industry.

Silesia, as Poland's coal mining hub, exemplifies a region where the transformative process is intensifying (TPSL WSL, 2022). The region's economy is undergoing a series of sanctioned changes as part of Silesia's development strategy. The focus on innovative development, including the selection of the green economy as one of the smart specialisations (Model RSI, 2018; RSI, 2013), has led to targeted and dynamic actions in the development of environmental technologies. The pivotal areas for the green economy in Silesia include renewable energy,

clean technologies, energy-efficient construction, public transport, waste management and recycling, sustainable land, water, and forest use, and (RSI, 2013, 2021). The green economy entails resource management, the utilization of economic instruments that favour environmental protection, support for innovative projects, more efficient water and waste management policies, and efforts towards sustainable consumption and production. Furthermore, given that energy (including renewable energy) is one of the smart specialisations, it has been decided that the green economy in Silesia will encompass green products and services, green investments, green economic sectors, green public procurement, green jobs, as well as the aforementioned technological areas (RSI, 2021).

The green economy in the Silesian Voivodeship comprises over 51,000 entities, according to REGON data (as of the end of June 2020), and more than half of them are thematically related, accredited, and active research laboratories (RSI, 2021). There is considerable potential in the Silesian Voivodeship for activities related to the green economy, including a significant potential for the location of photovoltaic farms, which can serve as a means of redeveloping parts of post-mining areas. Moreover, the region is also a leader in the production of components for PV modules in Poland (Zielone Śląskie, 2020). The robust industrial character of the economy in the Silesian Voivodeship means that the region is a place where new material solutions are developed and implemented, embodying the concept of a circular economy (Pichlak, Kruczek, 2017).

The development of technology, particularly environmental technology, regardless of the region, will be influenced by a variety of diverse factors, each with its unique characteristics and classifiable on multiple criteria. These factors can be external, arising from operating within a specific political, legal, economic, social, environmental, or technological environment, as well as internal (Bonds, Downey, 2012; Cao, Wang, 2017; Wasiq et al., 2023; Yue et al., 2021; Zeng et al., 2022), emanating from the specificities of the sector or region concerned, or even from individual enterprises (Ben Arfi et al., 2018; Chen, Liang, 2023). The development of environmental technologies in transitioning regions is an especially complex process, necessitating support at various levels: political, financial, technological, and social. In the case of transitioning regions, both external and internal factors need to be considered. The impact of these external and internal factors on the development of environmental technologies is variable, and the interdependencies between them may differ depending on the environmental dimension the technology addresses. With this in mind, an attempt was made to identify and then verify and evaluate the factors determining the development of environmental technologies in a transitioning region, formulating the hypothesis that: There are specific regional factors influencing the development of environmental technologies in regions undergoing transformation.

3. Methods

Research related to the identification and evaluation of the impact of various groups of factors on the development of environmental technologies in a region undergoing transformation was conducted in 2022. The study consisted of the following stages:

- A critical review of the literature, which resulted in the identification and systematization of factors conditioning the development of technologies. The outcome of this stage was a list of 61 factors divided into 5 groups (table 1);
- Verification of the developed list of factors through in-depth interviews;
- Development of an updated list of factors and its organization according to expert recommendations – the list after verification comprised 43 factors organized into four groups (political-legal, economic, social, regional) – table 2;
- Assessment of the significance of factors for the development of environmental technologies in the Silesian Voivodeship using the method of relative importance of objects;
- Identification of key factors for the development of environmental technologies.

Table 1.
Groups of factors identified from the literature review and their numbers

Group of factors	Number of factors in the group
environment	15
technical and technological	16
economic	11
legal	15
social	4

Source: own elaboration.

Table 2.
Factors breakdown after verification in the IDI

Group of factors	Number of factors in the group
politico-legal	11
economic	12
social	6
regional (specific)	14

Source: own elaboration.

For the study, two research tools were developed – an interview form used during conversations with experts and a survey questionnaire, employed to assess the significance of factors influencing the development of environmental technologies.

The verification of the preliminary list of factors, based on a critical literature review, was conducted through interviews with 7 experts engaged in the development of the Territorial Just Transition Plan for the Silesian Voivodeship up to 2030. The experts recommended changes in the grouping of factors, including the introduction of a group of regional factors reflecting the specifics of a region in transformation and the nomenclature of the factors.

The distinction of regional factors emphasizes the significant impact of the transformation process on mining regions and the possibility of phenomena that are not observed in other regions. The revised list of factors was finalized by the experts.

Subsequently, a survey questionnaire was prepared, asking respondents to assess the importance of individual factors for the development of environmental technologies in the region. This verified tool, in electronic form, was distributed to companies generating and implementing environmental technologies in the Silesian Voivodeship. The selection of companies was purposeful, based on the database of the existing regional Observatory for Environmental Technologies, listing 412 participants in the innovation ecosystem of the Silesian Voivodeship, engaged in activities related to the development of environmental technologies. Surveys were sent to all entities in the database, with responses received from 116 entities, of which 102 were complete. The rationale for such a selection of respondents was a critical analysis of the Silesian Voivodeship's development documents, where technological areas forming the basis of regional smart specialization and directions of just transition (TPSL WSL, 2022) were identified. Additionally, the resolutions adopted in the regional strategy (Zielone Śląskie, 2020) indicate that environmental technologies constitute a significant component of the development of a transforming region.

The collected results were subjected to scoring assessment with elements of statistical analysis. In this approach, based on the assessments of the importance of factors made by the respondents and the weights of criteria recommended by experts, it is possible to identify a set of factors with varying levels of significance[1].

4. Results and discussion

To conduct the hierarchization of factors influencing the development of environmental technologies in a region undergoing transformation, weights were assigned to the criteria for evaluating factors based on the extent to which they condition this development. Experts who conducted the verification of factors identified the following weights by consensus depending on the assessment of the factors:

- for a high level of significance - 60%,
- for a medium level of significance - 30%,
- for a low level of significance - 10%.

[1] Mathematical methods for assessing, ranking and selecting technologies.

The assessment of each factor was determined based on the collected data as follows:

$$S_i = 60\% \text{ Hr} + 30\% \text{ Mr} + 10\% \text{ Lr} \quad (1)$$

where:

S - score,

Hr - number of times the factor was identified as highly significant,

Mr - number of times the factor was identified as moderately significant,

Lr - number of times the factor was identified as not very significant.

The relevance of a factor in a given group of factors was then determined (i.e. one of political-legal, economic, social, regional):

$$\text{RSg} = \frac{S_i}{\sum_{i=1}^{m} S_i} \quad (2)$$

where:

RSg - relative score,

m - number of factors in the group.

and relevance of the factor considering all groups:

$$\text{RSt} = \frac{S_i}{\sum_{i=1}^{n} S_i} \quad (3)$$

where:

RSt - total relative score.

n - number of factors (n = 43).

In this way, the significance of the factors relative to the group and across the study was established. The results are summarised in table 3.

Table 3.

Assessment of the determinants of environmental technology development for a region in transition

Factor	Factor code	Hr	Mr	Lr	S	RSg	RSt
Political and legal factors							
Political situation	P1	84	12	6	54,6	0,1	0,026
Environmental and climate policy	P2	102	0	0	61,2	0,112	0,029
Supporting competitiveness and internationalization of enterprises	P3	60	30	12	46,2	0,085	0,022
Protection of industrial property and regulations related to commercialization	P4	15	57	30	29,1	0,053	0,014
Revitalization policy	P5	42	27	33	36,6	0,067	0,018
Efficiency of public administration operations	P6	69	9	24	46,5	0,085	0,022
Tax policy	P7	102	0	0	61,2	0,112	0,029
Environmental standards	P8	102	0	0	61,2	0,112	0,029
Regulations on conducting business activities	P9	12	57	33	27,6	0,051	0,013
Cooperation between R&D sector and enterprises	P10	96	6	0	59,4	0,109	0,029
Energy security	P11	102	0	0	61,2	0,112	0,029

Cont. table 3.

Economic factors							
Level of investment in new technologies	E1	102	0	0	61,2	0,103	0,029
Expenditure on R&D (Research and Development)	E2	102	0	0	61,2	0,103	0,029
Digital transformation	E3	45	33	24	39,3	0,066	0,019
Sectoral structure of the economy	E4	18	45	39	28,2	0,047	0,014
Availability of investment lands	E5	54	21	27	41,4	0,07	0,020
Credit and grant facilities	E6	90	0	12	55,2	0,093	0,027
Utilization of secondary raw materials	E7	90	3	9	55,8	0,094	0,027
Level of foreign investments	E8	63	0	39	41,7	0,07	0,020
Basic macroeconomic indicators (GDP, inflation, unemployment)	E9	93	0	9	56,7	0,095	0,027
Availability of grant funds (EU funds)	E10	81	0	21	50,7	0,085	0,024
Intensity of competitive struggle	E11	60	12	30	42,6	0,072	0,021
Prices of fuels and energy, raw materials, and land	E12	102	0	0	61,2	0,103	0,029
Social factors							
Ecological awareness	S1	60	3	39	40,8	0,139	0,02
Social acceptance in the context of implementing modern and innovative technologies	S2	96	0	6	58,2	0,199	0,028
Availability of human resources with desired qualifications	S3	81	0	21	50,7	0,173	0,024
Quality of life	S4	84	15	3	55,2	0,188	0,027
Development of staffing potential in entities within the higher education and science system in terms of creating innovative solutions	S5	87	3	12	54,3	0,185	0,026
Creation of new jobs places	S6	45	6	51	33,9	0,116	0,016
Regional (specific) factors							
Development strategies for mining municipalities	R1	93	0	9	56,7	0,088	0,027
The level of the region's dependence on the mining sector	R2	75	6	21	48,9	0,076	0,024
The amount of post-industrial land, including post-mining and degraded areas	R3	48	12	42	36,6	0,057	0,018
The level of reclamation and development of degraded and undeveloped post-industrial areas	R4	27	45	30	32,7	0,051	0,016
The demand for the use of waste materials from coal mining	R5	99	0	3	59,7	0,093	0,029
Educational profiles in mining regions	R6	63	15	24	44,7	0,07	0,022
Professional activity of workers in the mining and energy sectors	R7	69	6	27	45,9	0,072	0,022
Operation of companies associated with mining	R8	42	9	51	33	0,051	0,016
Investment attractiveness of post-mining regions	R9	81	0	21	50,7	0,079	0,024
Costs of developing land after the cessation of mining operations	R10	63	24	15	46,5	0,072	0,022
Seismic threats	R11	21	27	54	26,1	0,041	0,013
Scientific achievements and research and development potential of the region	R12	87	0	15	53,7	0,084	0,026
Influence of neighbour regions	R13	72	3	27	46,8	0,073	0,023
Investment activity in the region / investments in the region	R14	99	0	3	59,7	0,093	0,029

Source: own elaboration.

The process of identifying the determinants of environmental technology development in the transition region is finalized by ranking them according to their level of importance. To this end, a procedure was carried out to create a separable series, guided by the total relative scores (Rst) obtained. The following statistical guidelines were followed:

- the number of class intervals was calculated as the square root of the number of observations,
- the range of variation of the parameter under study was calculated from the formula: $\Delta x = x_{max} - x_{min}$,
- the optimal width of the class interval was calculated using the formula: $i = \Delta X / k$

The results obtained, together with the assignment of factors, are summarized in Table 4.

Table 4.
Importance of factors

Compartments	Numbers	Evaluation	Factors
<0.013-0.016>	7	redundant	P9; R11; P4; E4; S6; **R4**; **R8**
(0.016-0.018>	2	unimportant	P5; **R3**
(0.018-0.021>	5	relevant	E3; E5; E8; S1; E11
(0.021-0.024>	10	important	P3; P6; **R6; R7**; **R10**; **R13**; E10; S3; **R2**; **R9**
(0.024-0.027>	3	very important	P1; S5; **R12**
(0.027-0.029>	16	key	E6; E7; E9; S4; **R1**; S2; P2; P7; P8; P10; P11; E1; E2; E12; **R5**; R14

Source: own elaboration.

The analysis of factors within each group indicates that political and legal factors are key to the development of environmental technologies in transformation areas. This is primarily due to these factors being associated with national and international policies on environmental and climate protection, which have gained significance in recent years. These policies now form the basis of the transformation process, mandating regions and enterprises to take actions for environmental protection and climate change adaptation. Policies related to research and development, emphasizing collaboration between R&D sector and businesses, and the introduction of standards for sustainable investments support this process. Notably, the importance of energy security for the development of environmental technologies is highlighted, signalling that transformation processes, though critical, should not disrupt this vital aspect.

Among the economic factors influencing the development and implementation of environmental technologies in transforming regions, investment levels in new technologies, R&D expenditure, and the prices of fuels, raw materials, and land are deemed most significant. These factors are linked to political and legal factors, clearly indicating the investment needs of respondents in new environmental technologies, whose development is not feasible without increased expenditure on generation and implementation. Particularly for SMEs, financial resources for developing environmental technologies are often insufficient, and their actions are dictated by the need to comply with changing legal conditions. However, with the provision of economic financing instruments for investments in environmental technologies, including research, the expected outcome would be increased activities in this area.

Social factors critical for the development of environmental technologies include social acceptance and quality of life. Society expects new environmental technologies to primarily improve living conditions in health, wellbeing, and economic aspects. Unfortunately, these

technologies are often perceived as contributors to job reduction and the closure of production plants, especially in regions dominated by traditional industries. Therefore, building ecological awareness and ensuring conditions for new professions are key.

Regional factors, specific to the mining region of Silesia, are not considered key by respondents but are important forces influencing the development of environmental technologies. Noteworthy are factors related to investment activity in the region and the potential use of mining waste. Investment activity is one of the biggest challenges for transforming regions, as a change in economic profile, such as moving away from coal, may determine innovative activity. Particular attention should be paid to the challenges faced by the Silesian Voivodeship, which is undergoing a transformation process, intending to carry out a "green transformation" where environmental technologies will be one of the pillars of the region's modern economy. Environmental technologies not only enable the elimination or reduction of environmental damage but also the repair of existing damage and, in line with the circular economy, the use of what was previously seen as waste as a secondary raw material. This factor is a premise for finding new applications for mining waste. In the transformation process, a special role is assigned to mining municipalities, whose strategies should also support the development of environmental technologies. Usually, this support is indirect, linked to achieving goals related to reducing low emissions, improving waste and sewage sludge management, and preserving the environment and biodiversity.

The conducted research on the determinants of environmental technology development in regions undergoing transformation showed that mainly political-legal and economic factors are important for this process. Regional factors are significant for the development of environmental technologies but are not key, and therefore do not conclusively determine whether these technologies will be developed.

5. Summary

This study, investigates the factors influencing the growth of environmental technologies in areas undergoing socio-economic change, with a focus on the Silesian Voivodeship. Known for its heavy industrialization, especially in mining, this region is now transitioning towards sustainable practices. The research methodology involved identifying various factors potentially impacting environmental technology development, followed by expert analysis and categorization. These factors were then ranked for their influence on technology development.

Key findings indicate that while regional factors are significant, political-legal and economic factors play a more decisive role. Supportive policies, legal frameworks, and economic incentives are essential for fostering environmental technology development and adoption. The study highlights the need for comprehensive approaches that encompass political,

economic, and social dimensions for effective environmental technology development. It emphasizes the importance of designing legal and economic tools that facilitate this development and encourages regional authorities to use these findings for policy-making and fostering local stakeholder collaboration.

The research also acknowledges its geographical limitation to the Silesian Voivodeship and suggests expanding to other mining regions and sectors for broader insights. Additionally, it underscores the role of social factors such as quality of life and social acceptance in environmental technology implementation. The paper offers valuable insights into the factors crucial for planning the development of environmental technologies, particularly in regions experiencing socio-economic transformation. A multifaceted approach considering political, economic, and social dimensions is needed to effectively support the transition to environmentally sustainable technologies.

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