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Innovation in Polish industry: The cluster concept applied to clean coal technologies in Silesia

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A B S T R A C T

This paper discusses the characteristics of an economic policy based on the innovation cluster concept, which (in contrast to production clusters) promotes partnership and cooperation between enterprises and local governments as well as between companies and scientific and research communities. The Innovative Silesian Cluster of Clean Coal Technologies (ISCCCT) brings together broad cooperation among enterprises, universities, local governments, and business support companies in the Silesian Voivodeship, which should have a leveraging effect on regional innovativeness and competitiveness.

1. Introduction

A fundamental factor for success in a contemporary enterprise is continual improvement in the quality of services provided as well as the creation and implementation of innovative solutions, both technical and organizational, through planning and realization of long-term activities, and assessment of trends and future developments scenarios [1–4]. In this context, innovativeness meaning the ability of enterprises to continually seek and implement new ideas and inventions, and it is considered to be a driving force in the economies of developed countries [5–12].

In today's era of globalization characterized by considerable interdependence between the development of economic organizations and scientific, technical, and technological progress, enterprises should actively cooperate with research and development institutes and universities [3,8,13–15], as access to knowledge frequently provides a competitive advantage.

In some sectors of business, such as electronics, information science, pharmacy, or telecommunications, innovative processes and their diffusion are especially intense [4,12,14,16–18]. Also, the processes may result in an increased number of innovative enterprises, i.e., "intelligent" organizations that generate and implement innovations that result in providing highly competitive and novel services and products [9,19,20].

2. The case of Poland

The economic development of Poland is predicated on building a knowledge-based economy that is an outgrowth of enterprise innovativeness, that introduces new technologies, and that motivates enterprises to implement scientific research achievements [1,21,22]. The strategy of the Ministry of Economy [23] is to boost the national economy by increasing sector competitiveness through implementing new technologies, developing small and medium enterprises, and creating innovative

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organizations capable of implementing new technologies and methods of knowledge management. The key is acceptance of innovativeness, which will increase the competitiveness and attractiveness of Polish enterprises. However, a realignment of corporate attitudes is needed, moving beyond price competition to development based on cooperative innovation and implementation of research work results. Among large companies, this also involves carrying out R&D activities.

3. Clusters and prospects for development in Poland

Cooperation between enterprises in order to frame clusters is particularly important for strengthening competitiveness, as it ensures broad access to knowledge and experience, as well as sharing of investments and risk related to innovation activities [1,5,15,24–28].

According to Michael Porter, clusters can be defined as ''geographic concentrations of interconnected companies, specialized suppliers, service providers, firms in related industries, and associated organizations (such as universities, standard agencies, trade associations) in a particular field linked by commonalities and complementarities'' [30]. There is competition between them as well as cooperation. Clusters put strong emphasis on building interactions within the triple helix—a system of interrelationships among three main economic actors: enterprises, the scientific community, and local and state governments.

A successful cluster can be a driving force in the development of a particular economic sector or a regional and/or state economy. Economic policy based on the cluster concept can offer an effective response to the challenges of globalization as the policy helps to increase productivity by ensuring easier access and exchange of information, support for innovative solutions development, and implementation of a learning process and expertise exchange.

Clusters are present in all sectors of the world economy. They vary in scale (micro-, mezo- and mega-clusters), areas of interest, territorial coverage (i.e., local, regional, national, transboundary, international clusters), and level of innovation and technological advance. Major diversification among clusters makes each one unique, as specific sector and/or territorial-related aspects were taken into account while creating their structure.

Cluster development is one of the priority activities of the European Commission (EC) [3,30–33], with the specific aim of increasing the competitiveness of member countries. In Poland, initiatives in support of clusters did not begin to appear until 2005 [34]. The EC report [35] also indicated that Poland and other countries of the former Eastern bloc, such as the Czech Republic, Slovakia, and Estonia, had neither developed nor implemented a cluster-based development policy. Government support for cooperative relations, including clustering is still missing in Poland, and financial support for clustering is currently available only within the framework of operational programs.

Two external factors influence the process of cluster development: the strong position of coal as a primary energy source, and a new approach to the role of coal in European energy sector. The latter is manifested in the development of clean coal technologies to improve the technical and economic effectiveness of coal production, processing, and utilization as well as efforts to mitigate the harmful environmental impact of these processes.

One goal of the EU is to become the world leader of sustainable economic development [36]. On January 10, 2007, the European Commission published a document that outlined activities aimed at establishing a new European Energy Policy that takes into account issues related to climate change, energy supply security, and competitiveness [37,38]. Two principal tasks set by the European Commission relate to reducing clean-energy production costs and helping European industry achieve a leading position in low-emission technologies. The document also provided the rationale for creating sustainable coal, natural gas-based, and hydrogen-based power industries.

Mechanisms for constructing and implementing some 12 commercial installations for sustainable fossil fuels-based energy production are to be developed by 2015, with specific dates for retrofitting existing coal and natural gas-based power plants with systems of CO_2 capture and storage [39]. The establishment of a European Technology Platform for Zero Emission Fossil Fuel Power Plants, as well as activities within the energy sector of the 7th FP Cooperation Work Program to promote the development of innovative, clean coal technologies proves the importance of coal in the EU energy security policy.

4. The innovative Silesian cluster of clean coal technologies

The Silesian Voivodeship (or Silesian Province) is located in southern Poland. The most industrialized part of the Voivodeship created on January 1, 1999, out of the former Katowice, Częstochowa and Bielsko-Biała Voivodeships, pursuant to the 1998 Local Government Reorganization Act is the Upper Silesia Agglomeration. The Silesian Voivodeship borders both the Czech Republic and Slovakia to the south.

The Silesian Voivodeship is a highly industrialized region of Poland, but the dominant heavy industry does not facilitate a strong and competitive regional economy nor does it encourage the growth of small and medium enterprises. Nevertheless, the potential of the region in terms of traditional industries and new services is undeniable.

The Innovative Silesian Cluster of Clean Coal Technologies (ISCCCT) was established on July 1, 2005. The main founder and coordinator of the ISCCCT was the Central Mining Institute (GIG). On November 10, 2005, a Partnership Agreement was signed by 14 founders representing the sciences, industry, and local governments including, among the others: Institute of Chemical Engineering of Polish Academy of Sciences, Coal Company SA, Jastrzebie Coal Company, cities of Gliwice, Jastrzebie Zdroj, Katowice, Rybnik, and Tychy. An opening ceremony took place on May 29, 2006, during the International Conference on ''Future EU Energy Mix: Will Coal Play an Important Role?''

The main aim of the ISCCCT is to define the strengths of the region in terms of developing clean coal technologies that can offer opportunities for modernization of traditional industrial sectors—especially coal mining and businesses related to hard coal utilization, including combustion and chemical processing. The mission of ISCCCT is to provide a platform for cooperation among competing companies and institutions, that will identify common products from the Cluster partners, their competences, and benefits resulting from this new form of cooperation [40].

ISCCCT's interests cover these areas:

- Safe and efficient production of coal and preparation of ultra-clean coals for the power industry, especially new technological solutions for production of final energy carriers
- Systems for coal conversion into energy carriers, including:
  - Combustion-dust and fluidal technologies (supercritical and ultra-supercritical parameters)
  - Coal gasification and polygeneration
  - Combined heat, electricity, and cold generation
  - Coal-based technologies for combined steel and energy carriers production
  - Hydrogen-based power industry
  - Combustion of coal in small environment-friendly heating boilers
  - Reduction of hazardous substance emissions (including carbon dioxide) in the processes of coal utilization.

The development of organizational structures for the initiative, which was joined by more than ten new members, was co-financed by the European Social Fund (ESF). As part of the research project, a competitiveness analysis of the Silesian Voivodeship was undertaken to determine its likely potential for creating a clean coal technologies cluster, especially when compared with selected domestic and foreign regions. The analysis identified factors that would facilitate the location of a cluster in the Silesia region, and would stimulate its development as well as identify other regions that might be suitable for cluster development [40]. The factors used in the analysis were generally based on Porter's methodology [29], which argues that the successful initiation and development of a cluster in a region depends on four groups of location factors (see Table 1), although some modifications of the method resulting from the specificity of the ISCCCT were applied.

Next, regions were identified that could compete with the Silesia region. The following competitive combinations were defined:

- The Silesian Voivodeship
- The Silesian Voivodeship and other selected Polish Voivodeships
- Selected international regions, e.g.: Silesia–Moravia region (Czech Republic), West Virginia region (US), Donetsk region (Ukraine)
- International, EU, Poland, US – based on political and institutional characteristics of cluster creation and development.

Based on the results of the competitive analysis, the Silesian Voivodeship was deemed particularly suitable owing to advantages such as its broad technical infrastructure, significant gross fixed assets, and the natural environment in the region which would appeal to pro-ecological investors. Its weaknesses included limited financial resources, few active and educated human resources, and limited R&D infrastructure or potential (see Table 2). The main Polish competitor to the Silesian Voivodeship was the Mazowieckie Voivodeship. In terms of industrial R&D infrastructure and research, the Silesia region was second to the Malopolskie Voivodeship.

At the international level, the benchmarks for the Silesian Voivodeship were the following: the Malopolskie Voivodeship, the Mazowieckie Voivodeship, the Silesia–Moravia region, the Donetsk region, and West Virginia.

West Virginia was determined to be best suited for locating a clean coal technology cluster. The factors that most influenced the results were supply, strategy, branch competition, and development of sectors. Results for the demand factor analysis were similar for both the Silesian Voivodeship and for West Virginia, but the Silesian Voivodeship was ranked second based on results for the factors of demand, supply, and related supporting sectors.

The Silesia–Moravia region was identified as the main competitor to the Silesia Voivodeship (except for West Virginia). Its advantage was a favorable political context at the local and regional levels and a good economic situation in related sectors.

Equivalent ranking were determined for the Donetsk region and the Mazowieckie Voivodeship. The former had distinctive natural resources, high potential for human resources, a growing number of companies in the sector, and favorable political context at local and regional levels. The Mazowieckie Voivodeship had high infrastructure resources, good potential for a scientific and entrepreneurial culture, and strength in related sectors.

The analysis determined that competitiveness would be increased in the following ways if a cluster were located in the Silesian Voivodeship:

- ***Cluster financial support***: search for external financial support required for cluster development, including identifying local and regional financial resources, funds from initiatives of the 7th EU Framework Program and Operational Programs for the years 2007–2013, and investors interested in joining the cluster

Table 1
Selected location factors of the clean coal technologies cluster.

Supply	Strategy and competition in the sector	Related and supporting sectors	Demand
• Natural resources, e.g.: coal resources, their accessibility and sufficiency • Capital resources, e.g.: companies' investments (value), financial organizations, venture capital funds, business angels • Technical infrastructure, e.g.: networks: roads, railway, sewage system, international airports • Research infrastructure and potential, e.g.: research institutes, higher education, researchers, technical research workers, research studies on clean coal technologies, investments in research and development activities, patents, technical sciences students • Business support services, e.g.: special economic zones, business centers, technological parks, industrial parks, business incubators • Human resources, e.g.: number of citizens, migration balance, population growth, unemployment rate, qualified human resources-technical professions, mining industry employees, education profile and offer, professionally active persons • Entrepreneurial culture, e.g.: commercial awareness, entrepreneurship, social acceptance of mining industry	• Competitiveness in the sector, e.g.: number of competing companies, potential interest in the development in the frame of the sector, coal price, salary levels in mining industry, in cluster's companies, in the region, production costs in the sector • Companies' strategy orientation in the sector, e.g.: development direction in the sector, principal strategic targets, investment climate: level of investments in the region • Political-institutional aspects, e.g.: level of authorities' (state, regional, local) interest in creation and development of the Cluster, openness of authorities to foreign investments, policy and institutional environment in terms of innovative clusters' development, research and development, commercialization of inventions, financial support for research projects and programs both national and international	• Cooperation and related sectors, e.g.: companies of related sectors, employment level in companies of related sectors, complementary sectors (steel industry, power industry, heat engineering, chemistry, coke engineering), new companies in the sector, including the ones isolated in the restructuring process from big mining and power industry companies • Networking, e.g.: common aspirations to the sector and cluster membership, cooperation agreements, common undertakings, regional and sectoral business associations, common economic promotion of the region	• Products recipients (including products of companies – members of the Cluster), e.g.: number of recipients, potential recipients, demand level for the Cluster's products, demand quality (assortment, product diversity) • Natural environment, e.g.: air pollution, soil contamination; environmental protection standards, exceeding the allowable limits of contaminations, market trends resulting from environmental standards (for example emission market), environmental programs and projects initiated and financed by public authorities

Source: [40].

Table 2
Clean coal technologies cluster location factors of the highest and lowest potential in the Silesian Voivodeship.

Location factors	Strong potential	Weak potential
Supply	Good natural resources in the region, potential human resources, entrepreneurial culture	Capital resources, business support services
Demand	Current number and potential for local and regional recipients of the Cluster's products	Economic image of the region
Related and Supporting Sectors	Presence of related sectors in the Silesian Voivodeship, good economic conditions, high level of development	Poor economic promotion of the region, few common complex R&D projects related to clean coal technologies
Strategy and Competition in the Sector		Weak competition in the sector at regional scale, poor conditions for hard coal mining, unfavorable political context at the national level (little interest in clean coal technologies)

Source: [40].

- ***Economic promotion and changing the regional image***: greater emphasis on clean coal technologies as they relate to national energy security and sustainable development
- ***R&D projects***: initiate cooperative research projects on development, demonstration, and implementation of clean coal technologies
- ***Business services***: create specialized services that support the activities of regional companies and institutions. These might include transfer of knowledge and clean coal technologies; information on external financing capacities (including preparation of project proposals); establishing business contacts to help implement clean coal technologies on a commercial scale
- ***Economic policy***: ISCCCT initiate transitions in the regional and national fuel and energy sectors.

A SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) was performed [41–43] to determine synergies between the cluster development factors and conclusions based on typology of cluster strategy development. The analysis proceeded in the following stages:

- Develop characteristics for a list of internal and external conditions of cluster development to identify factors for the SWOT analysis
- Specify general targets for creating and developing the cluster based on a working meeting between representatives of institutions and enterprises interested in establishing a cluster
- Identify a list of strengths, weaknesses, opportunities, and threats
- Perform the SWOT analysis
- Draw conclusions that would constitute guidelines for the cluster's strategy development.

Twenty strengths and 17 weaknesses were identified and divided into categories: participants, value chain and marketing, knowledge potential and the organization, infrastructure and financial potential. A list of 32 opportunities included categories of political, economic, and social factors. Furthermore, 17 weaknesses/threats were identified in the categories of political, economic, social, and technological factors. The main targets (C) of cluster establishment and development were as follows:

- C1. Support development and implementation processes for clean coal technologies
- C2. Innovative use of a regional development potential
- C3. Create conditions for effective hard coal utilization
- C4. Develop multi-sector cooperation
- C5. Utilize external financial support.

The compilation of strengths, weaknesses, opportunities, and threats (see Table 3) was based on an assessment of each factor's influence on general targets illustrated by four matrices *factors x targets*, in which the targets were assigned weights (0 – no influence, 1 – minor influence, 2 – medium influence, 3 – significant influence).

Table 4 identifies driving forces that could affect the process of taking an advantage of the opportunities (A: *strengths – opportunities*); those that can be used to mitigate threats (B: *strengths – threats*); the most severe threats to cluster development (C: *strengths – threats*); weaknesses that could significantly hinder cluster development (D: *weaknesses – opportunities*); key opportunities that might be limited by the weaknesses (E: *weaknesses – opportunities*); and weaknesses that could intensify the adverse effects of the threats (F: *weaknesses – threats*).

The main opportunities for cluster development included:

- O_{o3}. Incentives for innovation development and dissemination
- O_{o5}. Political support to the initiative at regional and European (European Parliament) level

Table 3
The final list of strengths, weaknesses, opportunities and threats for SWOT analysis.

Strengths	Weaknesses	Opportunities	Threats
S_{o1}: High concentration of mining, power, and related companies in the region	W_{o1}: Diverse levels of market awareness in R&D centers – the Cluster members	O_{o1}: Increasing role of local and regional governments in creation of a development policy	T_{o1}. Influence of political decisions on the power industry operation
S_{o2}: High number of R&D institutions specialized in hard coal mining and use	W_{o2}: Lack of a common and consistent vision of mining and energy sectors development in the region	O_{o2}: Increasing international role of regional government	T_{o2}. Stoppage of privatization processes
S_{o3}: Advanced technology centers and centers of excellence related to power industry and environmental protection in the region	W_{o3}: Low level of internationalization (in terms of organization & ownership) of mining and mining-related companies	O_{o3}: Incentives for innovation development and dissemination	T_{o3}. Increasing competitiveness between energy producers
S_{o4}: Long-term presence of mining industry in region; long-term cooperative inter-relation network with power industry. Natural cluster development	W_{o4}: Lack of common promotion initiatives	O_{o4}: Activities of EU institutions focused on improving energy security of EC member countries	T_{o4}. Limited market capabilities of the electric power industry
S_{o5}: Strong position of cluster founders in integrating economic and scientific circles involved in industry-related fields	W_{o5}: Lack of common offer of Cluster products and distribution channels	O_{o5}. Political support to the initiative at regional and European (European Parliament) level	T_{o5}. Significant migration resulting in "brain drain"
S_{o6}: Location of cluster in traditional techno-productive culture	W_{o6}: Domination of competition over the cooperation between the Cluster members resulting in high transaction costs	O_{o6}. Increasing demand for inexpensive and clean energy	T_{o6}. Prolonged significant unemployment level among low-qualified former mining industry workers
S_{o7}: Strategic importance of cluster's companies to national energy security	W_{o7}. Insufficient networking in the innovation aspect	O_{o7}. Increasing expenses on communal and individual heating plants modernizations	T_{o7}. Prolonged low investments in R&D in companies
S_{o8}: New environment-friendly technologies for power industry	W_{o8}. Low level of commercialization of research results of R&D centers related to production and utilization of hard coal	O_{o8}. System of environmental penalties and fees	T_{o8}. Increasing role of renewable energy resources
S_{o9}: Related production technologies for key cluster products	W_{o9}. Insufficient level of activities in the frame of common policy of effective funds allocation for research infrastructure	O_{o9}. Recognition of energy-consuming sectors as high opportunity sectors	T_{o9}. Competitiveness of technical research centers, including foreign ones
S_{o10}: Applicability of R&D sector results to hard coal mining, coal utilization and environmental protection in companies		O_{o10}. Increase in energy prices	
So_{11}. Consolidation of GIG position as an institution – animating and managing the Cluster's development		Oo_{11} Increasing social awareness in terms environment protection Oo_{12} Motivation to CCT implementation resulting from the fact that coal is considered to be an 'out-of-date' fuel Oo_{13} Increasing awareness of the importance of R&D activities Oo_{14} Increasing international financial support for R&D activities Oo_{15} Development of CO_2 storage and utilization technologies	

Source: [40].

Table 4
Relations between the clean coal technology cluster strengths, weaknesses, opportunities and threats.

	Strengths	Weaknesses
Opportunities	A S_{o2}. High number of R&D institutions specialized in hard coal mining and utilization S_{o3}. Advanced Technology Centers and Centers of Excellence related to power industry and environmental protection in the region S_{o6}. Location of the Cluster in the region of traditional techno-productive culture S_{o7}. Strategic importance of Cluster's companies to national energy security S_{o8}. New environment-friendly technologies for power industry etc	D W_{o2}. Lack of a common and consistent vision of mining and energy sectors development in the region W_{o3}. Low level of internationalization (in terms of organization and ownership) of mining and mining-related companies W_{o4}. Lack of common promotion initiatives W_{o6}. Domination of competition over the cooperation between the Cluster members resulting in high transaction costs W_{o7}. Insufficient networking in the innovation aspect E O_{o3}. Incentives for innovation development and dissemination O_{o5}. Political support to the initiative at regional and European (European Parliament) level O_{o12}. Motivation to CCT implementation resulting from the fact that coal is considered to be an 'out-of-date' fuel O_{o13} Increasing awareness of the importance of R&D activities O_{o14} Increasing international financial support for R&D activities
Threats	B S_{o7}. Strategic importance of Cluster's companies to national energy security S_{o8}. New environment-friendly technologies for power industry etc S_{o10}. Applicability of R&D sector results related to hard coal mining, coal utilization and environmental protection in companies – Cluster's members C T_{o1}. Influence of political decisions on the power industry operation T_{o4}. Limited market capabilities of the electric power industry T_{o7}. Prolonged low investments in R&D in companies	F W_{o2}. Lack of a common and consistent vision of mining and energy sectors development in the region W_{o3}. Low level of internationalization (in terms of organization and ownership) of mining and mining-related companies W_{o5}. Lack of a common offer of the Cluster's products and products' distribution channels W_{o6}. Domination of competition over the cooperation between the Cluster members resulting in high transaction costs W_{o7}. Insufficient networking in the innovation aspect

Source: [40].

- O_{o9}. Recognition of energy-consuming sectors as high opportunity sectors
- O_{o13}. Increasing awareness of the importance of R&D activities
- O_{o14}. Increasing international financial support for R&D activities
- O_{o15}. Development of CO_2 storage and utilization technologies.

The following threats to the development of the cluster were identified as most critical:

- T_{o3}. Increasing competition between energy producers
- T_{o4}. Limited market capabilities of the electric power industry
- T_{o7}. Prolonged low investments in industrial R&D activities
- T_{o9}. Competitive domestic and foreign technical research centers.

The SWOT analysis revealed an aggressive strategy resulting from estimates of relative strengths and emphasizing the economic necessity of developing and widening the range of activities that would benefit cluster interests. Other vital factors were investors, strong but risky investment cost initiatives with a high probability of generating profits.

Driving forces included:

- New pro-ecological technologies applied in the power industry
- Strategic importance of cluster-related companies in ensuring national energy security
- High number of R&D institutions in the field of hard coal mining and use

- Centers of advanced technologies and excellence related to power industry
- Environmental protection in the region
- Strong traditional techno-productive culture.

Key weaknesses hindering cluster development included:

- Domination of competition over cooperation between cluster members resulting in high transaction costs
- Lack of a common and consistent vision of development for the mining and energy sectors in the region
- Low level of internationalization (in terms of organization and ownership) of mining and mining-related companies
- Insufficient networking to develop innovation
- Lack of joint initiatives to promote the cluster
- Lack of promotion and distribution channels for cluster products.

Key threats were identified:

- Competitive domestic and foreign technical research centers
- Increasing competition between energy producers
- Limited market capabilities of the electric power industry
- Prolonged low investments in industrial R&D activities
- Influence of political decisions on the power industry operation.

5. Summary and conclusions

The ISCCCT was established in response to demand from the Silesian Voivodeship to create new directions for regional economic development, taking into account potential cooperation between companies, universities, R&D centers, and local government. The ISCCCT aimed to ensure a high level of innovation and competitiveness among the economic entities as well as social development and improvement of the region's quality of life.

Focusing Cluster activities on clean coal technologies was natural considering the region's enormous supply of coal, the potential for highly qualified human resources, a strong and growing industrial structure, and a high concentration of entities involved in the production and utilization of coal. The Cluster's international dimension was apparent in activities aimed at creating efficient and environment-friendly technologies for hard coal production, processing, and utilization. These are the subject of R&D initiatives supported by the EC, which aim to create sustainable economic systems based on sustainable energy systems.

The project systematically analyzed the external and internal conditions needed to create and develop a clean coal technologies cluster in the Silesia region, and then to identify its strengths, weaknesses, opportunities, and threats and to formulate recommendations for increasing the competitiveness of the Silesian Voivodeship.

As a result of the analysis, innovations and implementations in the field of clean coal technologies within the Cluster have led to the creation of a generation succession system and the development of cooperative enterprises and institutions that enable the Cluster to effectively create and implement process, product, and organizational innovations.

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