The Impact of Industry Clusters on Twin Transition: Green and Digital Transformation

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**Abstract.** The study explores the significant role of clusters in the twin transition towards digital and green transformation. Clusters, defined as geographic concentrations of interconnected companies and institutions, are crucial for fostering Industry 4.0 technologies and sustainable practices. This research assesses the impact of clusters on digitalization and green transformation among companies in Poland, utilizing data from a survey of 41 cluster initiatives and 642 member firms. The findings reveal that cluster membership enhances firms’ digital capabilities and adoption of Industry 4.0 technologies through pro-innovation services and effective leadership. Similarly, participation in clusters positively influences green transformation, promoting the adoption of Circular Economy concepts, environmental certifications, and low-carbon technologies. The study underscores the importance of strategic cluster coordination and shared goals in driving digital and green initiatives, providing valuable insights for policymakers and cluster managers.

**Keywords:** clusters, cluster initiatives, benchmarking, digital technology, Industry 4.0, green transformation, sustainability.

# Introduction

The global economy is currently facing two pivotal challenges: the shift towards Industry 4.0, characterized by widespread digitalization, and the movement towards a sustainable economy, particularly emphasized within the European Union through the European Green Deal policy. Industry 4.0, also known as the Fourth Industrial Revolution, represents a significant transformation in business paradigms, driven by advancements in digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics. These technologies promise enhanced productivity, innovation, and efficiency, but also require substantial changes in organizational structures and processes.

This study focuses on evaluating the impact of clusters on companies’ digital transformation and green transformation within the context of the Polish economy. Clusters were defined by Porter (1998) as ‘geographic concentration of interconnected companies, specialized suppliers, service providers, firms in related industries, and associated institutions (e.g. universities, standards agencies, and trade association) in particular fields that compete but also co-operate’. However, policymakers and practitioners in certain nations tend to view clusters as organized systems, so it is essential to establish a clear differentiation between clusters and cluster initiatives. A “cluster initiative” is a term used to describe organized efforts to enhance the competitiveness of clusters in a particular geographical region. These projects usually require the active involvement of cluster enterprises, government bodies, and research units (Sölvell et al., 2003). A cluster initiative is managed by a cluster organization, which is a legal entity that represents the members of a particular cluster. The organization's main role is to enhance collaboration and networking among cluster members by offering business support services to encourage joint activities (Lis & Kowalski, 2022).

Clusters have been shown to significantly enhance the ability of firms to innovate and adapt to new technologies. The interactive nature of learning and knowledge generation within clusters suggests that regional factors are vital in facilitating the investment and development processes associated with Industry 4.0. Clusters inherently possess key components such as robust teamwork, shared trust, and the dissemination of tacit knowledge, which are essential for the adoption of new technologies and sustainable practices. The article’s objective is to evaluate the impact of clusters on companies’ twin transition towards digital and green transformation as investigated through the prism of companies forming clusters. Data come from cluster benchmarking in Poland, a survey carried out for the Polish Agency for Enterprise Development in 2022-2023 on the sample of 41 formalized cluster initiatives in Poland and 642 of their member firms.

This study's empirical investigation aims to fill the gap in existing literature by providing concrete evidence on the role of clusters in facilitating the twin transition in the Polish context. The findings will contribute to a deeper understanding of how clusters can act as catalysts for digital and green transformation, ultimately supporting the broader objectives of economic competitiveness and sustainability.

The paper is structured as follows: first, an overview of the concept of clusters is provided, followed by the development of hypotheses related to the impact of clusters on digital and green transformation. The data sources, variables, operationalization, and methods are then presented, leading to the empirical results. The article concludes with a discussion of key findings, their novelty and contribution, managerial and policy implications, and limitations of the study.

# 1. Literature review

The global economy is currently facing two major challenges: the shift towards Industry 4.0, characterized by digitalization, and the move towards a sustainable economy. These are particularly evident in the European Union, as highlighted by the European Green Deal policy. Various studies, such as those conducted by Ching et al. (2022), Rehman et al. (2023), and Wang et al. (2023), examine the connections between green and digital transformation, called the “twin transition” (Bianchini et al., 2023). The fourth industrial revolution has raised hopes that longstanding social, economic, and environmental goals, including sustainable and inclusive growth, could be achieved. The transition of the economy towards Industry 4.0 and the Green Deal highlights the importance of implementing new and intricate procedures for the technological and organizational transformation of industrial clusters. These processes encompass a wide range of activities, including the implementation of innovative business models, the digitalization of operations, and the enhancement of resource efficiency through the transition to a sustainable, circular economy.

Digital technologies have revolutionized industrial clusters (Teng, et al. 2024). Industry 4.0 is linked to a significant change in business paradigms, which brings both obstacles and new possibilities for creating and managing clusters. The interactive nature of learning and the specificity of knowledge generation suggest that the regional factor is a vital component, as it provides the necessary mechanisms to facilitate investment and development processes associated with the implementation and adoption of Industry 4.0 techniques. Industry 4.0 is dependent on key components that are naturally found in clusters, such as robust teamwork, shared trust, the dissemination of unspoken knowledge, and exchanges and links between participants in regional innovation networks, as well as compatibility and shared standards. Clusters can offer a conducive setting for testing Industry 4.0 technologies and act as a fertile ground for the development of Industry 4.0 (Götz & Jankowska, 2017). Firms' growing engagement in innovations is thereafter accompanied by their broader utilization of Industry 4.0 technologies. Companies are focusing on adopting Industry 4.0 technologies to improve their innovation performance. However, they may encounter difficulties in keeping up with the rapid pace of digital transformation, particularly when it comes to the procedures and costs associated with implementing these technologies (Jankowska et al., 2023).

Clusters have a crucial role in expanding economic activities and fostering a more ecologically aware economy, both in theory and in practice (Sjøtun & Njøs, 2019). (Berkowitz & Gadille, 2023) assert that clusters have the potential to overcome several barriers to transformative change, such as the tendency to stick to established growth patterns, lack of proper responsibility, and failure to adapt work methods adequately to maintain long-term viability. Clusters play a crucial role in facilitating the green transition by enabling businesses to overcome their constraints and gain access to a wide range of knowledge and relevant expertise (De Noni et al., 2021). Industries that are part of clusters often demonstrate better resources and energy efficiency compared to isolated units. Nevertheless, the advantages or drawbacks of clustering for attaining substantial emission reductions and other revolutionary changes are not clearly characterized. Although centrally-driven clusters might accelerate improvements, clusterisation can also lead to inertia, lock-in, and collective action challenges when managing the transition to climate neutrality and circularity (Janipour et al., 2020)

Recently, there has been a growing inclination to establish clean technology clusters, which are seen as a vital solution in the shift towards a more environmentally friendly economy. These clusters have the potential to stimulate regional economic growth while simultaneously solving environmental issues. Academic focus on cleantech clusters is essential because of the policy implications for environmentally friendly economic growth and the capacity of corporate clusters to promote sustainable economies (Tvedt, 2019). This may play an important role in achieving resilient competitiveness, understood as an economy’s capability to recover from or respond to negative external shocks (Kowalski, 2025).

Therefore, for further testing of this relationship in the reality of the Polish economy leads to the formulation of the following hypothesis H0: Cluster membership positively influences digitalisation and Industry 4.0 technologies implementation due to using cluster pro-innovation services related to digital transformation and use of Industry 4.0 technologies (H1), positive evaluation of the activities of the cluster coordinator in the area of digitization of the cluster/implementation of Industry 4.0 technologies (H2), and the importance expressed by member of the cluster digitization efforts / implementation of Industry 4.0 technologies (H3).

# 2. Data and research methods

Data come from cluster benchmarking in Poland, a survey carried out for the Polish Agency for Enterprise Development in 2022-2023 on the sample of 41 formalized cluster initiatives in Poland and 642 of their member firms. In measuring the impact of clusters on the digitalization of the economy, the dependent variable is the improvement of the level of digitization and use of Industry 4.0 technologies as a result of participation in the cluster reported by surveyed companies.

*Overview: Firm Characteristics*

Table A1 provides a number of aggregate characteristics of firms within each, particularly in terms of firm age and size. We see that member firms are oldest on average in the Lower Silesian Educational Cluster (average start age: 1966), while the newest is the West Pomeranian ICT Cluster (mid-2016).

More small firms than large ones. Most common within each group is Microenterprise (0-9 employees) with 19/41, followed by Small enterprise (10-49 employees) with 11. Three clusters (Lublin Enterprise Cluster, Lublin Eco-Energy Cluster, Mazovia Cluster ICT) have more than 80 percent of firms with 0-9 employees. Two clusters (NUTRIBIOMED Cluster and MedSilesia - The Silesian Network of Medical Devices) have 30 percent micro and small respectively. As we note below, a promising research direction would be to look at firm size distributions by Polish region and by cluster.

The largest clusters are Mazovia Cluster ICT and Polish Construction Cluster, with 42 and 47 firms, respectively. Eight of the 41 clusters have only five firms.

We see in Table A2 that clusters are concentrated by region as well. The most firms are located in Mazovia (with six firms), Lower Silesia (Lower Silesia, 5) and the Lubelskie region (5). Four of Poland’s 16 regions have only one cluster. Repeating the analysis of firm age in Table A3, we see that the oldest firms are found in Lower Silesia and the Lodz region (median age: 1996), while the newest are in Opolskie (2010). Regarding firm size, micro enterprises are the most common type in six regions. Large firms make up half of the total in Warsaw’s Mazovia region. This is in contrast to the fact, shown in Table A5, that most firms in our sample are microenterprises with 0-9 employees, with progressively decreasing proportions as size categories increase.

To formally measure this interesting finding, we calculate a Herfindahl-Hirschman (HHI) concentration measure using the shares of the total number of firms in each cluster or region for each firm size. This measure is calculated as :

(1)

Where s is the share of firms of type i, and n is the number of firm-size categories. A high value (with a maximum value of 1) indicates that all firms in a cluster or region are of a single size category—for example, if all were microenterprises. In practice, perfect concentration is impractical, so lower thresholds may indicate the presence of size concentrations. A low number (which has a minimum of 0.2 when there are five categories) would mean that firm sizes are equally distributed within a given cluster or region.

We see in Table A4 that the Mazovian region, which includes Warsaw, has the highest HHI. Among the clusters, Mazovia Cluster ICThas a very large HHI value. We leave a detailed analysis of the full range of values for a future study, and simply note this promising research direction here.

*Probit analysis*

In our regression we have two explanatory variables in two separate estimations: First, we look at whether membership in the cluster has helped the firm’s functionality in Industry 4.0. Second, we examine whether this membership has helped with Green Transformation. We name these explanatory variables IND4 and GT, respectively. Since both are yes/no questions, these are coded [1,0] and we conduct a Probit analysis, which is appropriate for binary dependent variables. Our independent variables are as follows:

* (*SERV*) using pro-innovation services related to digital transformation and use of Industry 4.0 technologies provided in the cluster by or through the cluster in the last 2 years,
* (*COORD*) positive evaluation of the activities of the cluster coordinator in the area of digitization of the cluster/implementation of Industry 4.0 technologies,
* (*IMPL*) the importance expressed by members of the cluster with respect to cluster efforts in the area of implementation of Industry 4.0 technologies in the perspective of the next 2 years.

In measuring the impact of clusters on green transformation, the dependent variable is the improvement of an organization’s performance in green transformation as a result of participation in the cluster reported by surveyed companies. This is related to such activities, as using the Circular Economy concept in operations, having and implementing environmental certificates for technology (ETV) or for products (Ecolabel) or others, implementing solutions resulting from energy efficiency audit, R&D work in the field of low-carbon technologies or technological innovations in the area of green economy, production and distribution of energy from renewable sources (e.g. own photovoltaic installations, heat pumps, biogas plants), implementation of low-carbon economy projects carried out by the cluster coordinator or members. Explanatory variables are:

* *(INNOV) using pro-innovation services related to green transformation provided in the cluster by or through the cluster in the last 2 years,*
* *(EVAL) positive evaluation of the activities of the cluster coordinator in the area of green transformation activities of the cluster,*
* *(IMPT) the importance expressed by members of the cluster with respect to green cluster transformation activities.*

# 3. Research results and discussion

The study aims to determine whether and to what extent participation in cluster initiatives enhances the digital and green of member firms. The first model was conducted to test the impact of clusters on the digital transformation of member companies.

Table 1. The results of Probit analysis on the impact of clusters on digital transformation (IND4)

|  |  |
| --- | --- |
| **Variable** | **Coeff. (p-val)** |
| (Intercept) | -3.033 (0.000) |
| SERV | 2.038 (0.000) |
| COORD | 1.698 (0.000) |
| IMPL | 0.316 (0.157) |
| Pseudo-R-sq | 0.505 |

Source: own calculations.

The study confirms that cluster membership positively influences the digitalization and adoption of Industry 4.0 technologies among firms. This is evidenced by the significant improvement in innovation performance reported by companies participating in cluster activities. The provision of pro-innovation services related to digital transformation within clusters has been identified as a crucial factor driving the adoption of Industry 4.0 technologies. Firms benefit from tailored support, access to cutting-edge technologies, and specialized training, which collectively enhance their innovation capabilities.

The positive evaluation of cluster coordinators’ activities in the realm of digitization underscores the importance of effective leadership and management within clusters. Coordinators play a pivotal role in orchestrating collaborative initiatives, facilitating knowledge exchange, and ensuring that members can leverage digital tools effectively. The importance attributed to digitization efforts by cluster members further supports the idea that collective action and shared goals are essential for successful digital transformation. Firms within clusters are more likely to prioritize and invest in digital technologies when they perceive a collective benefit.

The second model was conducted to test the impact of clusters on the green transformation of member companies.

Table 2. The results of Probit analysis on the impact of clusters on green transformation (GT)

|  |  |
| --- | --- |
| **Variable** | **Coeff. (p-val)** |
| (Intercept) | -2.797 (0.000) |
| INNOV | 2.593 (0.000) |
| EVAL | 1.037 (0.000) |
| IMPT | 0.473 (0.033) |
| Pseodo-R-sq | 0.575 |

Source: own calculations.

The regression analysis results indicate a positive relationship between cluster participation and the improvement of organizational performance in green transformation. Companies that engaged with cluster activities, particularly those utilizing pro-innovation services related to green transformation, reported significant advancements in their sustainable practices. This includes the implementation of Circular Economy concepts, environmental certifications, and the adoption of low-carbon technologies.

The positive evaluation of cluster coordinators’ activities further supports the notion that effective leadership and coordination within clusters are critical for driving green initiatives. Cluster coordinators act as catalysts, fostering collaboration among member firms and ensuring that the collective efforts are aligned with sustainability goals. This confirms the assertions by (Berkowitz & Gadille, 2023) that clusters can serve as agents of transformative change when there is responsible actor guiding their actions.

The importance expressed by cluster members regarding green transformation activities underscores the growing awareness and prioritization of sustainability within the industrial sector. This shift towards valuing green initiatives is crucial for achieving long-term environmental and economic benefits. The study suggests that when companies perceive green transformation as vital, they are more likely to engage in activities that contribute to ecological sustainability.

# Conclusions

This study contributes to the understanding of the impact of clusters on the twin transition encompassing both digital and green transformations. Through an empirical investigation involving 41 cluster initiatives and 642 member firms in Poland, the findings reveal several critical insights that inform both academic discourse and practical applications in the fields of industrial clustering and sustainable development.

The results demonstrate that cluster membership significantly enhances firms' digitalization and adoption of Industry 4.0 technologies. Companies that engaged with cluster activities, particularly those utilizing pro-innovation services, reported notable improvements in their digital capabilities. This underscores the role of clusters as facilitators of digital innovation, providing necessary resources, knowledge, and networks to support technological advancements.

Similarly, participation in clusters positively impacts firms’ performance in green transformation. The utilization of pro-innovation services related to sustainability, combined with effective cluster coordination, leads to substantial advancements in implementing sustainable practices. This includes the adoption of Circular Economy concepts, environmental certifications, and low-carbon technologies, highlighting clusters' pivotal role in promoting ecological sustainability.

Effective leadership by cluster coordinators is crucial for driving digital and green transformations. Coordinators facilitate collaboration and knowledge exchange and ensure that cluster activities align with broader sustainability goals. Member firms’ positive evaluations of their activities reinforce the importance of strategic management within clusters.

The significance attributed to digital and green transformation activities by cluster members reflects a growing awareness and prioritization of sustainability and innovation within the industrial sector. Firms are more likely to invest in and prioritize these initiatives when they perceive collective benefits and shared goals.

This research adds to the body of knowledge on cluster dynamics and their impact on digitalization by providing empirical evidence from a substantial sample of clusters and member firms in Poland. The findings have significant implications for policymakers aiming to enhance industrial competitiveness through clustering. Supporting cluster initiatives and ensuring robust coordination can amplify the benefits of digital transformation across industries. For cluster managers and coordinators, the study offers practical insights into effective strategies for fostering digitalization, highlighting the importance of tailored pro-innovation services and active member engagement.

While the study offers valuable insights, it is not without limitations. The reliance on self-reported data may introduce bias, and the cross-sectional nature of the survey limits the ability to draw causal inferences. Future research could address these limitations by employing longitudinal designs and incorporating more objective measures of digitalization and green performance. Moreover, exploring the specific challenges faced by firms in different sectors and regions within clusters could provide a more nuanced understanding of the barriers to digital and green transformation. Investigating the interplay between digital and green transitions in greater detail would also be a fruitful avenue for further research.

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# References

Berkowitz, H., & Gadille, M. (2023). Meta-organising clusters as agents of transformative change through ‘responsible actorhood’. In E. N. F. D. Lupova-Henry (Ed.), *Clusters and Sustainable Regional Development* (pp. 61-76). Routledge.

Bianchini, S., Damioli, G., & Ghisetti, C. (2023). The environmental effects of the “twin” green and digital transition in European regions. *Environmental and Resource Economics*, *84*(4), 877-918. <https://doi.org/10.1007/s10640-022-00741-7>

Ching, N. T., Ghobakhloo, M., Iranmanesh, M., Maroufkhani, P., & Asadi, S. (2022). Industry 4.0 applications for sustainable manufacturing: A systematic literature review and a roadmap to sustainable development. *Journal of Cleaner Production*, *334*, 130133. <https://doi.org/https://doi.org/10.1016/j.jclepro.2021.130133>

De Noni, I., Ganzaroli, A., & Orsi, L. (2021). Green Invention as Leverage for Economic Growth in Locally Collaborative European Regions. In S. R. Sedita & S. Blasi (Eds.), *Rethinking Clusters: Place-based Value Creation in Sustainability Transitions* (pp. 17-31). Springer International Publishing. <https://doi.org/10.1007/978-3-030-61923-7_2>

Götz, M., & Jankowska, B. (2017). Clusters and Industry 4.0 – do they fit together? *European Planning Studies*, *25*(9), 1633-1653. <https://doi.org/10.1080/09654313.2017.1327037>

Janipour, Z., de Nooij, R., Scholten, P., Huijbregts, M. A. J., & de Coninck, H. (2020). What are sources of carbon lock-in in energy-intensive industry? A case study into Dutch chemicals production. *Energy Research & Social Science*, *60*, 101320. <https://doi.org/https://doi.org/10.1016/j.erss.2019.101320>

Jankowska, B., Mińska-Struzik, E., Bartosik-Purgat, M., Götz, M., & Olejnik, I. (2023). Industry 4.0 technologies adoption: barriers and their impact on Polish companies’ innovation performance. *European Planning Studies*, *31*(5), 1029-1049. <https://doi.org/10.1080/09654313.2022.2068347>

Kowalski A.M. (2025), *Clusters and Cluster Policy Models: Driving Competitiveness in the Global Economy*, Edward Edgar.

Lis, A. M., & Kowalski, A. M. (2022). Cluster organization as a form of non-technological innovation. In M. W. Popowska, J.E. (Ed.), *Organizational Change, Innovation and Business Development* (pp. 99-120). Routledge.

Porter, M. E. (1998). Clusters and the new economics of competition. *76*(6), 77-90.

Rehman, S. U., Giordino, D., Zhang, Q., & Alam, G. M. (2023). Twin transitions & industry 4.0: Unpacking the relationship between digital and green factors to determine green competitive advantage. *Technology in Society*, *73*, 102227. <https://doi.org/https://doi.org/10.1016/j.techsoc.2023.102227>

Sjøtun, S. G., & Njøs, R. (2019). Green reorientation of clusters and the role of policy:‘the normative’and ‘the neutral’route. *European Planning Studies*, *27*(12), 2411-2430.

Sölvell, O., Lindqvist, G., Ketels, C., & Porter, M. E. (2003). The cluster initiative greenbook.

Teng, Y., Zheng, J., Li, Y., & Wu, D. (2024). Optimizing digital transformation paths for industrial clusters: Insights from a simulation. Technological Forecasting and Social Change, 200, 123170.

Tvedt, H. L. (2019). The formation and structure of cleantech clusters: Insights from San Diego, Dublin, and Graz. *Norsk Geografisk Tidsskrift - Norwegian Journal of Geography*, *73*(1), 53-64. <https://doi.org/10.1080/00291951.2019.1568295>

Wang, J., Liu, Y., Wang, W., & Wu, H. (2023). How does digital transformation drive green total factor productivity? Evidence from Chinese listed enterprises. *Journal of Cleaner Production*, *406*, 136954. <https://doi.org/https://doi.org/10.1016/j.jclepro.2023.136954>

# Appendix

Table A1. Cluster Characteristics

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Cluster** | **Median\_**  **StartYr** | **Median\_**  **JoinYr** | **Most\_Common\_Type** | **% of total** | **# Firms** | **Region – voivodship** |
| LODZistics - Logistics Business Network of Central Poland | 1996 | 2019 | Scientific unit/University | 33.3 | 9 | Lodzkie |
| Metal Processing Cluster | 2002 | 2016 | Small enterprise (10-49 employees) | 42.9 | 35 | Holy Cross |
| Podkarpackie Flavors Cluster | 2007 | 2015 | Small enterprise (10-49 employees) | 60 | 5 | Podkarpackie |
| East Automotive Alliance | 2002 | 2017 | Large enterprise ( > 250 employees) | 42.9 | 7 | Podkarpackie |
| Carpathian Tourist Cluster | 2012 | 2014 | Microenterprise (0-9 employees) | 60 | 5 | Podkarpackie |
| Cluster "Polish Automotive Group" | 1996 | 2020 | Large enterprise ( > 250 employees) | 38.5 | 13 | Pomeranian |
| Food Cluster of Southern Wielkopolska Association | 1997 | 2016.5 | Microenterprise (0-9 employees) | 40 | 10 | Greater Poland |
| Polish Cluster of Composite Technologies | 2005 | 2019 | Microenterprise (0-9 employees) | 38.1 | 21 | Masovian |
| Polish Construction Cluster | 2005 | 2019 | Microenterprise (0-9 employees) | 40.4 | 47 | Podlaskie |
| Waste Management and Recycling Cluster | 2003.5 | 2018.5 | Microenterprise (0-9 employees) | 40 | 10 | Masovian |
| Mazovia Cluster ICT | 2014.5 | 2019 | Microenterprise (0-9 employees) | 88.1 | 42 | Lubelskie |
| Bydgoszcz Industrial Cluster Tool Valley | 2003 | 2016 | Small enterprise (10-49 employees) | 32.4 | 34 | Kuyavian-Pomeranian |
| Lublin Medicine | 2004.5 | 2017 | Microenterprise (0-9 employees) | 42.3 | 26 | Lubelskie |
| MedSilesia - The Silesian Network of Medical Devices | 1992 | 2018 | Small enterprise (10-49 employees) | 30.4 | 23 | Silesian |
| Silesia Automotive & Advanced Manufacturing | 2003 | 2019 | Medium enterprise (50-249 employees) | 36 | 25 | Masovian |
| NUTRIBIOMED Cluster | 2004 | 2017 | Microenterprise (0-9 employees) | 30 | 20 | Silesian |
| Lower Silesian Educational Cluster | 1966 | 2020 | Local government unit | 46.2 | 39 | Lower Silesia |
| ITCorner | 2012.5 | 2015 | Small enterprise (10-49 employees) | 50 | 6 | Lower Silesia |
| Radom Metal Cluster | 1989.5 | 2013 | Medium enterprise (50-249 employees) | 50 | 8 | Masovian |
| Cluster for Photonics and Fiber Optics | 2012 | 2017.5 | Microenterprise (0-9 employees) | 42.9 | 21 | Lubelskie |
| The Easter Metalworking Cluster | 1992.5 | 2016 | Medium enterprise (50-249 employees) | 42.9 | 14 | Lubelskie |
| Lubuski Metal Cluster | 1995.5 | 2010 | Medium enterprise (50-249 employees) | 40 | 15 | Lubuskie |
| Lower Silesian Automotive Cluster | 1999 | 2020 | Medium enterprise (50-249 employees) | 60 | 5 | Lower Silesia |
| North-South Logistics&Transport Cluster | 2012 | 2020.5 | Microenterprise (0-9 employees) | 53.8 | 13 | Masovian |
| Polish Nature Cluster | 2004 | 2016 | Microenterprise (0-9 employees) | 50 | 6 | Łódzkie |
| Lodz ICT Cluster | 1988 | 2013.5 | Large enterprise ( > 250 employees) | 66.7 | 6 | West Pomeranian |
| Associaton West Pomeranian Chemical Cluster "Green Chemistry" | 2002 | 2015 | Medium enterprise (50-249 employees) | 42.9 | 35 | Lower Silesia |
| Silesian Aviation Cluster | 2012 | 2019 | Microenterprise (0-9 employees) | 65.2 | 23 | Pomeranian |
| Interizon ICT Cluster | 2004 | 2015.5 | Small enterprise (10-49 employees) | 53.3 | 15 | Małopolskie |
| Cluster of Information Technologies in Building Industry | 2013 | 2020 | Microenterprise (0-9 employees) | 64.3 | 14 | Masovian |
| Digital Creative Cluster | 2016 | 2022 | Small enterprise (10-49 employees) | 55.6 | 9 | Małopolskie |
| Bydgoszcz IT Cluster | 2004 | 2018 | Microenterprise (0-9 employees) | 60 | 5 | Greater Poland |
| Wielkopolska ICT Cluster | 2008 | 2012 | Microenterprise (0-9 employees) | 40 | 5 | Lubelskie |
| Lublin Enterprise Cluster | 2015 | 2019 | Microenterprise (0-9 employees) | 80 | 5 | Podlaskie |
| The Cluster of Tourist Brands of Eastern Poland | 2002 | 2012 | Small enterprise (10-49 employees) | 60 | 5 | Podkarpackie |
| Construction Cluster INNOWATOR | 1999.5 | 2016.5 | Microenterprise (0-9 employees) | 50 | 6 | West Pomeranian |
| West Pomeranian ICT Cluster | 2016.5 | 2021.5 | Small enterprise (10-49 employees) | 33.3 | 6 | Podlaskie |
| Sustainable Infrastructure Cluster | 2009.5 | 2016 | Small enterprise (10-49 employees) | 39.1 | 23 | Lower Silesia |
| Cluster of Innovative Manufacturing Technologies (CINNOMATECH) | 2008 | 2018 | Microenterprise (0-9 employees) | 57.1 | 14 | Opolskie |
| Lublin Eco-Energy Cluster | 2012 | 2018 | Microenterprise (0-9 employees) | 85.7 | 7 | Kuyavian-Pomeranian |
| Kuyavian Agro Cluster | 2007 | 2018 | Small enterprise (10-49 employees) | 60 | 5 | Lodzkie |

Table A2. Distribution of clusters (41 total) by region – voivodship

|  |  |
| --- | --- |
| Region | Freq |
| Masovian | 6 |
| Lower Silesia | 5 |
| Lubelskie | 5 |
| Podkarpackie | 4 |
| Podlaskie | 3 |
| Kuyavian-Pomeranian | 2 |
| Lodzkie | 2 |
| Małopolskie | 2 |
| Pomeranian | 2 |
| Silesian | 2 |
| Greater Poland | 2 |
| West Pomeranian | 2 |
| Warmińsko-Mazurskie | 1 |
| Lubuskie | 1 |
| Opolskie | 1 |
| Holy Cross | 1 |

Table A3. Firm Characteristics By Region

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Region – voivodship** | **Median\_StartYr** | **Median\_JoinYr** | **Most\_Common\_Type** | **% of total** | **# Firms** | **Region – voivodship** |
| Masovian | 2009 | 2018 | Large enterprise | 51.1 | 90 | Masovian |
| Lubelskie (Lublin) | 2007 | 2017 | Local government unit | 41.0 | 83 | Lubelskie (Lublin) |
| Silesian | 2002 | 2018 | Small enterprise | 27.4 | 73 | Silesian |
| Lower Silesian | 1996 | 2019 | Small enterprise | 25.7 | 70 | Lower Silesian |
| Podkarpackie | 2003 | 2017 | Small enterprise | 29.5 | 44 | Podkarpackie |
| Małopolskie | 2010 | 2018 | Small enterprise | 34.9 | 43 | Małopolskie |
| Podlaskie | 2004 | 2017 | Small enterprise | 42.9 | 42 | Podlaskie |
| Lodzkie | 1996.5 | 2019 | Microenterprise | 21.9 | 32 | Lodzkie |
| Kuyavian-Pomeranian | 2003 | 2016.5 | Microenterprise | 34.4 | 32 | Kuyavian-Pomeranian |
| Greater Poland | 2010 | 2018 | Microenterprise | 36.7 | 30 | Greater Poland |
| Pomeranian | 2004 | 2018 | Microenterprise | 33.3 | 27 | Pomeranian |
| Lubuskie | 1999 | 2018.5 | Microenterprise | 27.3 | 22 | Lubuskie |
| West Pomeranian | 2003 | 2015 | Microenterprise | 33.3 | 21 | West Pomeranian |
| Warmińsko-Mazurskie | 2009 | 2019 | Microenterprise | 40.0 | 15 | Warmińsko-Mazurskie |
| Holy Cross | 2009 | 2019 | Medium enterprise | 44.4 | 9 | Holy Cross |
| Opolskie | 2015 | 2019 | Medium enterprise | 33.3 | 6 | Opolskie |

Note: Large enterprise ( ≥ 250 employees), Medium enterprise (50-249 employees), Small enterprise (10-49 employees), Microenterprise (0-9 employees)

Table A4. Hirschman Indices of Industry Concentration in Firm

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Cluster** | **HHI** |  | **Region** | | **HHI** |
| Mazovia Cluster ICT | 0.780 |  | Masovian | | 0.328 |
| Lublin Eco-Energy Cluster | 0.755 |  | Podlaskie | | 0.321 |
| Lublin Enterprise Cluster | 0.680 |  | Holy Cross | | 0.309 |
| Podkarpackie Flavors Cluster | 0.520 |  | Lubelskie | | 0.284 |
| Carpathian Tourist Cluster | 0.520 |  | Kuyavian-Pomeranian | | 0.283 |
| Silesian Aviation Cluster | 0.520 |  | Opolskie | | 0.278 |
| The Cluster of Tourist Brands of Eastern Poland | 0.520 |  | Warmińsko-Mazurskie | | 0.262 |
| Kuyavian Agro Cluster | 0.520 |  | Małopolskie | | 0.261 |
| Digital Creative Cluster | 0.506 |  | Pomeranian | | 0.259 |
| Lodz ICT Cluster | 0.500 |  | West Pomeranian | | 0.243 |
| Cluster of Information Technologies in Building Industry | 0.500 |  | Podkarpackie | | 0.233 |
| Lower Silesian Automotive Cluster | 0.440 |  | Greater Poland | | 0.229 |
| Bydgoszcz IT Cluster | 0.440 |  | Lodzkie | | 0.203 |
| Radom Metal Cluster | 0.406 |  | Silesian | | 0.203 |
| Cluster of Innovative Manufacturing Technologies (CINNOMATECH) | 0.398 |  | Lubuskie | | 0.202 |
| ITCorner | 0.389 |  | Lower Silesian | | 0.164 |
| East Automotive Alliance | 0.388 |  |  |  | | |
| Cluster for Photonics and Fiber Optics | 0.365 |  |  |  | | |
| North-South Logistics&Transport Cluster | 0.349 |  |  |  | | |
| Cluster "Polish Automotive Group" | 0.337 |  |  |  | | |
| Polish Nature Cluster | 0.333 |  |  |  | | |
| Interizon ICT Cluster | 0.333 |  |  |  | | |
| Construction Cluster INNOWATOR | 0.333 |  |  |  | | |
| The Easter Metalworking Cluster | 0.326 |  |  |  | | |
| Associaton West Pomeranian Chemical Cluster "Green Chemistry" | 0.306 |  |  |  | | |
| Sustainable Infrastructure Cluster | 0.301 |  |  |  | | |
| Polish Construction Cluster | 0.297 |  |  |  | | |
| Silesia Automotive & Advanced Manufacturing | 0.290 |  |  |  | | |
| Lower Silesian Educational Cluster | 0.290 |  |  |  | | |
| Food Cluster of Southern Wielkopolska Association | 0.280 |  |  |  | | |
| Wielkopolska ICT Cluster | 0.280 |  |  |  | | |
| West Pomeranian ICT Cluster | 0.278 |  |  |  | | |
| Lublin Medicine | 0.269 |  |  |  | | |
| Bydgoszcz Industrial Cluster Tool Valley | 0.266 |  |  |  | | |
| Metal Processing Cluster | 0.265 |  |  |  | | |
| Polish Cluster of Composite Technologies | 0.261 |  |  |  | | |
| Waste Management and Recycling Cluster | 0.260 |  |  |  | | |
| LODZistics - Logistics Business Network of Central Poland | 0.259 |  |  |  | | |
| Lubuski Metal Cluster | 0.244 |  |  |  | | |
| MedSilesia - The Silesian Network of Medical Devices | 0.221 |  |  |  | | |
| NUTRIBIOMED Cluster | 0.220 |  |  |  | | |

Table A5. Firm Size Distribution (N = 641)

|  |  |  |
| --- | --- | --- |
| **Type** | **N** | **%** |
| Local government unit | 19 | 3.0 |
| Scientific unit/uiversity | 47 | 7.3 |
| Microenterprise (0-9 employees) | 209 | 32.6 |
| Small enterprise (10-49 employees) | 156 | 24.3 |
| Medium enterprise (50-249 employees) | 119 | 18.6 |
| Large enterprise (250 or more employees) | 63 | 9.8 |
| Other | 17 | 2.7 |
| Business environment institution | 6 | 0.9 |
| None | 6 | 0.9 |