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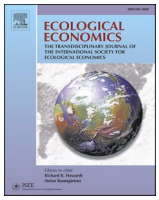

The implementation of green transformation through clusters

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ABSTRACT

The paper addresses a poorly documented issue in the literature, namely the role of clusters in green transformation, including processes related to green, low-carbon, and circular economies. The purpose was to identify and understand the practices of clusters in this area. The adopted mixed research strategy consisted of both qualitative and quantitative research. Both research phases were conducted in a group of Polish Key National Clusters. Through qualitative research, the authors abductively identified practices that are vital for green transformation and categorized them into three thematic areas: Integration, Access to resources, and Education and awareness building. On this basis, the authors developed a method to measure the clusters' level of advancement in green practices, which was used in quantitative research. The results show that the surveyed clusters undertake a number of practices to promote green transformation. They are active in each of the distinguished areas and also engage in its most demanding forms. The study sheds new light on the concept of the clusters, showing how such organizations can be used as agents of change in favor of green transformation.

1. Introduction

The concept of clusters was introduced to the literature by Porter (1990, 2000) who emphasized the synergy effect generated by the cooperation of companies operating in geographical proximity and representing the same or related sector of the economy. In the literature, several other cluster-related concepts have been developed, such as districts – both Marshall's industrial districts (Marshall, 1890) and their Italian variant (Becattini, 2002; Bellandi, 2002; Pyke et al., 1990; Sforzi, 2002), innovative milieu (Aydalot, 1986; Maillat, 1998), regional innovation system (Cooke et al., 1997; Braczyk et al., 1998), and innovation ecosystem (Adner and Kapoor, 2010; Autio and Thomas, 2014). The aforementioned concepts, which are included in the group of theories of regional development based on knowledge and innovation (Martin, 2003) – like clusters, place "territory" at the center of their considerations and emphasize the role of geographical proximity in the development of relationships among economic entities (Lis, 2018, 2019; Lis and Lis, 2023).

Clusters are a natural part of regional business ecosystems and there is ample evidence pointing to the link between clusters and entrepreneurship (Kerr and Robert-Nicoud, 2019; Ketels and Protsiv, 2020). It can be stated that the main effect of cluster activity is the improvement of cluster members' functioning, in particular an increase in their profits, e.g. through the establishment of research and development cooperation, the development of innovations, the expansion of sales markets and the improvement of international competitiveness (Mackiewicz, 2019). Cluster development in a region can be further supported by launching a cluster initiative (Sölvell et al., 2003), which by virtue of its organizational attributes is also referred to in the literature as a cluster organization. This type of organization operates at a higher level of aggregation and consists of institutional members who have intentionally and voluntarily joined it, engaging in collaboration to achieve common and/or individual goals (Lis, 2018; Lis and Lis, 2021). The designator of the term cluster is a geographical concentration of enterprises, linked by commercial and non-commercial dependencies, while the cluster organization forms the organizational base of the cluster and performs representative functions. The remainder of this paper essentially discusses cluster organizations, although they are interchangeably referred to as clusters (due to the fact that the concept of a cluster is much more widespread and, in addition, very often equated with a cluster organization, both in science and in practice).

Clusters, as actors specializing in a particular field, can be a tool for development, mainly at the regional level. The positive impact of clusters on various economic phenomena has been studied empirically by many researchers. According to Porter's definition, companies in a cluster collaborate and compete at the same time. This creates

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environment for changes – competition is a driver for new solutions, and cooperation facilitates the innovation process through learning from peers, learning by doing, knowledge flows, etc. In this way, clusters influence the development of companies (Yan et al., 2021). Chapain and Comunian (2010) argue that joint learning in a cluster is the reason why clustered companies develop faster. Another reason is the close cooperation of cluster companies with research institutions and creation of informal networks (Balland et al., 2016; Apa et al., 2021). This observation was confirmed by Li and Wang (2019) who claim that clusters attract research institutions and service-oriented organizations, providing convenient environment for creating innovations. Another factor that facilitates the development of cluster companies is the use of common resources. The flow of knowledge within clusters influences the performance of cluster members as a result of cooperation, workforce mobility and geographical proximity (Fioravanti et al., 2021). Clusters are a source of practical knowledge, so they are an ideal partner for conducting studies in the dual system as well as for conducting training (Kuberska and Mackiewicz, 2022). Therefore, cluster companies have access to practical training-oriented programs based on technical aspects (Canet-Giner et al., 2020). Xu et al. (2022) provide evidence that clusters play a role in social learning and facilitating knowledge flows, which is strengthened by cooperation and a complementarity effect between enterprises. This happens because of the trust between cluster members (Rozkwitalska and Lis, 2020).

Influencing specific areas through clusters in accordance with the cluster-based economic development policy requires establishing cooperation with an entity that can represent the cluster. Therefore, in this paper the authors refer to clusters, which have a legal personality and are represented by a cluster coordinator. For this reason, they can carry out some tasks related to green transformation, although this area has not been explicitly indicated as part of cluster-based economic development policy. Under the term green transformation, the authors include three categories: the green economy, the low-carbon economy, and the circular economy. The green economy is defined as "low-carbon, resource efficient, and socially inclusive. In a green economy, growth in income and employment are driven by public and private investments that reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services" (UNEP, 2010, 2011). The low-carbon economy is based on sustainable operations and using energy sources that generate low levels of greenhouse gases. In turn, the circular economy can be understood as "an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes" (Kirchherr et al., 2017). As the green economy, the low-carbon economy, and the circular economy are becoming an increasingly pressing need, the European Commission set up an Expert Group on Clusters to strengthen the potential of clusters to accelerate the green and digital transition. The Group drafted recommendations to focus cluster activities on leading the green transformation (European Commission, Expert Group on Clusters, 2021). Formalized clusters in particular, due to their characteristics and goals, seem to have great potential for spreading green transformation practices.

Given the objectives of the European Green Deal and the clustering phenomenon, it is, therefore, necessary to understand how clusters can be a tool in the implementation of green transformation processes. To this end, it is important to examine the current state of knowledge in this area and identify a potential knowledge gap. Hence, a comprehensive review of scholarly research focusing on the concept of a cluster in terms of green transformation was conducted. This was done on the basis of a systematic literature review and a three-step procedure proposed by Tranfield et al. (2003). Three global multidisciplinary platforms were selected for the study: the Web of Science (Clarivate), Scopus (Elsevier), and ProQuest Central. The criteria for their selection were primarily their coverage and international recognition. They index all of the world's leading journals and provide access to a number of databases that deliver reference and citation data, including from academic journals, conferences, and other documents (in case of ProQuest Central also trade publications, newspapers, magazines, dissertations, working papers, case studies, and market reports). Selected platforms cover multiple disciplines such as science, social science, arts, humanities (WoS), life sciences, social sciences, physical sciences, and health sciences (Scopus), and business, health and medical, social sciences, arts and humanities, education, science and technology, and religion (ProQuest Central). Due to the subject of the functioning of clusters covered, the choice of the above platforms seems to be fully justified. Moreover, the review also included a broad general literature, searched using Google Scholar (e.g., European Commission publications, cluster reports, etc.) that may shed additional light on issues related to the implementation of green transformation by clusters.

The review stage involved using the determined keywords and criteria to select the publications found. These can be divided into two topic groups: "Cluster" and "Green Transformation", which were then encapsulated with additional terms to obtain the broadest set of search results. In the case of clusters, synonyms such as "cluster", "clustering", "cluster organization" or "cluster initiative" were taken into account. The search process also considered the cluster-related concepts, which include "district", "innovative milieu", "regional innovation system", and "innovation ecosystem". In turn, for green transformation, various related concepts were selected, such as "green economy", "green deal", "circular economy", "low-carbon economy", "industrial symbiosis" and "industrial ecology". The searched publications had to include at least one keyword from both defined subject groups in the article title, abstract, or keywords. A literature search was conducted on 20/10/2022, yielding a total of 1899 search results. Two search criteria were used: bibliography types and subject area. For the first criterion, it was limited to journal articles, conference proceedings and book chapters. The second criterion was only applicable to WoS and Scopus – the focus was on papers published in the field of Management, Business and Economics[1] (ProQest Central did not provide an easy way to select publications based on discipline). The above procedure allowed to reduce the number of papers to 683 (WoS: 81 search results, Scopus: 226 search results, ProQest Central 376).

Data files were uploaded to the Zotero citation and reference management software. Files were merged into a single library and 62 duplicate files were removed, resulting in 621 files remaining. Screening included exploration and filtering of bibliographic data. In phase 1 of the screening, publications in languages other than English were removed (3 items), while in phase 2, publications deemed irrelevant to the given subject area – based on the abstract, title and keywords – were removed (441 items). Phase 3 consisted in reading 177 available full-text publications and selecting only those that contribute to the research on the concept of cluster in terms of green transformation. The final review of literature consisted of 121 scientific publications.

The results of the systematic literature review conducted indicate that research on clusters in relation to green transformation is essentially in its infancy – no systematic reviews have been conducted so far on clusters in this context. Very few papers were found on this topic, still very poorly disseminated, as evidenced by their low citation rates. For most (109) publications, the citations do not exceed 100, and almost half (58) have no more than 10 citations. The top 12 highest cited papers include four papers on the cluster concept (McCauley and Stephens, 2012; Deutz and Gibbs, 2008; Daddi et al., 2017; Baldassarre et al., 2019), two each on the ecosystem of innovation (Korhonen, 2001; Konietzko et al., 2020) and eco-industrial park (Shi et al., 2010; Taddeo et al., 2012) and one on regional industrial system (Baas and Boons,

[1] In the Web of Science database, three science categories were selected: Management, Business, and Economics, while in the Scopus database, two subject areas were selected: Economics, Econometrics and Finance, and Business, Management and Accounting.

2004) (the other three papers referred to geographic concentrations in general, without reference to a specific concept). In the context of green transformation, four papers in this group referred to industrial symbiosis (Wen and Meng, 2015; Bain et al., 2010; Baldassarre et al., 2019; Daddi et al., 2017), and two each were related to the topics of industrial ecology (Baas and Boons, 2004; Deutz and Gibbs, 2008) and circular economy (Ormazabal et al., 2018; Konietzko et al., 2020). The found papers are distributed in journals of varying prestige. About 40% of the publications were published in highly ranked journals (h-index: over 100) at the intersection of Business/Management/Economics and Environmental Science.

As for the industry context and geographical distribution, most of the papers (98) referred to a single country, with an evidently strong interest in Europe (a total of 49 papers), probably due to the well-developed cluster policies in that region. Italy is the most studied (15 papers), followed by Sweden (4 papers), and then – Germany and Spain (3 papers each). The second group in terms of the number of articles consists of Asian countries (a total of 34 papers), with a preponderance of articles dedicated to China (26 papers). About half of the papers were focused on a single industry, and the small group of articles (18) on multiple industries was limited to describing a maximum of three selected industries; half of these were cases from European countries such as Italy (Taddeo et al., 2017; Daddi et al., 2019), Scandinavian countries (Tolstykh et al., 2020; Feiz et al., 2021; Ingstrup et al., 2021), Germany (Konietzko et al., 2020), and Lithuania (Razminienė et al., 2021). With regard to the research design, most of the papers were found to be descriptive, conceptual or exploratory, which supports the argument of the initial stage of research on the subject of this study. In terms of the research approach, the vast majority of papers were based on qualitative research (mainly case studies), while a pure quantitative approach was identified in 1/3 of the publications. Also remarkable is the small number of mixed-method articles presenting both quantitative and qualitative research findings (only 12, including 8 articles that additionally use both secondary and primary data, such as Ashton, 2011; Taddeo et al., 2017; Camanzi et al., 2020; Joshi et al., 2020; Noori et al., 2020; Kayikci et al., 2021; Poponi et al., 2021; Zeng et al., 2021).

As for the substance, i.e. the main issue of the identified publications, many references to clusters were found in them – whether to the general concept, some attributes of clusters or specific cases. However, in many of the papers, clusters were not the main topic but merely a secondary one. Moreover, while most of the papers that emerged seemed to fundamentally deal with what clusters have to do with green transformation, they focused narrowly on issues primarily related to the green economy, the low-carbon economy and the circular economy. And finally, no publication was found on formalized clusters, i.e. cluster organizations or cluster initiatives, which could be an effective instrument in the implementation of green transformation. However, there are examples of such approach in policy papers and policy reports published by the European Commission or being a result of projects financed by the European funds.

The authors of the Towards Green Transition' facility report point out that recent years, and the post-pandemic crisis in particular, have revealed many weaknesses in European economies. The need to implement solutions to save raw materials and circular models has become even clearer (European Union, 2021). High hopes are placed on clusters, which provide a natural environment for circular economy through cooperation between cluster members. A report compiled by the European Expert Group on Clusters notes that "green transition needs agents of change" and points to clusters as supporting actors for public policies in this regard (European Commission, Expert Group on Clusters, 2021). With their ability to combine bottom-up and top-down initiatives and a place-based approach, clusters can effectively support SMEs in green transformation (Morisson and Pattinson, 2021). On one hand – clusters know the needs of companies on the other – they see the possibilities for crossovers and cooperation (European Union, European Resource Efficiency Knowledge Centre, 2019). Practical examples of such efforts from Denmark show how clusters are building green partnerships for circular transition (Nielsen and Nielsen, 2019). Given the growing interest of policymakers, it is worth providing scientific evidence on the role of clusters in the green transformation.

Therefore, in response to the identified knowledge gap, this paper aims to identify and give an understanding of clusters practices in the context of green transformation as assessed through the exploratory research. This study addressed two main research questions:

RQ1. What are the main practices in clusters that facilitate green transformation?

RQ2. How advanced are the Polish Key National Clusters in applying green transformation practices?

The country chosen for the study – Poland – is of high relevance for investigating the role of clusters in green transformation, because Polish public policy in this respect is not sufficient to reach the Green Deal goals. Poland is lagging behind other European countries in implementing the climate goals for 2030 and 2050. This raises the question of whether clusters can be the implementers of the idea of green transformation in countries such as Poland where, on the one hand, cluster policy has been implemented and clusters are well recognized and developed, and on the other hand, green transformation processes are inhibited.

The main body of this paper is structured as follows: in the initial section, the authors describe the research methodology, in the next section, they present the results of the qualitative and quantitative research, and in the final section, they provide the discussion and conclusions.

2. Material and methods

2.1. Research process

A mixed research strategy was adopted in this paper – a sequential exploratory design with qualitative research conducted in the first stage and quantitative research in the second stage of the research (Fig. 1). The reason for using a mixed strategy and the associated logic of triangulation in this study was the need to obtain a broad picture of the issues analyzed. The order in which the two distinctive research stages were carried out resulted from the objectives guiding the research.

The aim of the qualitative study was to identify specific pro-environmental practices that facilitate green transformation and to categorize them. On this basis, it was possible to develop a method for measuring clusters' level of advancement in green practices.

In addition, the trajectory of development of cooperative relationships in clusters (Lis, 2018; Lis and Lis, 2021) was used as a framework to categorize the identified practices. This concept presents the life cycle of clusters with four main levels of cooperation. Level I "Integration at the unit level", which is the basis for the development of subsequent levels of cluster cooperation, is aimed at creating a basic network of relationships among cluster partners. Level II "Allocation and integration at the process level" is designed to facilitate access to an increased pool of resources, including information. The two highest levels (III and IV) are found in the most developed clusters and include the most mature forms of cluster cooperation. Level III "Impact on the environment" aims at gaining impact on the external environment of the cluster, while Level IV "Creation and integration at the organizational level" is about setting up conditions to create common added value by pooling resources. Additionally, as qualitative research showed, at each of the distinguished levels of collaboration, clusters implement green practices, which can be grouped into three thematic blocks: Integration, Access to resources, and Education and awareness building.

The quantitative research, in turn, aimed to evaluate selected clusters (the Polish Key National Clusters) in terms of their environmental sophistication, based on the previously developed measurement

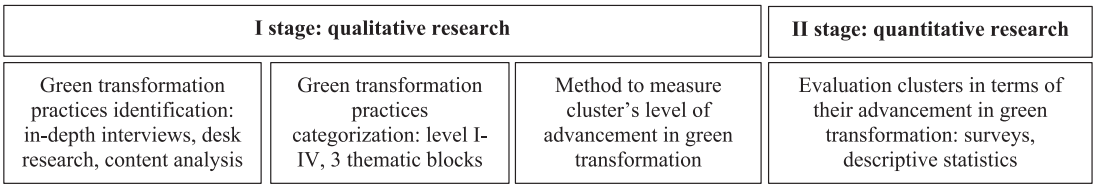

Fig. 1. Research process.
Source: own elaboration.

method.

The prioritization of qualitative research indicates the predominance of the inductive approach. On the other hand, the method of data interpretation used is typical of abduction (Peirce, 1931–1958).

2.2. Qualitative research

Data were extracted separately at both stages of the study. The qualitative research planned in the first stage was conducted in 2021. It was based on the in-depth interviews with cluster managers and the representatives of the science sector that play a significant role in a cluster. The sample was purposeful. The focus was on the Key National Clusters – the clusters that play a significant role in the economy and are selected in a 3-step competitive procedure. These clusters are mature and must prove that they provide services to cluster members but also some services for the public. In the year of the study, there were 15 Key National Clusters in Poland, and for the purpose of the study, 8 clusters were selected. Each of the selected clusters operates in a different sector – metal processing, life science, ICT, chemicals, aviation, construction and photonics. Three interviews were carried out with the researchers that are also managers in research institutions being cluster members. This perspective provided a better recognition of the role of cooperation between the science sector and business on R&D projects designed to provide new green solutions for cluster members. The purpose of the interviews was to collect information on the activities undertaken by the cluster manager or a group of cluster members that facilitate a faster green transformation. The questions concerned the nature of cluster activity, attempts to deliver new solutions for the green economy, the low-carbon economy and the circular economy and the results of such activities. The questions focused also the way how the cluster manager promotes green solutions among cluster members. The time of one interview was between 30 min and one hour, depending on the number of projects or activities undertaken by a particular cluster.

The primary technique for analyzing the data was qualitative content analysis. The information collected in the interviews was analyzed with the use of professional tools for qualitative text analysis (NVivo) which allowed for categorizing the activities facilitating green transformation that are undertaken by clusters.

As a complement to the qualitative research, a desk study was also conducted. The comprehensive desk study included the documents and reports provided by the cluster managers, cluster strategies as well as descriptions of projects implemented by clusters. This ensured that none of the important areas of cluster activities would be missed.

2.3. Quantitative research

The quantitative research which is the second stage in the research process was conducted in March 2022, with the use of a survey. All the Key National Clusters operate in Poland were surveyed. At the time of carrying out the survey, there were 18 Key National Clusters in Poland. The questions were directed to the managers of the clusters and all of them responded, therefore the response rate was 100%. The characteristics of the sample are presented in Table 1.

The questionnaire contained 26 questions that corresponded to the green practices identified during the qualitative research stage. The categorization of these practices further assessed the level of sophistication of the surveyed clusters in their green transformation efforts. All questions were to be assessed by respondents on a Likert scale. The questionnaire was pilot tested to check if all the questions are formulated comprehensibly and cover the whole scope of activities that clusters undertake to promote the green economy, the low-carbon economy and the circular economy and help companies to transform. The questionnaire was sent directly to the cluster manager by e-mail (the person was identified, which probably was a factor influencing getting a high response rate). Data analysis included descriptive statistics and a correlation of variables.

Table 1
Description of the sample.

Cluster	Region	Field(s) of activity	Year of foundation	Number of members
C1	Podlaskie	Construction	2011	331
C2	Zachodniopomorskie	New materials and chemistry	2007	157
C3	Podlaskie	Production and engineering Manufacture of food products, Advanced	2007	112
C4	Dolnośląskie	Packaging	2007	96
C5	Podkarpackie	Aviation and space	2003	148
C6	Śląskie	Health and medical science	2007	128
C7	Lubelskie	Other professional, scientific and technical activities, digital industries	2012	51
C8	Wielkopolskie	Energy and environment	2007	103
C9	Mazowieckie	ICT	2007	326
C10	Śląskie	Mobility: Vehicles, rail, traffic systems	2011	138
C11	Kujawsko-Pomorskie	Production and engineering	2006	137
C12	Małopolskie	Mobility: Vehicles, rail, traffic systems	2016	48
C13	Małopolskie	Health and medical science	2006	63
C14	Pomorskie	ICT	2009	94
C15	Śląskie	Aviation and space	2006	88
C16	Pomorskie	Transportation and mobility	2012	170
C17	Świętokrzyskie	Construction	2011	131
C18	Małopolskie	Mobility Technologies	2018	74

Source: own elaboration.

3. Results

The description of the research results was carried out in three main thematic blocks corresponding to the distinguished roles of clusters in terms of green transformation: Integration, Access to resources, and Education and awareness building. At the beginning of each block, the identified green transformation practices used by the surveyed clusters

are presented, followed by the results of qualitative research, and finally the results of quantitative research. The fourth and final block is the clusters strategy thread, analyzed in terms of green transformation efforts.

3.1. Integration

The first group of activities undertaken by clusters was called "Integration". The actions performed by the cluster manager that facilitate green transformation were classified into four groups reflecting different dimensions of integration: (Level I) social integration (e.g. contact initiation), (Level II) process integration (e.g. joint procurement / joint sales, common standards, green certificates, (Level III) integration with external actors (e.g. cooperation with public authorities or other clusters), (Level IV) organizational integration (e.g. building local value chains). Fig. 2. presents the identified green transformation practices undertaken by clusters within the "Integration" thematic block.

The analysis of the qualitative data provided the following evidence that these activities are being implemented in the framework of clusters. All the interviewed cluster managers organize periodical meetings of cluster members, which fosters social integration (Level I). Personal contacts are maintained and supplemented by a newsletter and a communication platform. Although they serve broader purposes than green transformation, sometimes they initiate cooperation in these areas.

There are many examples of integration at the process level (Level II). One of the respondents presented the use of technological processes to minimize production waste. The waste that is generated is entirely recycled. The solution used in many clusters is purchasing platforms for joint procurement and sales platforms offered to cluster members. Facilitating contact between companies is a role frequently performed by a cluster manager. For example, the manager of C3 initiates the collection of waste from abrasive machining, its transfer and sale to a scrap yard or transfer to other companies for recycling.

Integration on Level III can be reflected by examples from C1. The cluster manager, on behalf of companies and institutions cooperating within the cluster, established a foundation in the region, aiming to provide training, advisory services, and demonstration in the field of circular economy. The partners (the manager of C1, the regional authorities and the technical university operating in that region) jointly prepared the project "GREEN DEAL – the Podlaskie Center for green transformation" which aims to create an integrated ecosystem for the whole region in order to implement the Green Deal strategy there.

There are also other forms of integration at Level III; the manager of C8 represents a cluster of companies in public consultations. This is an important part of the cluster's activity – participation in the work on new regulations. Representatives of the cluster have the legal knowledge and are familiar with current changes in regulations at the EU level that relate to waste management. After the entry into force of the new regulations, they help companies implement solutions allowing them to adapt to these changes (e.g. related to the landfill of hazardous waste).

A product development path can serve as an example of the highest level (IV) of integration. In this area, C4 offers a platform for the use of biomass by-products for the manufacture of specialized products from plant and animal raw materials and their derivatives with the use of chemical, physicochemical or biochemical processes. The cluster manager facilitates the development and the practical use of comprehensive technologies for the processing of plant, animal and waste raw materials from the agri-food industry, chemical industry, energy industry, sewage treatment plants, landfills, etc. for the manufacture of semi-finished products for further processing for the chemical, pharmaceutical, household chemicals and other industries.

Another example at this level is partnerships in waste collection and reuse. The solution used by the cluster members is the recovery of spills formed during aluminium casting and re-smelting them and returning them to the production process. One company from the cluster is responsible for dividing materials into types of plastics, grinding and recirculating.

To supplement the information collected in the interviews on the forms of clusters' operations in green transformation, a survey was launched to investigate which forms are more and which are less popular among clusters. The survey questions in this field were grouped according to the level of the collaboration life cycle (from I to IV – the first question related to Level I, two questions related to Level II and III and three questions related to Level IV). Level I is presented at the bottom of the figure and Level IV at the top (Fig. 3).

It is visible that the majority of clusters undertake some actions at Level I, but almost the same share of clusters cooperate with other clusters or other entities external to the cluster, jointly implementing activities related to green transformation. Surprisingly, a relatively small share of clusters offer the possibility of joint procurement (e.g. group purchases) and/or joint sales (e.g. joint distribution channels) and/or other services related to green transformation (e.g. maintenance of machines and production equipment). As the majority answered "We don't undertake such activities, but we plan to," it can be assumed that these types of actions are relatively important, although they were not on the agenda yet or the cluster did not have sufficient resources (human, financial, organizational) to launch these types of actions. In general, it is visible that Level III is better represented than Level II, but the majority of clusters are still far from excellence in terms of integration in the field of green transformation.

3.2. Access to resources

The second type of activity identified in the model is related to "Access to resources". The basic level (I) in this thematic block is related to the access to information, the more advanced (Level II) – the access to different types of resources (material, financial, etc.). The services offered by a cluster manager at Level III encompass the provision of external information to cluster members. The most demanding services, classified as Level IV, can be described as the co-creation of resources (e.g. co-creation of new technologies). The examples are presented in Fig. 4.

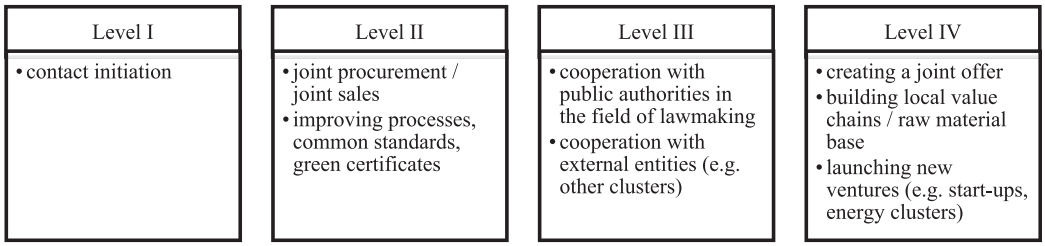

Fig. 2. Green transformation practices of clusters within "Integration". (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Source: own elaboration.

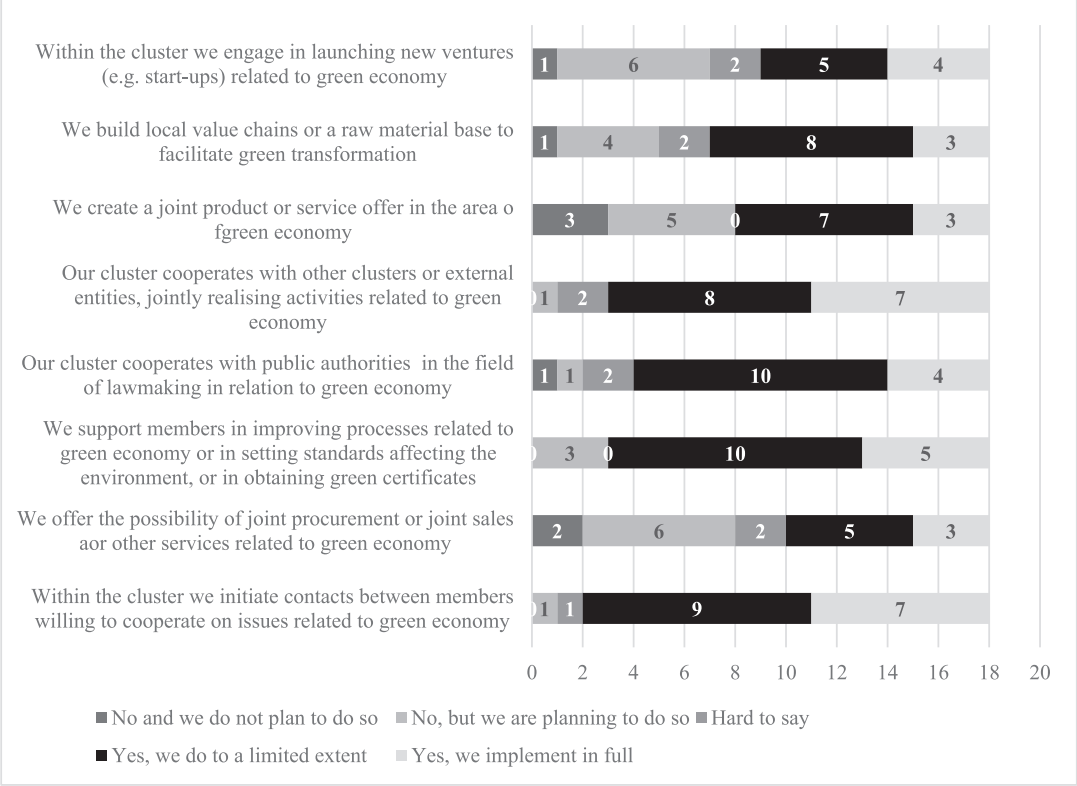

Fig. 3. Responses of cluster managers concerning "Integration".
Source: own elaboration on the basis of a survey among cluster managers (n=18).

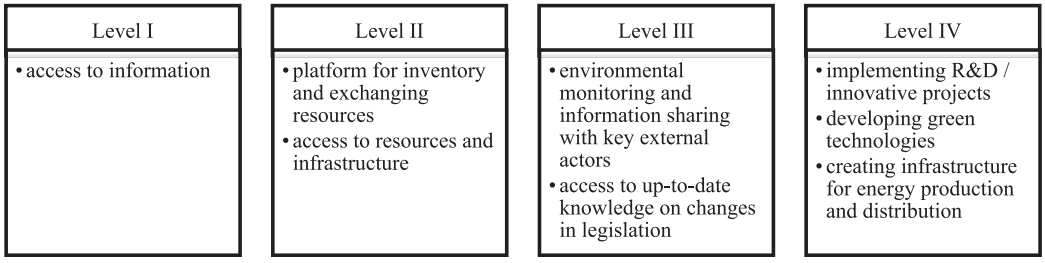

Fig. 4. Green transformation practices of clusters within "Access to resources". (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Source: own elaboration.

The interviews proved that clusters provide services at all the levels. One of the examples at Level I is initiating a webinar on waste management and process design in enterprises. One of the sessions was dedicated to the exchange of experience and good practices in the application of solutions and new technologies in waste management.

A practice from Level II can be presented from C7 – a cluster member of C7 has developed a system for providing information on the sources of air pollution emissions, based on intelligent image recognition technologies and video streams monitoring air quality in real time. The algorithms use machine learning techniques that process data from a large number of images obtained from direct users in order to compare them with image patterns produced in laboratory conditions for precise and unambiguous identification and classification of the level of air pollution. If a potentially dangerous situation is detected, the system notifies the user and automatically warns about dangerous, predefined states of air pollution with unprecedented accuracy.

At Level III, the activities performed in the framework of a cluster may be related to enabling the exchange of information with key actors outside the cluster involved in the design and implementation of green economy policy/legislation. One of the examples is the implementation of the Clean Business project. As part of the project, environmental audits were carried out, and recommendations for pro-environmental activities were indicated, including activities related to the minimization of waste generation. Cluster members have undergone energy audits and implemented their recommendations, e.g. construction of a photovoltaic installation, installation of cascade aerators to reduce water consumption or thermal modernization of buildings.

At the highest level (IV), the greatest number of practices can be identified, because joint R&D focused on the development of green technologies was classified as joint resource creation, for example conducting research and development works in the field of reducing emissions related to the use of hazardous substances by monitoring the consumption of substances (i.e. monitoring the consumption of substances necessary in the process of dyeing fibre and analyzing any deviations from the state of normal wear).

These observations were also reflected in the results of the quantitative research (Fig. 5).

The analysis of responses to the survey shows that the majority of

Fig. 5. Responses of cluster managers concerning "Access to resources".
Source: own elaboration on the basis of a survey among cluster managers (n=18).

clusters confirmed that they undertake actions assigned to Level I, declaring support for their members in accessing information on green transformation by organizing meetings and thematic events (e.g. conferences, seminars). Actions classified at Level IV seem to be more popular among respondents than actions at Level II. Fairly popular are also actions classified at Level III. In particular, the joint implementation of R&D projects thematically related to green transformation is a common practice.

3.3. Education and awareness building

The last group of activities is related to "Education and awareness building" (Fig. 6). In this thematic block, the authors distinguished relatively basic services starting from open training sessions and workshops for cluster members (Level I), through specialized training (Level II), awareness building among the external actors (Level III), and ending with practical training tailored to the needs of a specific company (Level IV).

The interviews provided information about cluster practices at all the distinguished levels. An example of practice at Level I may be C6 which established cooperation with the Specialist Regional Observatory of Technologies for Environmental Protection and the Specialist Regional Observatory of Energy. As part of this cooperation, cyclical editions of the New Economy Forum are organized. An important topic appearing at the forum is green energy – changes and innovations in the energy sector.

Training sessions and workshops dedicated to industry-specific knowledge sharing (Level II) are organized by the manager of C2. The agendas of training courses include strategies, best practices for circular economy in the chemical sector, and the principles of monitoring. The training also includes the preparation of enterprises to apply for project co-financing under the EU programs for R&D projects in the field of circular economy.

Another example illustrates activities at Level III which covers

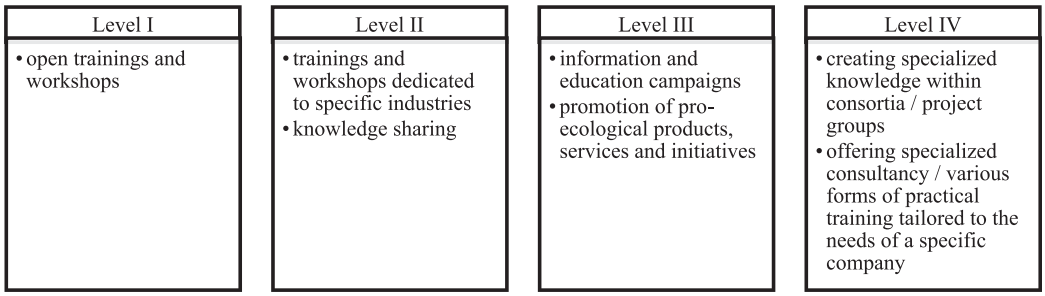

Fig. 6. Green transformation practices of clusters within "Education and awareness building". (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Source: own elaboration.

information and education campaigns, promotion of pro-ecological products, services and initiatives. C5 runs the "Econnected" project which aims to build awareness in the area of ecological activities of member companies and joint responsibility for the natural environment. The project also aims to develop a common ecological approach to reducing paper consumption, eliminating plastic, managing waste and saving energy in the resources used. The initiative is open to all small and medium-sized companies operating in the region.

The last example (at Level IV) comes from C8: a cluster that runs the educational project Recycling Academy. It is carried out by the cluster manager together with cluster members. It provides comprehensive education to companies (including employees, management, and other interested parties) and institutions in terms of waste recovery and recycling technologies, as well as the direction of a closed-loop CE. During training sessions and webinars, enterprises are provided with knowledge about global trends and technologies in the field of management and neutralization of all categories of waste, recovery, and recycling, including ferrous and non-ferrous metals, plastics, rubber, wood, glass, cellulose, multi-material waste, and also concerning financing investments taking advantage of EU funds and the latest legal solutions. The project is targeted at cluster members, to use their common potential (their substantive resources), as well as at external entities for which initiatives are being undertaken.

Having proved that all the levels are represented in the practice of clusters, it was interesting to investigate which level of activities is most popular among the clusters. The survey results shows that Levels I and II are less represented than Level III (Fig. 7).

Half of the respondents declared that their cluster is engaged in activities aimed at education and building awareness of green transformation (e.g. through cooperation with educational institutions, regional authorities and/or other regional partners, preparation of information and education campaigns, etc.). Moreover, they engage in such activities in full (the highest score). It is also quite popular to promote pro-ecological products, services, and initiatives (e.g. increasing energy efficiency and creating green jobs).

3.4. Strategy

The study shows that the surveyed clusters are serious about issues related to green transformation, which is reflected both in their strategy and organizational structure. The vast majority of them take into account the goals and actions related to the GE in their cluster strategy. No cluster manager replied that the strategy did not take into account such activities and was not planned. Moreover, clusters are almost equally intensively involved in forming subgroups (task groups, areas of competence, etc.) thematically related to green transformation (Fig. 8).

In addition, it was found that there is a statistically significant correlation between having a cluster strategy that includes green transformation goals and activities and the specific green practices implemented by the clusters surveyed. Also, there is a statistically significant correlation between the establishment of subgroups thematically related to green transformation and two types of activity of clusters: developing green technologies and offering access to highly specialized knowledge (Table 2).

The presented study not only identified a set of possible cluster practices for green transformation, but it also found that the surveyed clusters already demonstrate quite a strong commitment in this area. This is true for all four levels of collaboration (I-IV) and three thematic blocks: Integration, Access to resources, and Education and awareness building. What is more, it is clear that it is not necessary to undertake actions from Level I to be more advanced in the promotion of green transformation. For example, in the case of the "Education and awareness building" thematic block, the mean number of answers at Level III is higher than at Levels I and II. The values higher than the mean value are

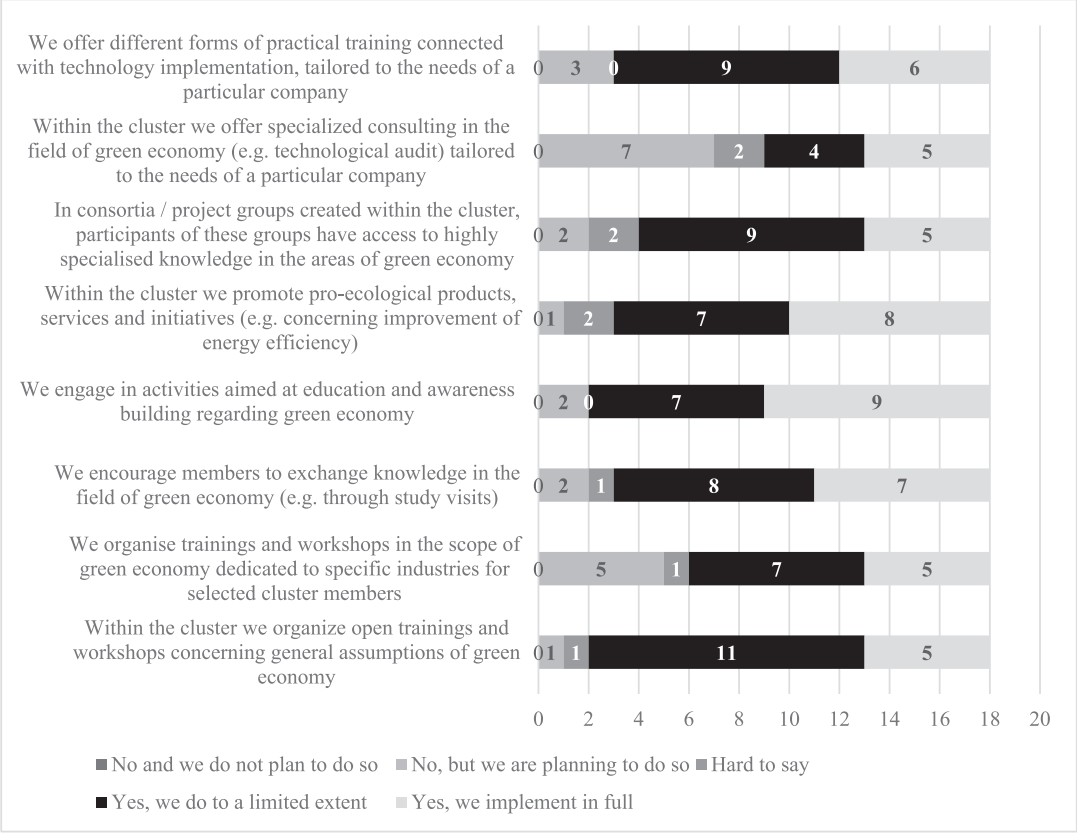

Fig. 7. Responses of cluster managers concerning "Education and awareness building".
Source: own elaboration on the basis of a survey among cluster managers (n=18).

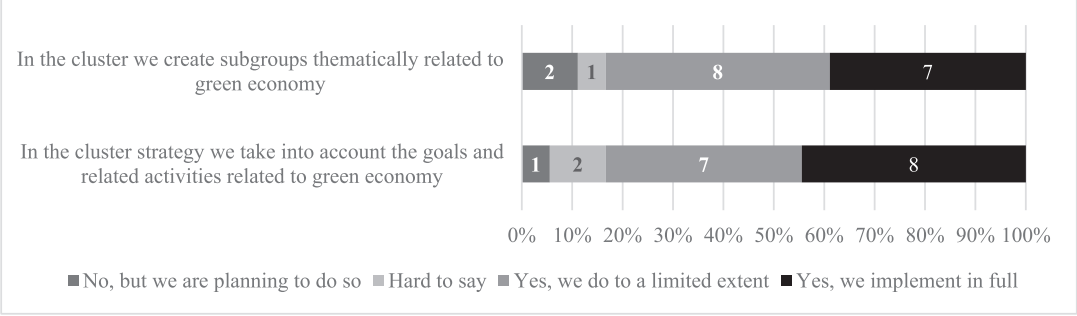

Fig. 8. Responses of cluster managers concerning strategy.
Source: own elaboration on the basis of a survey among cluster managers (n=18).

Table 2
Evaluation of clusters by cooperation levels and thematic blocks.

Green transformation practices in clusters	Correlation coefficient r	*p*-value
Cooperation with other clusters or other entities external to the cluster and joint implementation of activities related to green transformation	0.66	0.003
Building local value chains or the raw material base	0.47	0.048
Developing green technologies	0.68	0.002
engagement in activities aimed at education and building awareness of green transformation	0.48	0.045
Offering specialized consultancy in the field of green transformation (e.g. technological audit, energy audit, feasibility study, consulting in the field of energy transformation) tailored to the needs of a specific company	0.74	0.000
Developing green technologies	0.49	0.039
Offering access to highly specialized knowledge in the areas of green transformation for the project groups or consortia created within the cluster	0.54	0.020

Source: own elaboration.

marked in bold (Table 3). The total score is the highest in the thematic block "Education and awareness building".

4. Discussion

The study approached its main aim and specific objectives and research questions through a holistic method that included three layers of research: cognitive, methodological, and empirical. The authors have identified how existing research describes the role of clusters and clusters in green transformation processes, following the principles of a systematic literature review that stands out from traditional reviews in its breadth and rigor in collecting and synthesizing prior research (Okoli, 2015). The adoption of a sequential research model by combining qualitative and quantitative research was also an invaluable contribution to the objectives. The study is exploratory in nature, which is primarily due to the early stage of research on the role of clusters in green transformation processes. Nevertheless, it stands out from other papers identified in a systematic literature review. Moreover, it is one of the few works that rely on primary data and additionally combine quantitative and qualitative research in order to achieve the widest range of objectives and compensate for the disadvantages of both approaches. Furthermore, it uses a multi-industry perspective, considering as many as 12 different economic sectors represented by 18 of the Polish Key National Clusters. And although the focus is on Poland, account is taken of as many as 12 different Polish regions in which the analyzed clusters are located.

Table 3
Evaluation of clusters by cooperation levels and thematic blocks.

Level	Mean	Integration	Access to resources	Education and awareness building
		3,63	3,71	3,97
I	4,3	**4,2**	**4,67**	**4,11**
II	3,6	3,5	3,3	3,9
III	4,0	**4,0**	3,6	**4,3**
IV	3,6	3,3	**3,8**	3,8

Source: own elaboration.

The study shows that clusters act as drivers of change and enablers of green transformation. In particular, their role can be seen in raising awareness through information and education campaigns, as well as the promotion of pro-ecological products, services and other initiatives. The mechanisms through which clusters catalyze the green transition are very similar to those identified in the literature on the impact of the regional development of clusters (Ketels and Protsiv, 2020). Clusters help with rethinking business models and facilitate implementing them (Apa et al., 2021), therefore the use of clusters in sectoral policies (cluster-based development policies) may be successful. The knowledge spillover of technological innovation that takes place in clusters (Xu et al., 2022) can be an impetus for change in the green economy. It is the nature of a cluster to facilitate platforms for cooperation between companies, public institutions, research organizations and business environment institutions. Canet-Giner et al. (2020) claim that cluster companies may encourage the development of practical training-oriented programs and development of other skills and competences. The findings of this study are not that specific but confirm that clusters organize training on different levels, including specialized trainings and workshops, to prepare cluster members for the green transition and rise knowledge and awareness in this field. Bittencourt et al. (2022) claim that the main positive externalities tend to emerge when the cluster has reached critical mass and a collective strategy has been established.

The findings show that creating sectoral/thematic working groups within clusters can accelerate green transformation by developing new green technologies and offering access to highly specialized knowledge within this areas, for the working groups or project consortia created within clusters. This is in line with the findings of Alberti et al. (2021) showing that working groups in clusters encourage knowledge exchange. The findings of this study confirm the findings of other authors (Bittencourt et al., 2022) who suggest that when the collective strategy is in place and strengthened by local public policies, the commercialization of innovations generated by its firms is facilitated. Moreover, this study, similarly to Bittencourt et al. (2022), shows that mature clusters have potential for transmission of new solutions, transformation (in this case towards green economy), and application of knowledge created and exchanged between cluster members.

5. Conclusions

5.1. Study contributions

The presented research addresses a poorly documented problem in the literature related to the implementation of green transformation by clusters and helps fill this gap. First, the article serves the academic community as the first study to synthesize previous academic research on clusters in the context of green transformation – it identifies limitations and points to a research gap. The systematic literature review procedure applied in the study is reproducible and can be adapted to other similar studies. Second, it allows to understand the role of clusters in green transformation and to identify their practices with the example of specific studies. Third, it carries practical implications for those involved in clusters development (primarily policymakers at various levels, cluster coordinators and facilitators, etc.) by providing methodological assumptions for assessing CO's level of advancement in green transformation. Since green transformation processes require the interaction of various actors, it is important that the regional economy and society can benefit from the peculiarities of clusters also in terms of implementing the objectives of the European Green Deal.

5.2. Research limitations and directions for future studies

The presented study has several limitations that touch on essentially every dimension of research. In the cognitive dimension, limitations arise from the use of a systematic literature review procedure, which has many advantages but also implies a very rigorous selection process, which may involve the risk of omitting some valuable publications in the analyzed subject area. The limitations identified in the methodological and empirical dimensions are of a similar nature and are due to the limited research field. The study was conducted in the Polish cluster reality, in addition from the perspective of cluster coordinators. Although the research subjects were the most mature cluster structures in Poland, which guarantees the widest possible spectrum of cluster activities in the area of green transformation, it should be assumed that the list of these activities is not yet complete.

Therefore, this paper should be treated as an important voice starting a discussion on the role of clusters in the green transition. Future research should seek to further explore this area by carefully identifying all possible intra- and extra-cluster interactions leading to the implementation and dissemination of green practices. It would also be valuable to further develop models for assessing the advancement of clusters in green transformation practices (including developing research tools, testing scales, etc.). They would be an important basis for designing and carrying out benchmarking studies, which on the one hand would make it possible to identify leaders and disseminate good practices, and on the other hand, would make it possible for clusters to compare their activities in this area. For this, however, a broader research perspective is needed – to include not only cluster coordinators but also cluster members and to conduct research in other countries, especially with regard to European countries in which cluster policy has been implemented for a long time.

Further research may also be more causal in nature, focusing on determining the impact of clustering on the effectiveness of achieving green transformation goals, which in the context of European countries may be linked to the implementation of the European Green Deal. While the study suggests that collaboration in clusters can foster the implementation of these goals, more detailed research (e.g., based on structural equation modelling) is needed to test this hypothesis.

Declaration of Competing Interest

None.

Data availability

Data will be made available on request.

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