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Knowledge pluralisation in for-common-good science: cross-disciplinary, cross-institutional and cross-sectoral research in *Environmental Conservation* in Poland

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Abstract

Developing applicable solutions to urgent environmental concerns, which would reconcile the interests of various stakeholders with regard to the common good, requires the adoption of different perspectives related to knowledge processes. Thus, some authors have proposed undertaking cross-disciplinary, cross-institutional and cross-sectoral research. The objective of this paper is to inquire into the network structure, and investigate the rarely considered interdependence of these three types of collaboration within the environmental conservation field, as it is recognised in Poland. Research grant data from the POL-on database (the central nationwide ICT system) were used, and social network analysis (SNA) was applied. This study is institution-oriented and depended on formal collaboration in the form of partnership agreements, which are rarely applied but benefit the research process.

Environmental conservation in Poland is weakly internally integrated, but is well connected with neighbouring disciplines, as well as with the technical sciences. Industrial research institutes, as well as profiled higher education institutions, hold more influential network positions than leading large universities. Moreover, cross-disciplinarity does not offer significant stimulation for cross-organisational or cross-sectoral collaboration. This study is embedded within the specific national context of the science sector, which is currently undertaking a transition period (especially since the most recent reform of the Polish science and higher education in 2018), and the presented results shed light on the present and future challenges which it faces. The work contributes to studies on the knowledge production processes involved in the environmental sciences and provides results

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that may be used by the science sector for assessing and adjusting its strategic position at both the national and the institutional levels.

Key words

knowledge production, cross-disciplinarity, research partnership, environmental conservation, social network analysis.

Introduction

In contemporary science, there is a demand for cross-boundary research collaboration, resulting from some popular theories of knowledge and innovation that emerged at the end of the last century and were developed in subsequent years. The systemic approach to innovation (within national and regional innovation systems) emphasises the significance of mutual interactions between private and public entities (Cooke et al., 1997; Edquist, 1997; Lundvall, 1992), which enhance the creation, import, modification and diffusion of new technologies. The Mode 2 concept concentrates on knowledge production, with a requirement of social embeddedness, which may be ensured by including different non-academic participants in the research process (Gibbons et al., 1994). In addition, this research is carried out across disciplines, as it is focused on problem-solving and requires the contribution of representatives from various fields to achieve applicable results (Nowotny et al., 2003). In turn, the triple helix model assumes interactions between entities from the three sectors of a knowledge-based society, namely university, industry and government (UIG) (Leydesdorff and Etzkowitz, 1996). Moreover, beyond their core roles (of creating, implementing, and integrating knowledge for the public good, respectively), they also support the other sectors, and display functional overlapping (Etzkowitz, 2008; Zhou, 2014). Civil society and the public (as influenced and manifested by media and culture) (Carayannis and Campbell, 2009), as well as nature (Carayannis and Campbell, 2010), are also involved in knowledge and innovation processes as significant elements of the quadruple and quintuple helix models that ensure sustainable development.

The emergence of the above concepts has coincided with the global spread of environmental concerns that require immediate and applicable solutions. The scale and complexity of these threats necessitate the crossing of various boundaries (including those related to knowledge processes). Environmental issues are subjects of interest for numerous stakeholders who must integrate their efforts in order to protect the world (including nature, future generations and economies) from the disastrous consequences of environmental degradation, as part of the sustainable development approach. These endeavours are taken on within environmental conservation science, which today not only aims to understand and change destructive human behaviour, but also focuses on mutual interactions between the biosphere and the human world (Martin et al., 2016; Pooley et al., 2014). Thus, many authors have postulated the need to establish cooperation between environmental researchers and other actors (from different disciplines, organisations or sectors) (Evely et al., 2010; Hirsch Hadorn et al., 2006; Perz et al., 2010; Pohl, 2005; Reed, 2008). When problem-driven research (such as in this area of sustainability) arises not in response to the intellectual pursuits of the science, but to the practical needs of the public (Nowotny et al., 2003), it must be focused on applicable knowledge outputs, while methodological issues are of secondary importance. This encourages a cross-disciplinary approach[1]. Moreover, the societal character of environmental problems of general interest necessitates taking multiple viewpoints into account and developing an understanding of the "common good" concept as shared by various entities (including researchers from different disciplines (Hirsch Hadorn et al., 2006), as well as non-academic stakeholders (Reed, 2008)). Van Opstal and Hugé (2013) have assumed that contemporary sustainable science requires the pluralisation of knowledge, which may be provided, for instance, by the co-production of knowledge via shared learning and collaborative action, collaborative research, and transdisciplinarity. Pohl (2005) has argued that the social utility of the outputs of the environmental sciences specifically requires the participation of social scientists in the research process, while Upreti (1994) specifically mentioned the need to integrate environmental conservation with economic and philosophical approaches. In turn, Evely et al. (2010) stated that the potential outcomes of cross-disciplinary research may create strong connections, not only between researchers, but also between academic and non-academic entities. The active role of practitioners within the research process makes research more accessible, and more likely to be applied in practice. Moreover, stakeholder participation that integrates local and scientific knowledge can increase project sustainability (Reed, 2008).

The systemic cross-disciplinary approach requires cross-sectoral collaboration and the involvement of governmental (including international) and non-governmental entities, as well as business and industrial stakeholders. This explains the necessity for translation from one language, as suited to one discipline, to languages applicable in other disciplines, and of ensuring that the message is understood by the non-academic community. When the holistic approach is applied in the research process, challenges related to determining shared assumptions, methods, problems and objectives arise. We should also remember that stakeholders have different motivations and interests in relation to environmental research projects (Dovers, 2005). These conflicts between perspectives potentially affect the creation, management and recognition of impactful research, and this therefore requires thorough negotiation (Gooch et al., 2017). All this gives rise to a time-consuming research process, which demands a large amount of resources (Zscheischler and Rogga, 2015). In addition, systemic problems sometimes arise (related, for example, to the organisational structures of scientific institutions, the reward systems of research participants, or the funding mechanisms of research initiatives) that may hinder the potential of academic institutions to provide research that transforms society (Whitmer et al., 2010). In turn, Hessels and van Lente (2008) suggested that more studies should be carried out in different national contexts and in different scientific disciplines, as multidisciplinary and application-oriented research does not reveal organisational diversity. This study attempts to fill this gap by analysing the potential of Polish scientific institutions to collaborate across disciplines, as well as to produce scientific knowledge together with various economic entities within the environmental conservation (EC) field.

This paper contributes to studies on knowledge production processes in the context of environmental sciences and is embedded in a specific national context of a science sector in a transitional period. The work uncovers the network structure of research collaboration in multi-respects and considers whether the various methods of

[1] The term "cross-disciplinarity" is used in this paper as a collective term to refer to all research approaches that break with disciplines (multidisciplinarity, interdisciplinarity and transdisciplinarity) (see Evely et al., 2010; Klein, 2020).

knowledge pluralisation (namely cross-disciplinarity, as well as cross-institutional and cross-sectoral partnerships) in research processes are inter-related. These three research characteristics have rarely been considered together. This elaboration is institution-oriented, and enriches the empirical investigation of challenges faced by the Polish science sector within the environmental conservation discipline.

The following section describes the state of the environmental conservation discipline in Poland, as well as the major problems and challenges faced by the Polish science sector. These considerations give rise to detailed research questions. The subsequent section reviews the applied research method. Section 3 is divided into four parts, which analyse the research results obtained and discuss the findings as they relate to cross-disciplinary (3.1), cross-institutional (3.2) and cross-sectoral research collaboration (3.3), and the co-existence of these three structures in EC research in Poland (3.4). The conclusion indicates the future challenges faced by the Polish environmental sciences, presenting recommendations and the limitations of the research.

1. Theoretical background

Environmental conservation, as a cross-disciplinary science, provides information not only on the scientific and technical means for the protection and maintenance of life, but also on the restoration of species, ecological and evolutionary processes, and the environment (Evely et al., 2010). Although this discipline has traditionally been narrowly associated with conservation biology (which focuses on maintaining biodiversity and protecting it from human impact) (Soulé, 1985), in this paper it is understood in broader terms as the endeavour to use natural resources wisely, with a primary concern for nature (Kareiva and Marvier, 2012) (as such, it may also be identified within the term "environmental protection"). EC research covers a wide array of problems (i.e. climate change, pollution, governmental neglect of environmental problems, deforestation due to the development of human settlements, smog in large cities, and others) that are prioritised differently at the global, national and local levels (Skórka et al., 2021). Despite the fact that environmental conservation assumes a non-anthropocentric perspective (in contrast to sustainable development) (Sauvé et al., 2016), the abovementioned problems relate not only to nature itself, but also to processes integrated within daily human life, such as urbanisation, education, policy and consumerism. This is why it should be understood as a for-common-good science, oriented towards the well-being of both human and nonhuman entities (Martin et al., 2016).

Environmental conservation is not a new research area within the Polish scientific community (see, for instance, Dołęga, 2006); however, it was only officially classified as a separate discipline in Poland approximately a decade ago. From 2011 to 2018, it could be identified within three separate domains of scientific systematics: agricultural, biological, and chemical sciences (Rozporządzenie…. 2011). This classification suggests the variety of research methods that are applied within this discipline. Its assignment within separate domains suggests strong specialisation, while the global approach towards the environmental sciences is rather more holistic. Nevertheless, as a result of the most recent reform of Polish sciences and higher education (Rozporządzenie…, 2018), the scientific domains and disciplines are now divided according to the OECD classification (the field in question being Earth and related environmental sciences). However, concern has arisen as to whether this new discipline has already developed its own approach, methods and research language, derived from the different underlying (and more well-established) domains. Hence the first group of research questions (related to cross-disciplinarity): To what extent is environmental conservation research integrated within these three domains in Poland? To what extent is EC interconnected with other parallel scientific disciplines (agricultural sciences, life sciences, formal and physical sciences), as well as with disciplines beyond this specific scientific field (technical, social, medical sciences and humanities)?

The public science system is an essential knowledge and innovation performer in Poland, but it is fragmented, and there is insufficient diversity in institutional missions (European Commission. Directorate General for Research and Innovation, 2017). There are a large number of specialised higher education institutions (HEIs)[2], as well as public research organisations (PROs). The latter include the Polish Academy of Sciences (PAN), which focuses on basic science and competes with universities for employees (as it can award doctoral degrees) and funds, and research institutes that mainly conduct applied R&D and experimental research. The European Commission recommended a consolidation strategy, aiming to establish a few large flagship comprehensive universities (created by incorporating the excellent research potential of all types of Polish scientific institutions) and a modern university of applied sciences (European Commission. Directorate General for Research and Innovation, 2017). Currently, the government encourages HEIs to voluntarily merge through the offer of grants. The science sector in Poland is undergoing a transition, which is why the institutional infrastructure of knowledge processes should be carefully and empirically investigated in each particular field. As such, a second set of questions emerges (about cross-institutional research collaboration): Which type of Polish scientific institution can make the greatest potential contribution to EC? Which entities exhibit better network positions in collaborative research than others?

In recent years, policymakers in Poland have mostly focused on enforcing science–industry linkages by offering grants on the condition of collaboration between partners from these two sectors (Klincewicz and Marczewska, 2017). Polish companies still exhibit the greatest propensity to participate in innovation cooperation with enterprises outside of their own group, but the cooperation of commercial entities (both industrial and service enterprises) and organisations outside of the business sector most often occurs with HEIs (usually domestic ones). Cooperation between the public sector and non-profit organisations is rather low (GUS, 2020). Despite the fact that private sector R&D research is growing, the lack of innovation transfer channels between universities and business, as well as the poor efficiency and effectiveness of intermediary institutions (such as science parks, technology transfer offices, innovation centres, technology incubators and academic incubators), are still noticeable (Wojewnik-Filipkowska et al., 2019). It is also important to consider the extended form of the knowledge production system, which includes not only traditional triple helix sectors (UIG), but also the entirety of the scientific infrastructure (with HEIs and PROs), the commercial sector (with industrial and service enterprises), and non-commercial entities (including governmental and non-governmental organisations (NGOs[3])), when considering environmental issues. As the implementation of the quadruple and quintuple helix model in Poland has not been widely

[2] According to POL-on (an integrated system of information on science and higher education in Poland), in 2021 there were 134 public higher education institutions in Poland (including 20 universities, 18 universities of technology, 6 universities of agriculture/life sciences, 10 medical universities, 5 military universities, 2 maritime universities, and others). Access: https://polon.nauka.gov.pl/opi/aa/rejestry/szkolnictwo?execution=e2s1 (02:16 a.m., 6 May 2021).

[3] The vital role of NGOs in knowledge production has been emphasised by many authors (e.g. Eden et al., 2006; Yoon et al., 2017).

studied (Łącka, 2020), this paper also considers a third kind of question (which applies to cross-sectoral interactions within research collaboration): To what extent does EC research incorporate other sectors (both commercial and non-commercial) in the knowledge production process?

There also arises a final collection of questions that integrate all of the above areas of interest and investigate their interdependence: Are cross-disciplinary research projects also cross-institutional? Do cross-sectoral undertakings occur more often among cross-disciplinary projects than single-disciplinary ones? Do cross-disciplinary initiatives offer better network positions (are they linked with more influential and well-connected institutions)? Only a few authors have considered all these issues together (Cummings and Kiesler, 2005; Hinze, 1999), but none of them have focused on the environmental sciences. As such, this article contributes to uncovering the possible co-existence of these three features of environmental conservation research in Poland, and assesses the possibility of their mutual reinforcement.

2. Methods and dataset

To address all of the above questions, social network analysis (SNA) was applied, as this type of analysis is widely used for cross-disciplinary (Hicks et al., 2019; Uddin et al., 2021; Yang and Heo, 2014; Zuo and Zhao, 2018) and cross-sectoral (Khan and Park, 2013; Yoon et al., 2017) research. Networks were constructed from research grant data taken from the POL-on "scientific projects" database – the central nationwide ICT tool that supports governmental decisions related to the science/research sector, collecting the obligatory report submissions of scientific units located in Poland[4]. The recorded data relate to the research financed by various public funds within the scope of various programmes[5]. POL-on provides a coherent dataset of initiatives with different scopes (international, cross-border, domestic, regional, local) that focus on basic research as well as applied research.

The project-based approach was chosen to reflect the network-like characteristics of research collaboration, despite the fact that bibliometric analyses are more popular (see Hicks et al., 2019; Zuo and Zhao, 2018), even though they reveal certain limitations. Papers are just one of the many possible outputs of research collaboration, and may only be a fragment of more expansive research activity. Moreover, not all of the research participants may be interested in publishing the research results at all, or at least in the same journal (Katz and Martin, 1997), as the profile of a journal may not necessarily reflect the multiple disciplines that contributed to the research process (Uddin et al., 2021). Additionally, the multiple affiliations of a paper's authors may give rise to some ambiguity within the analysis (Katz and Martin, 1997). This is why project data are also used in research collaboration inquiries (Ku et al., 2016; Scherngell and Barber,

[4] Available at: polon.nauka.gov.pl. Data retrieved: 5 May 2021.

[5] In total, 40% of the analysed research projects were funded via the national budget, allocated by the Ministry of Science and Higher Education (Ministry of Education and Science since 2020). These resources were devoted mainly to the maintenance of research capacity and equipment. The contributions of other ministries (such as the Ministry of Environment, the Ministry of Regional Development, the Ministry of Marine Economy and Inland Navigation – all restructured in 2020) are rather marginal, while the European Union (through various initiatives, such as Horizon 2020, Interreg, or Regional Operational Programmes) and the National Research Council (which sponsors basic research projects) made significant financial contributions to EC research. The National Centre for Research and Development, which mainly supports applied research, funded just 6% of the recognised research initiatives. Some of the analysed projects were financed by other sources, such as governmental agencies (e.g. the Chief Inspectorate of Environmental Protection), self-governmental bodies, municipalities, the Visegrad Fund, and others. Source: own elaboration based on POL-on.

2009; Mutz et al., 2015; Uddin et al., 2021). This elaboration is institution-oriented (it does not consider the perspectives of individual researchers) and takes only formal collaboration in the form of a partnership agreement into account. It ensures the participatory involvement of identified institutions, which (as opposed to consulting) incorporates social actors into the knowledge production process (Mobjörk, 2010).

406 research projects launched in 2016-2019 by at least one scientific institution in Poland that were assigned to at least one discipline within the environmental conservation field (out of three possible domains: agricultural, biological and chemical sciences[6]) were identified. A four-year research period was adopted: from 2016 (which was the final year of the period reported by Polish scientific entities as part of their penultimate compulsory evaluation) to 2019 (which was the last year with a complete dataset available). This enabled the collection of up-to-date data, which was as homogeneous as possible and adjusted to the changing regulations for reporting scientific activities.

Two undirected two-mode networks were constructed, the first of which contains research projects within assigned disciplines (P-D network), while the second presents research projects and all partners related to them (P-I network). Subsequently, each network was transformed into a one-mode network via the assumption that all the disciplines (D-D network), as well as all the partners (I-I network), were related to all the others that were assigned to the same research project. Various discreet features were also coded: the assignment of a discipline to a scientific area, the sector of an organisation (science, commercial, non-commercial (S-C-N[7])), the localisation of an institution (domestic, abroad), and the type of institution[8]. The networks were also reduced by some of these features. All network visualisations and calculations were performed with Pajek64 5.11 (Batagelj and Mrvar, 2004). Selected network indicators were identified (Nooy et al., 2011):

- components – a set of graph vertices (subgraph), within which there are direct or indirect connections between all pairs;
- degree centrality (DC) – the degree of a vertex refers to the number of connections between a given vertex and others;
- closeness centrality (CC) – shows that a node has shorter direct and indirect ties with other actors, meaning it has better access to the greater network area and less dependence on others (calculated as the reciprocal of the sum of the length of the shortest paths between the node and all other nodes in the graph);
- betweenness centrality (BC) – identifies critical vertices that could potentially have the most control over flows in the network (calculated as the ratio of the shortest paths between pairs of other nodes that contain this vertex).

Within the I-I network, bi-components were also recognised – sections of a network that are invulnerable to the deletion of a single vertex (as it is internally well connected), which may be connected with other bi-components by cut-vertices whose deletion in-

[6] All the analyses and conclusions relate to systems of science that were in force from 2011 to 2018 in Poland.

[7] The criterion for the distinction was the core mission of each institution type: science – knowledge creation, development and dissemination; commercial – utilisation of knowledge for profit generation; non-commercial sector – utilisation of knowledge for public benefits.

[8] The distinction included: universities, profiled universities (of technology, medicine, life sciences/agriculture, military, maritime), the Polish Academy of Sciences, public research institutes, other scientific institutions, private companies, state-owned companies, government (ministries, governmental agencies), self-government (regional authorities, municipalities, municipal enterprises, development agencies), NGOs (foundations, associations), and other non-commercial organisations.

creases the number of components in the network (linking nodes that create bridging ties) (Nooy et al., 2011).

The Pearson correlation coefficient between two following variables was computed:
- project cross-disciplinarity is reflected by the number of disciplines assigned to a particular research project (recognised as DC of projects within the first bimodal P-D network of projects);
- project cross-institutional collaboration is reflected by the number of partners assigned to a particular research project (recognised as DC of projects within the second bimodal P-I network after multiple line reductions).

Subsequently, the data on cross-sectoral collaboration within a project and the betweenness centrality of a project (calculated within P-I network[9]) were transformed into binary results:
- 1 if a project is cross-sectoral (among participants, there are representatives from at least two sectors) and 0 if not;
- 1 if BC > 0 and 0 if BC = 0.

The odds ratio (OR) was calculated in order to compare the chances of (a) cross-sectoral cooperation occurring and (b) projects being network intermediaries between two groups of identified projects: cross-disciplinary versus single-disciplinary ones.

3. Research results and Discussion

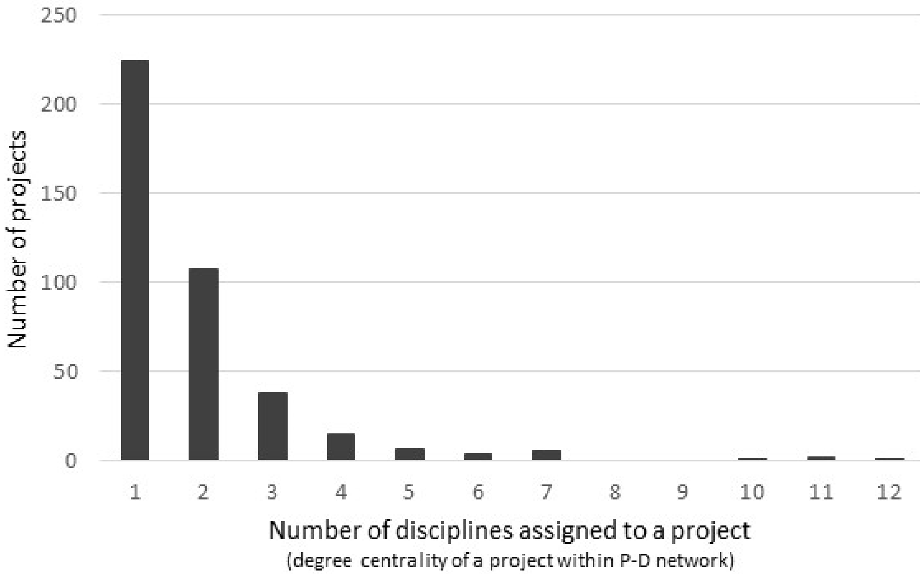
3.1. Cross-disciplinarity of environmental conservation research in Poland

A bimodal network of projects and assigned disciplines was constructed (P-D network). 56 scientific disciplines (including three EC disciplines in agricultural, biological and chemical sciences) that were allotted to the analysed projects via 753 relations were recognised. There were no loops or multiple lines (as the particular discipline may have been assigned only once to a particular project). A network is connected if it consists of one component, as this indicates that there is at least one connection between the projects conducted within the different disciplines.

At this stage, the degree of centrality was calculated in order to determine the most cross-disciplinary initiatives (projects with the largest number of direct connections). The distribution of the degree of centrality for the identified projects is presented in Figure 1.

[9] The betweenness centrality of a project within the bimodal P-I network indicates potential bridges between other nodes in the network, and, as research initiatives cannot be linked directly (but only by participants who take part in other projects too), those with high BC values are conducted by well-networked participants.

Figure 1. Distribution of degree centrality for projects within the P-D network



Source: own elaboration based on POL-on

Among all the 406 projects identified, nearly 45% were assigned to more than one scientific discipline, which means that over half of the environmental conservation research initiatives (224) in Poland are assumed to be of a non-cross-disciplinary nature. The highest DC result for a project was 12 disciplines within a single particular initiative. Only 15 projects (nearly 3.7% of the total) conducted investigations based on environmental conservation in different domains, and in just two cases were all three EC disciplines included (see Table 1).

Table 1. Number of research projects on environmental conservation by scientific domain

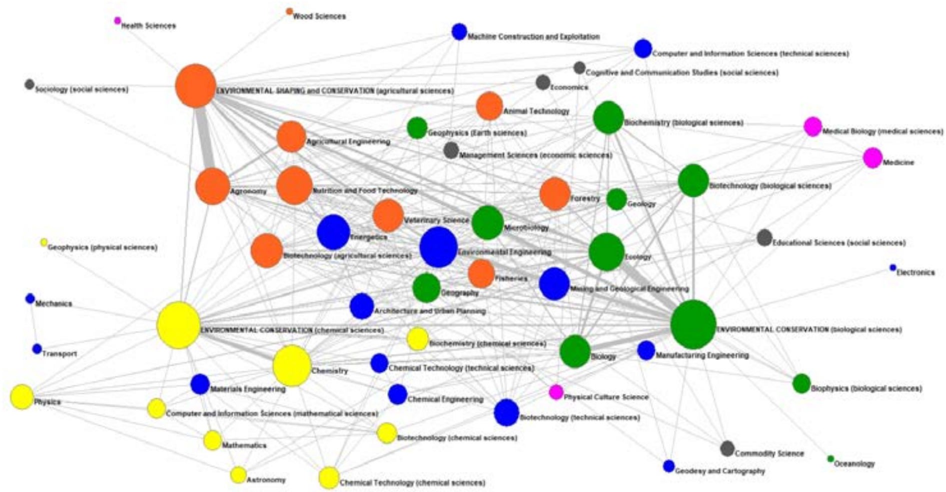
	EC*a**	EC*b**	EC*c**	EC*ab**	EC*ac**	EC*bc**	EC*abc**	Total
Projects with no other disciplines	98	86	40	2	0	2	0	228
Projects with other disciplines	63	72	32	4	3	2	2	178
Total	161	158	72	6	3	4	2	406

Notes: *EC – environmental conservation, *a* – agricultural sciences, *b* – biological sciences, *c* – chemical sciences.

Source: own elaboration based on POL-on

In order to identify the level of interconnectedness between disciplines within EC research, the bimodal network was transformed into a unimodal network of disciplines (D-D network) linked by an assignment to the same undertaking (see Figure 2). 314 relations, including 144 edges with a value higher than 1 (when two disciplines were both assigned to a project operating under numerous research initiatives), were identified.

Figure 2. Cross-disciplinary connections within EC research in 2016-2019 in Poland



Notes: Each colour represents a different scientific area: green – life sciences, orange – agricultural, forestry and veterinary sciences, yellow – formal and physical sciences, blue – technical sciences, pink – medical, health and physical culture sciences, grey – social sciences. The width of lines reflects their values, while the sizes of the vertices reflect the degree centrality of a node

Source: own elaboration based on POL-on

Within the structure, we can see a strong connection between EC in the context of agricultural sciences and Agronomy (classified in the same domain), as these two disciplines coexisted in 43 research projects, while 29 cases involved these two disciplines alone. Similarly, EC in the biological sciences showed a strong relationship (with a score of 33) with another discipline in the same domain (Ecology), similar to the connection shown between EC in the chemical sciences and Chemistry (a value of 16). Technical disciplines seem to be well integrated within EC science, while the medical and social sciences adopt rather more peripheral positions.

Centrality measures (DC, CC, BC) were calculated. Table 2 presents the top 10 highest ranking disciplines.

Table 2. Centrality measures for disciplines involved in EC research within a D-D network (top 10 positions)

Rank	DC	Discipline	CC	Discipline	BC	Discipline
1	38	EC*b**	0.7639	EC*b**	0.2374	EC*c**
2	34	EC*c**	0.7237	EC*c**	0.2247	EC*b**
3	30	EC*a**	0.6875	EC*a**	0.1530	EC*a**
4	27	Environmental Engineering	0.6627	Environmental Engineering	0.0830	Chemistry
5	26	Chemistry	0.6548	Chemistry	0.0565	Environmental Engineering
6	23	Nutrition and Food Technology	0.6322	Nutrition and Food Technology	0.0354	Mining and Geological Engineering
7		Ecology	0.6322	Ecology	0.0298	Ecology

Rank	DC	Discipline	CC	Discipline	BC	Discipline
8	22	Agronomy	0.6250	Agronomy	0.0277	Geography
9	20	Energetics	0.6111	Energetics	0.0179	Agronomy
10	19	Biotechnology*a**/ Microbiology	0.6044	Microbiology	0.0160	Microbiology

Notes: *EC – environmental conservation, *a* – agricultural sciences, *b* – biological sciences, *c* – chemical sciences

Source: own elaboration calculated in Pajek*64 5.11*

Despite the fact that EC in agricultural sciences was included in the highest number of scientific projects, it shows the lowest centrality values among the other EC disciplines in the unimodal network. This suggests that it is not as well connected with various disciplines (as it clearly shows a dominant relation with Agronomy) as EC in the biological sciences, which has shown the greatest capacity to contribute to and integrate knowledge from many different research fields (assessed by its high DC and CC scores). On the other hand, EC in chemical sciences achieved the highest BC rank, suggesting that it is linked to disciplines that are not so closely connected to each other, which increases the opportunity for access to knowledge that is unique (as it introduces peripheral nodes into the network).

The unimodal network of disciplines was limited by scientific area (with the omission of EC disciplines), with the aim of determining the embeddedness of EC research within overarching domains versus other sciences. The values of linkages have been noted (see Table 3).

Table 3. Interconnectedness between EC disciplines and scientific areas

Scientific area	EC*a**	EC*b**	EC*c**	Total
Agricultural, Forestry and Veterinary Sciences	*77*	24	8	109
Life Sciences	25	*94*	18	137
Formal and Physical Sciences	4	6	*34*	44
Technical Sciences	18	24	20	62
Medical, Health and Physical Culture Sciences	2	4	0	6
Social Sciences	7	5	1	13
Total	133	157	81	371

Notes: *EC – environmental conservation, *a* – agricultural sciences, *b* – biological sciences, *c* – chemical sciences. Values in italics reflect interconnectedness between EC disciplines and their overarching scientific areas.

Source: own elaboration calculated in Pajek*64 5.11*

All three EC disciplines analysed are strongly connected to their overarching research areas. A somewhat strong relationship between EC and technical sciences is confirmed. Medical sciences are rarely involved in research on environmental conservation in Poland (only six linkages out of 371).

Discussion on cross-disciplinary EC research collaboration in Poland

Environmental conservation is a discipline that may adopt various scientific perspectives, drawn from different empirical sciences, which may result in ambiguity in the scientific discourse between researchers in the context of the new classification of science in Poland, as the integration of EC disciplines in the areas of agricultural, biological and chemical sciences is unclear. The marginal share of research initiatives that include all three disciplines suggests future problems in this regard. On the other hand, the strong connections with disciplines similar to agricultural and life sciences (especially biological ones) (cf. Uddin et al., 2021) provide Polish scientific institutions with the experience of working with methods and techniques that are common within those other research areas.

Nevertheless, environmental conservation, as a discipline aimed at ensuring sustainable solutions, should incorporate not only values related to the preservation of the biosphere, but also economic and social values related to human health and well-being (Hirsch Hadorn et al., 2006). This is why all such sciences (biological, economic, social, medical and humanities) should be integrated. In Poland, this integration between EC and social sciences is noticeable, though not very strong (especially in comparison to technical disciplines). This finding is similar to results achieved in Slovenia (Rodela and Alašević, 2017), which may suggest that it is characteristic of Central and Eastern European countries. Some connections with social studies were noted, such as Sociology, Cognitive and Communication Studies and Educational Sciences, along with economic disciplines such as Management Sciences, Economics and Commodity Science, which offer a better chance to develop solutions that could be applied in a particular social and business context, with the use of appropriate communication and education channels or techniques. However, there is a lower probability of the research results being adopted and applied in practice by politicians, administrators, or the wider community (as no EC research projects have been formally conducted within Politics, Law and Legal Studies, or Cultural Studies). EC scientists also do not tend to show the kind of development approach, as suggested by Upreti (1994), that takes moral issues into account while solving EC problems (the lack of linkages between EC and humanities), thus seeking to avoid the dominance of a purely quantitative approach that only values environmental issues. Moreover, the very low input of medical sciences into EC research shows the lack of research initiatives focused on health issues related to environmental problems. Considering environmental and health issues separately may lead to conflicting views and contrary interests, but integrating these sciences in joint research projects may have a greater impact on the common good (Chan, 2019; Leemans, 2005).

My study reveals a clear relationship between all EC disciplines and technical sciences, with a dominant position held by Environmental Engineering. The growing importance of new technologies makes such connections inevitable. The emerging concept of Society 5.0, which incorporates solutions such as the Internet of Things, Big Data analytics, and artificial intelligence into industries and social activities to achieve both economic development and respond to social challenges (Keidanren, 2016), may accelerate and strengthen research collaboration between environmental and technical sciences. Technology offers opportunities to support environmental sustainability systemically and on an unprecedented scale, as it can be efficiently used to monitor and expand environmental compliance and control, improve the required resources, and determine environmental and social costs (Berawi, 2019).

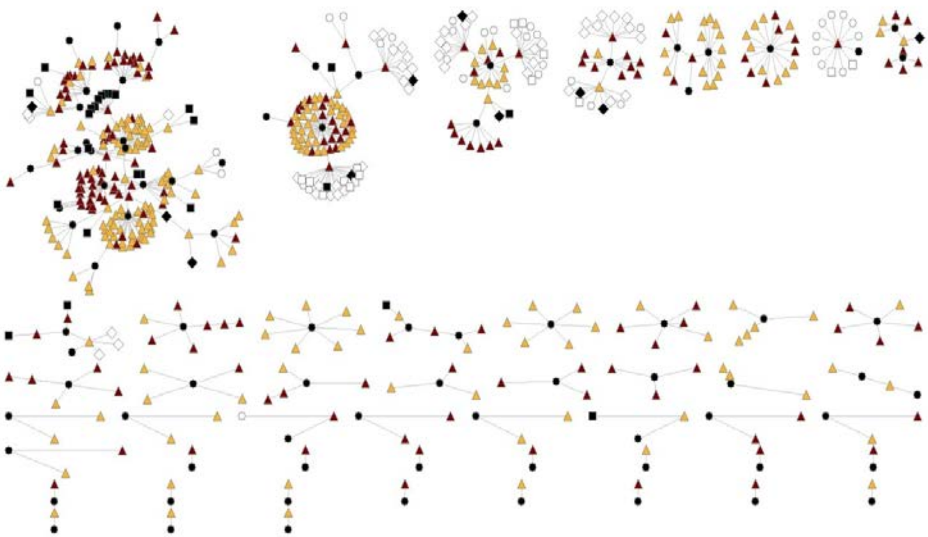
Above all, we need to remember that problem-driven research undertaken within EC is characterised by pressure to produce usable results (see: Pohl, 2005), which leads to the prioritisation of collaboration within applied disciplines, such as those prescribed to technical sciences. This need to find solutions to urgent environmental concerns may lead to a disinclination to collaborate across disciplines, as it lengthens the research process and makes it riskier.

3.2. Cross-institutional research collaboration on environmental conservation in Poland

A bimodal network of research projects in EC and their institutional participants has been constructed (P-I network). It identifies 212 partners, including 116 domestic and 96 foreign entities. The network contains 580 edges and eight multiple lines. These occur when two or more organisational units (e.g. different faculties from the same university) co-participate in the same project.

There are as many as 51 components, and the largest covers only 34.6% of the network (see Figure 3). The structure is dispersed, as only a small number of organisations create a research community within EC projects. In turn, there are many cases wherein a single scientific institution conducts many projects (of a single- or cross-disciplinary nature) on its own, which may be a result of intra-organisational collaboration between researchers. In total, 18 unconnected components showing a relationship between a single institution and a single EC project were recognised (of which eight projects were single-disciplinary and 10 were cross-disciplinary).

Figure 3. Bimodal network of environmental conservation research projects and their institutional participants

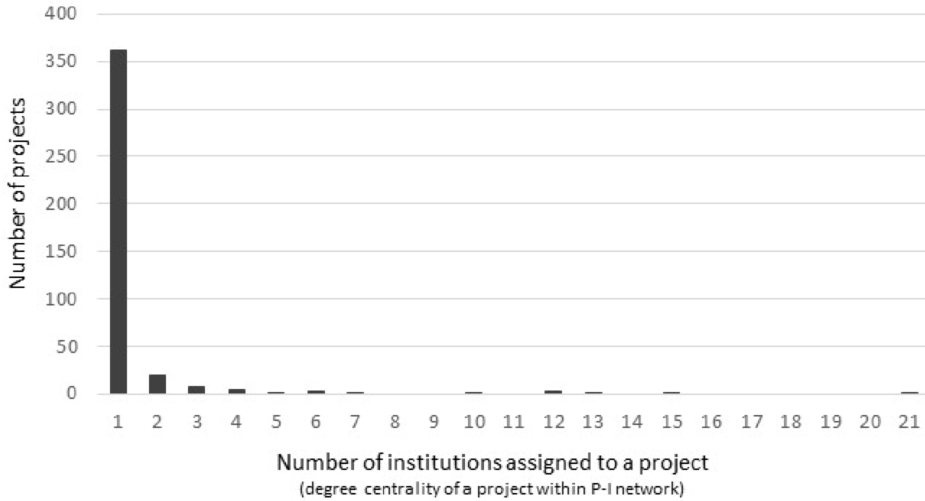


Notes: Shapes and colours represent different discreet features of nodes. Triangle – research project, yellow – single-disciplinary project, brown – cross-disciplinary project, circle – science, square – commercial sector, diamond – non-commercial sector, black – located in Poland, white – located abroad.

Source: own elaboration based on POL-on

The degree of centrality was calculated (after multiple line reduction) in order to identify projects with the largest number of participants (DC of projects; see Figure 4).

Figure 4. Distribution of degree of centrality for projects within the P-I network



Source: own elaboration based on POL-on

As many as 361 projects were conducted by a single institution, while 20 projects were conducted in a partnership of two entities. Fewer than 6% of EC research initiatives involved three or more partners. The most populous project had as many as 21 partners (including 18 foreign entities) and was sponsored by the European Commission via Horizon 2020 (Marie Sklodowska-Curie Actions). Polish scientific institutions usually conduct numerous EC research projects, but just a few of them are cross-institutional.

More than half of all Polish scientific institutions involved in publicly sponsored EC research participated in at least three such undertakings that were launched within the four-year period covered by the study, while nearly 36% of them participated in a single EC research initiative.

The bimodal P-I network (with multiple lines) was transformed into a 1-mode network (I-I network), which presents the linkages between partners collaborating within EC research projects. Recognised institutions are linked by 813 lines in total, including 11 edges with a value higher than one (when a pair of entities participated together in more than one EC research project). Three loops were also observed (as multiple lines, revealing formal intra-organisational collaboration, were changed into loops after transformation from the bimodal into the unimodal network). In this case, 51 components were also distinguished, and the largest contained 48 entities (covering less than 23% of the recognised network). Centrality measures were calculated after the reduction of multiple lines and loops (see Table 4).

Table 4. Centrality measures for institutions involved in EC research within the I-I network (top five positions)

Rank	DC	Institution	CC	Institution	BC	Institution
1	32	University of Agriculture in Cracow	0.1557	University of Agriculture in Cracow	0.0266	Warsaw University of Life Sciences
2	24	Institute of Environmental Protection (National Research Institute)	0.1382	Warsaw University of Life Sciences	0.0196	Institute of Technology and Life Sciences
3	22	Warsaw University of Life Sciences	0.1344	Institute of Environmental Protection (National Research Institute)	0.0170	Institute of Environmental Protection (National Research Institute)
4	20	City of Warsaw* / Iznab sp. z o.o.*	0.1223	Institute of Technology and Life Sciences	0.0162	The Institute for Ecology of Industrial Areas
5	18	Gdansk University of Technology	0.1185	The Institute for Ecology of Industrial Areas	0.0154	University of Agriculture in Cracow

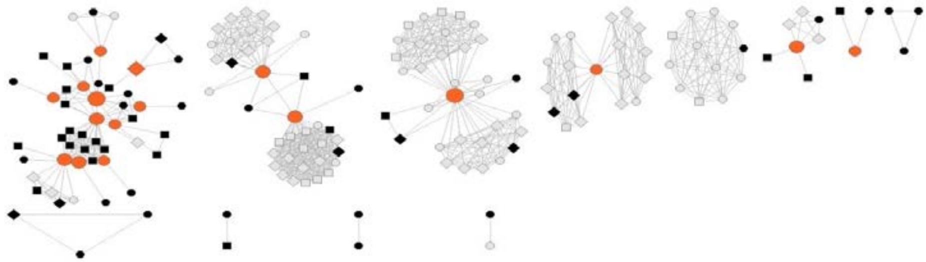
Notes: *The same position in the rankings (with DC of 20) was taken by numerous foreign institutions that participated in the same cross-institutional project, but which were not mentioned in the table.

Source: own elaboration calculated in Pajek*64 5.11*

In total, 39 scientific institutions did not collaborate with any other institution in EC research projects in 2016-2019 (unconnected nodes with DC of 0), and showed no CC at all. The top five institutions in terms of centrality measures in the I-I network include non-scientific entities that participated in the most populous project (mentioned above), which included municipalities, innovative enterprises, as well as scientific associations and foundations.

The University of Agriculture in Cracow exhibits the highest potential access to participants in EC research projects, as it is linked to as many as 32 entities, and these connections are direct in all cases (the path is shortest), which ensures a high CC value. The participation of this HEI in three international projects (out of four conducted in partnership) introduces the university into a multi-institutional research community. However, the greatest access does not guarantee the greatest potential control over knowledge flows, as the partners are also strongly linked to each other, and are not linked with further parts of the network. The best BC measure is shown by the Warsaw University of Life Sciences, which is directly connected with fewer partners (22), but took part in five inter-organisational research initiatives (of domestic and local scope). It is a critical node in a larger component, and connects other intermediaries in this part of the recognised network. Nevertheless, within the entire network, we may recognise only 17 intermediaries that show BC scores higher than 0, and these also show cut-vertices, which link the bi-components within the network (see Figure 5).

Figure 5. Cut-vertices within the I-I network with location distinction



Notes: The colour orange represents cut-vertices. The colour black represents domestic entities. The colour grey represents foreign entities

Source: own elaboration based on POL-on

In general, 36 HEIs of different types from Poland and 39 domestic PROs were included in the entire network (see Table 5). There is a degree of balance between the two types of scientific institutions involved in EC research projects. Furthermore, among the entities that seem to be the most significant within the I-I network (recognised as cut-vertices), HEIs (four included in agriculture or life sciences, three universities of technology and two comprehensive universities) and PROs (five research institutes focused on applied sciences, and two institutes of the Polish Academy of Sciences) were recognised. This could indicate that in Poland, EC issues are covered by both basic and applied research, but the funding sources (see footnote 5) suggest the dominance of the former (as a minority of projects are financed by the National Centre for Research and Development, devoted to supporting applied sciences).

The only non-scientific organisation that links to different parts of the network is WWF Poland.

Table 5. Number of scientific entities involved in EC research launched in 2016-2019

	Domestic	Foreign	Total
HEIs, incl.:	*36*	*20*	*56*
universities	16	12	28
universities of agriculture/life sciences	6	4	10
universities of technology	10	4	14
military universities	1	0	1
maritime universities	2	0	2
medical universities	1	0	1
PROs, incl.:	*39*	*9*	*48*
public research institutes	26	9	35
Polish Academy of Sciences	13	0	13
other scientific institutions	*6*	*6*	*12*
Total	**81**	**35**	**116**

Source: own elaboration based on POL-on

Discussion on cross-institutional EC research collaboration in Poland

The study has been conducted from a scientific perspective, as the scientific sector (especially the universities involved) is said to be a platform for research that transforms society (Whitmer et al., 2010). In this regard, the educational role of the higher education sector may expand the role of collaborative research in developing sustainable communities (Crilly et al., 2020). Among the various universities involved in EC inquiry in Poland, the most active are those listed under agriculture or life sciences. This potentially limits the opportunity for research across broad scientific fields to be conducted via internal collaboration in large multidisciplinary universities (as well as after merges), and could undermine the role of such institutions in this discipline. On the other hand, such comprehensive (non-profiled) universities are the most common type of HEIs present in the analysed networks. The consolidation of the higher education sector has been a trend in Poland in recent decades (Sułkowski et al., 2019), but the roles of leading large universities in creating formal cross- and intra-institutional research around environmental conservation are not significant (I observed only three organisations with formal internal relations between their different units – two universities of technology and one university of agriculture). This could also support the assumption of Evans (2017), who argued that consolidation does not necessarily guarantee more effective research collaboration.

Within environmental conservation, the greatest contribution (understood as participation in numerous research initiatives at an institution) is made by scientific units specialising narrowly in this field, including relevant industrial research institutes (mostly supervised by ministers responsible for the environment and climate, as well as for agriculture and rural development in Poland). This is why inter-organisational relations seem to be necessary in order to ensure a diverse approach to environmental problems. However, despite this demand, nearly half of the Polish scientific institutions (48%) that conducted research on EC in the study period did not formally collaborate with any other organisation. Many network actors gain experience in numerous single-organisational EC research projects, and rarely sign cross-organisational agreements. This may be due to the costly and time-consuming requirements of coordination, which are even more problematic than within cross-disciplinary initiatives (Cummings and Kiesler, 2005).

EC research in Poland does not seem to be an institutionally integrated environment. Of the numerous components, we may recognise only one with a few intermediaries that participate in several projects with different partners, and who may potentially combine this experience and thus introduce the opportunity to be exposed to a plurality of thought, work, and formal collaboration styles. Gaining good experience in this matter will help with compound research in the future, and, according to Pohl (2011), it may ensure the progress of transdisciplinary and cross-sectoral collaboration (although this has not been confirmed by this study). On the other hand, the greatest component includes few foreign entities (only three out of 12 intermediaries co-participated in EC studies with foreign partners), and encompasses numerous domestic companies, suggesting that this research community is embedded in the local environment and focused on practical problems.

3.3. Cross-sectoral environmental conservation research partnership in Poland

Among the 45 EC scientific projects that were carried out in the partnership, 28 included at least one non-scientific partner (commercial or non-commercial), but only five were conducted with representatives of all three sectors. The numbers of single- and cross-disciplinary projects that involved non-scientific partners are equal (see Table 6). More cross-sectoral projects were conducted with businesses.

Table 6. Collaboration between sectors by type of project (single- vs. cross-disciplinary)

	Included sectors			
Type of project	***S-C***	***S-N***	***S-C-N***	**Total**
Single-disciplinary	7	4	3	14
Cross-disciplinary	8	4	2	14
Total	**15**	**8**	**5**	**28**

Notes: S – science, C – commercial sector, N – non-commercial sector

Source: own elaboration based on POL-on

Despite the higher number of science–business projects, more institutions in non-commercial sectors were noted within the network as a whole (see Table 7), because many of them are involved in multi-organisational initiatives.

Table 7. Number of non-scientific entities involved in EC research launched in 2016-2019

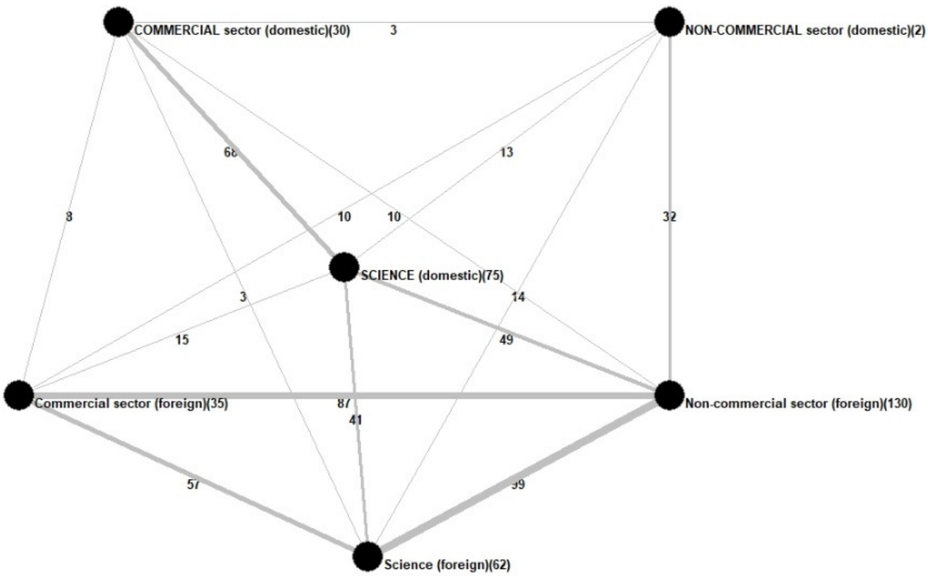
	Domestic	**Foreign**	**Total**
Commercial sector	25	15	40
private companies	24	14	38
state-owned companies	1	1	2
Non-commercial sector	**10**	**46**	**56**
government	1	5	6
self-government	4	18	22
NGOs	3	20	23
other non-commercial organisations	2	3	5
Total	**35**	**61**	**96**

Source: own elaboration based on POL-on

Most institutions from the non-commercial sector (especially self-government and NGOs) are from foreign countries. Among domestic non-scientific institutions that were official partners in EC research projects, the commercial sector is still predominant.

The 1-mode I-I network has been shrunk in order to identify the total number of relations between specified sectors (see Figure 6). Intra-sectoral linkages (loops) are presented in parentheses.

Figure 6. Shrunken network of cross-sectoral relations



Source: own elaboration based on POL-on

Polish scientific institutions develop more partnership relations with domestic companies (68) than with non-commercial organisations located in Poland (13), while the opposite is true for the linkages of foreign science sectors identified within the network. The weak involvement of domestic non-commercial entities in EC research collaboration is visible, as only two internal connections within this sector were noted, and there is a gap between these entities and Polish companies (only three linkages in total). This suggests that local scientific initiatives in the field of environmental conservation rarely bring together representatives of various stakeholder groups in particular research projects.

Discussion on cross-sectoral EC research collaboration in Poland

The scientific community in Poland establishes cross-sectoral relations in commercial and non-commercial sectors separately. The insufficient formal involvement of non-commercial institutions in EC research processes in Poland may be due to the roles they usually assume. According to Kronenberg et al. (2016), this wasted collaboration potential may be typical of post-transition countries, characterised by an unwillingness to cooperate with public institutions – who play the role of principals and delegate tasks to other actors – and domestic NGOs, who prefer to be independent watchdogs and prioritise environmental issues instead of being involved partners. This passive approach of non-commercial entities to research processes limits the opportunity for knowledge pluralisation. This sector reveals the pragmatic attitude of authorities, as well as of NGOs representing not only environmental but also business interests (Eden et al., 2006), who could contextualise and democratise knowledge production processes. Fortunately, the domestic non-commercial sector has developed more relations with foreign non-commercial institutions, and can thus gain experience in cross-institutional research collaboration related to environmental issues within the international community, which brings the hope of further public involvement in not only the appraisal, but also the creation, of EC research in future.

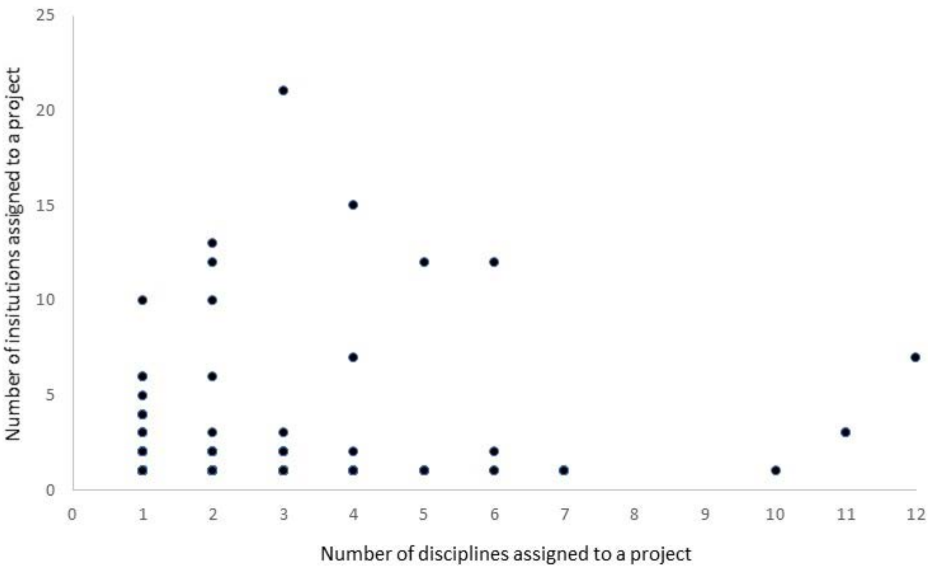
Above all, cross-national EC research projects integrate all three analysed sectors to a wider extent than domestic ones (four out of five projects that involved representatives of all three S-C-N sectors were international in scope). Additionally, the greatest share of non-commercial institutions (especially NGOs and local authorities) is visible. This may be caused by the conditions of European grant programmes.

Domestic cross-sectoral relations suggest that EC research carried out by Polish scientific institutions is more firmly embedded in business practice than in the social and political context. This gives rise to the assumption that research related to *Environmental Conservation* is subordinated to the economic and often short-term objectives of companies, with disregard for the wider impact on local communities and society as a whole.

3.4. Relations between cross-disciplinary, cross-institutional and cross-sectoral characteristics of environmental conservation research in Poland.

A weak relationship between the number of disciplines and the number of partners assigned to a particular project (N=406) was identified (Figure 7) with the use of the Pearson correlation coefficient ($r= .19$, $p< .001$).

Figure 7. Scatter plot of relations between the number of disciplines and number of partners assigned to an EC research project



Source: own elaboration based on POL-on

The value of this dependency indicator is lower than that presented by Cummings and Kiesler (2005), which was $r = .29$. This is why these two features of research projects on environmental conservation should be scrutinised separately (see Rip, 2002, p. 104). These results undermine the assumption of Mode 2 as a coherent concept, as presented by Gibbons et al. (1994; cf. Hessels and van Lente, 2008; Rip, 2002). The presented study has revealed that there is a great deal of cross-disciplinary research related to environmental conservation in Poland that is not characterised by organisational diversity, understood as formal partnerships in the research process. Although Stokols et al. (2008) suggested that institutional support for intra-departmental and inter-university collaboration, via modifications to organisational structures and administrative routines, would influence transdisciplinary team effectiveness, it is not certain whether these two types of collaboration would be equally effective. The lack of clear co-existence of cross-disciplinary and cross-institutional research suggests that there are no common characteristics of research initiatives that could facilitate these two types of collaboration to the same extent.

In general, more cross-disciplinary initiatives (182) were identified than projects conducted in cross-institutional partnerships (45), which may result from coordination, which is much more problematic within research conducted across various organisations than across disciplines (Cummings and Kiesler, 2005). Cross-institutional collaboration is a more demanding and cost-consuming practice, as it requires the arrangement of various forms of communication and travel, while cross-disciplinary research may be the result of the internal diversity of interests of the researchers employed in the same scientific unit (see Zuo and Zhao, 2018), who may develop their communication in a more informal way. Additionally, Hinze (1999), who investigated scientific collaboration related to autoimmune diseases, assumed that research of an intra-organisational nature (manifested by paper co-authorship) more often crosses disciplinary boundaries than inter-institutional studies. That is why, according to Cummings and Kiesler (2005), multidisciplinary projects have better outcomes if carried out by a single university.

As the linear dependency between these two project characteristics is very small, binary data were applied in the subsequent step (see Table 8). Two odds ratios (OR) within two groups of projects (cross-disciplinary and single-disciplinary) were calculated for (OR_a), the occurrence of cross-sectoral projects, and (OR_b), the occurrence of intermediary projects (identified by BC>0).

Table 8. Number of cross-sectoral projects and projects with BC>0 among cross- and single-disciplinary EC research initiatives in Poland launched in 2016-2019

			Cross-sectoral project		BC>0	
		N	*Yes*	*No*	*Yes*	*No*
Cross-disciplinary project	*Yes*	182	14	168	21	161
	No	224	14	210	16	208
	Total	406	28	378	37	369

Source: own elaboration based on POL-on

The likelihood of the project revealing cross-sectoral research collaboration was 25% higher in the case of cross-disciplinary projects than in single-disciplinary ones (OR_a=1.25; 95% CI=0.58:2.69), while the likelihood of projects showing intermediary characteristics (BC>0) was 70% higher in the group of cross-disciplinary research projects (OR_b=1.70, 95% CI=0.86:3.35). Although both OR indicators suggest there is a higher chance of two analysed project features occurring among cross-disciplinary projects (intermediary projects more so than cross-sectoral), the wide confidence intervals make the results ambiguous (with the high probability of results that can be interpreted as contradicting those presented above). Thus, this study does not confirm the significant influence of project cross-disciplinarity on the occurrence of analysed project characteristics (both cross-sectoral collaboration and intermediary potential).

Discussion on inter-relations between cross-disciplinary, cross-institutional and cross-sectoral EC research collaboration in Poland

In view of the above, I assume that cross-sectoral projects are undertaken mainly due to the practical demands of their beneficiaries, rather than being initiated by the disciplinary diversity of the research undertaken. The heterogeneity of the disciplines may introduce the need to search for appropriate points of reference from beyond science, in order to develop a common platform of communication that functions in practice. However, the present study cannot confirm such a situation. Pohl (2011) argued that the experience of thought pluralisation, which is present in cross-disciplinary discussions, shapes the specific approach of researchers, which may enhance their ability to collaborate with others. However, this ability is not systemic or characteristic of institutions, and seems to be significant only at the individual level.

Additionally, projects with a more influential network position (realised by cut-vertices of the I-I network) are not clearly characteristic of cross-disciplinary initiatives. Institutions that participate in numerous EC studies and create a coherent scientific community in the environmental conservation field in Poland do not necessarily focus on cross-disciplinary investigation. Thus, operating in various disciplines when searching for solutions to environmental problems is not the most significant factor prompting Polish institutions to undertake intensive processes of creating an inter-organisational community (and to take influential network positions) for the sake of knowledge production in the field in question.

Conclusions

Environmental conservation, which has been developed in Poland within different scientific domains in recent years, now faces the urgent need to construct shared paradigms and definitions, and to achieve standardisation in research methods within a newly classified discipline, namely Earth and related environmental sciences. This may pose a particular challenge, as Polish researchers do not have a wide range of experience in conducting initiatives that would reconcile separate EC perspectives within the agricultural, chemical and biological sciences. However, there are numerous linkages with neighbouring disciplines (also noted by Mutz et al., 2015; Rodela and Alašević, 2017; Uddin et al., 2021), which makes the work easier, as scientists use the same words and labels, and share their meanings (Sauvé et al., 2016). Nevertheless, there is a need to avoid the partition of the environmental sciences in Poland, and to stimulate the creation of an academic community around environmental issues, which could articulate standards of excellence, evaluate research outcomes, and promote the best practices of successful cross-disciplinary research. Public symposia that bring together researchers with various backgrounds, trial grants, and considerations of the risks associated with cross-disciplinary collaboration during faculty assessments for promotion, may together constitute strong institutional support. Such a coherent academic community is necessary for a thorough peer evaluation and review process, which will be constrained if it is conducted across disciplines (Whitmer et al., 2010). Moreover, one may observe that pressure is being put on the environmental sciences to combine with the social sciences (Hirsch Hadorn et al., 2006; Kracher, 2000; Pooley et al., 2014). Connecting scientific knowledge with societal practices is intended to enhance the implementation of problem solutions. As stated by Kowalczewska and Behagel (2019), policymakers in Poland sometimes use scientific knowledge instrumentally in their decision-making processes, which is why formulating complementary environmental, economic and societal concerns, which accord with sustainable development, may be the only way for conservation interventions to have a real environmental impact.

The institutional structure of environmental conservation research in Poland may be a source of some risk. Among the Polish scientific institutions involved in conservation research, entities profiled in agriculture or life sciences (universities as well as research institutes) hold the most influential positions within this discipline, as their centrality measures offer the highest results. These organisations reveal the ability to conduct cross-institutional collaboration, but their profile nature limits the opportunities available to conduct scientific practice on environmental issues across different domains. A concern about the financial dependency of some PROs that are supervised and sponsored by governmental bodies has also emerged, which may promote the demand-driven production of the environmental sciences (Kowalczewska and Behagel, 2019). Furthermore, industrial research institutes are fairly well represented within the population of scientific entities that conduct investigations on EC, and show cross-sectoral collaboration with business, which suggests the applied nature of the conducted research, while the main state agency responsible for financing such initiatives financed only 6% of the studied projects. In this context, the European Commission's recommendation of creating a federal university of applied sciences is worth considering, as is a wider proposal of grants funded by the National Centre for Research and Development, which would promote cross-institutional (or even cross-sectoral) initiatives focused on local environmental issues.

The insignificant role of multidisciplinary universities within the EC research collaboration network may be due to the fact that such collaborations often take place within organisational boundaries and are rarely formally established (this paper reported just a few cases of formal partnership agreements between different organisational units of a scientific institution, each within a profiled HEI), which makes it difficult to analyse and manage them from the institutional perspective. The creation of systemic enhancements that will institutionalise internal research collaboration within universities has been recommended, as this would help to measure, assess and form research groups (Kotsemir and Shashnov, 2017) under comprehensive institutional strategies.

Cross-disciplinarity does not constitute a sufficient stimulus to undertake cross-organisational or cross-sectoral collaboration within the field of environmental conservation. Rather, it results from informal internal interactions. Therefore, universal practices that could be undertaken by scientific institutions in order to affect these two aspects at the same time do not exist. Even initiatives that are carried out by critical network nodes (those with experience in working with different, unique entities) will not necessarily be cross-disciplinary. This inter-organisational collaboration does not result in a multidisciplinary approach. Disciplinary similarity or dissimilarity is ignored here in the selection of a partner. That is why these two characteristics of Mode 2 (Gibbons et al., 1994), namely cross-disciplinarity and cross-institutional collaboration, should be considered separately (Hessels and van Lente, 2008; Rip, 2002). The basic science, which is usually developed at multidisciplinary universities, increasingly requires knowledge pluralisation in order to solve compound environmental problems, while the applied sciences must adopt various stakeholders' perspectives in order to ensure the broad global impact of conservation research on society. Thus, different mechanisms (including public funding) should be proposed to support those processes. Nevertheless, subsequent proposals for further investigations into EC research collaboration (both basic and applied) have arisen in this context.

The presented study is project-oriented, presented from an institutional perspective, and based on a formal partnership. All of this has been justified above but does demonstrate some limitations. The cross-disciplinarity assessment was based on declarations taken from the grant applications of the research initiatives listed in a national database, which do not necessarily reflect the discipline orientation of scientific publications or researchers' scientific interests or affiliations; it also ignores the factual engagement of disciplines, which could change during the research process. Such discipline assignments made in advance may not be entirely coherent with the practices undertaken later (see Rodela and Alašević, 2017). Moreover, researchers are not always aware of crossing disciplinary boundaries, and the grant application content may be determined by the conditions of the grant offer. This is why future research should include qualitative methods of cross-disciplinarity appraisal. It should also be noted that the inquiry does not take into consideration the bilateral relations between the commercial and non-commercial sectors, or their direct linkages with foreign entities that do not cooperate with domestic research institutions. This determines the egocentric nature of the presented network, which limits the inferences that can be made in the context of Poland alone, and from the perspective of the science sector.

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