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Innovation in a heterogeneous CCS research centre, managerial and organizational challenges.

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Abstract

Recently, the Norwegian authorities have established a number of Centres for Environment-friendly Energy Research (CEER), intended to develop new knowledge, foster breakthrough technology and promote innovation in order to solve specific challenges in the field of energy and environment. The expectation is that these heterogeneous, multipartner research consortia will lead to excellent academic performance and at the same time, that the new knowledge is of such nature that it can be exploited for practical and commercial purposes. This paper suggests that the adoption of two concepts of knowledge production, denoting knowledge produced in an academic context and in a context of application, respectively. These concepts, referred to as Mode 1 and Mode 2 knowledge production, open up for insight and implications about the challenges inherent in the CEER scheme. Our key argument is that in order to move our understanding of innovation in heterogeneous research collaborations, research efforts should be seen as concurrent processes of problem solving around scientific and practical problems. The main management challenge identified is the need to perform well as a manager of basic research and at the same time, lay the groundwork for innovation, that is, to lead according to differing expectations. Our claims are based on an empirical example, drawn on the CEER Centre BIGCCS.

Keywords: International R&D consortium collaboration, Knowledge production, Innovation, CO2 value chain

1 Introduction

Successful innovation depends on many processes of knowledge production which are distributed over various settings [1]. Although the research on the management of such collaborative innovation efforts is extensive, focus is generally on performance seen from the perspective of individual companies or research institutes. However, in more recent studies on knowledge production, it has been argued that science systems are changing into more interactive and 'socially distributed' systems [2]. This is reflected in the increasing demand in European research councils for research consortia composed of partners from different research institutes, universities, private and public companies, and representing different nations. To the best of our knowledge, the dynamics of such heterogeneous collaborations and the managerial challenges in terms of innovation have, however, been explored only to a limited extent [3-6].

The current problem is related to the establishment of a number of Centres for Environment-friendly Energy Research (CEER) by the Norwegian Authorities, intended to develop new knowledge, foster breakthrough technology

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and promote innovation in order to solve specific challenges in the field of energy and environment. One of the prioritized areas is research on Carbon Capture and Storage (CCS). In 2009, an International CCS Research Centre (BIGCCS) aiming at extending and releasing the potentials for large scale deployment of CO_2 capture and storage was granted CEER status [7]. The authors of the present paper are members of the Centre Management Group for the BIGCCS Centre. As such, they are given a unique opportunity to learn about important aspects of heterogeneous, multiorganizational collaborations as a basis for innovation, and about the management of such processes. Thus, this paper explores experiences from the BIGCCS Centre efforts as observed from 'within' the ongoing processes [8].

The present research is based on a view that knowledge and innovation processes are emerging and evolving in the interplay between interdependent individuals representing different organizations, fields, interests and commercial considerations [9]. The particular focus in this paper is the management of what could be seen as heterogeneous, transdisciplinary processes for the development of new knowledge. To approach the current problem, the paper explores the relevance of two concepts of knowledge production, denoting knowledge produced in an academic context and in a context of application, respectively. The concepts are Mode1 and Mode 2 knowledge production, originally introduced by Gibbons et al. [10]. Among the main challenges is the question about the actual transformation of research results into both environmentally and commercially valuable solutions, i.e. innovation, and the possible part of the BIGCCS Centre in these processes. We have chosen to emphasize what we see to be an important, yet less explored aspect of innovation management, which is the management of differing expectations. Our key findings, which are discussed in section 6, are the consequence of purposive reflection on own experiences as well as on accounts of various events given by other BIGCCS participants. Before we go into the discussion, we provide a brief review of the established literature on Mode 1/Mode 2 knowledge productions. Next, we will present the methodological orientation adopted, the specific research approach, and the BIGCCS International Research Centre. In conclusion, we outline some of the possible practical implications of our findings.

2 Perspectives on knowledge production

Current development towards increasingly more complicated and interdependent technologies and processes has led to a demand for cooperation across organizational, geographical, and professional boundaries. Simultaneously a view has emerged that innovation no longer can be seen as processes taking place within the boundaries of a single company [11]. A now widespread idea is therefore that innovation develops within an innovation system [12], embracing a complex set of relations between actors in various companies, universities and public research institutes. In the wake of these developments, a notion of 'open innovation' has emerged. The concept was coined by Chesbrough [13], and involves a particular focus on collaborative structures and on the subject of intellectual property rights. His idea is that organizations can and should explore external knowledge sources as a supplement to employees' competence in all parts of their innovation processes. The suggested benefits of this approach are increased innovation in selected areas, fewer bad investments and extended markets and market channels for new products [13]. An underlying assumption in the open innovation thinking appears to be that the knowledge needed for any purpose is available in an open market, and may, at some cost, be exploited by any company. As will be discussed in section 6, the CEER scheme could be seen as a way to organize such 'markets of knowledge', open to collaborating members.

While the ideas of open innovation are developed with a focus on the potential benefits for individual companies, another area of research exists, which is based on the more general recognition that the science system is getting more oriented towards strategic goals and the production of relevant knowledge [2, 10, 14]. The concept of Mode 2 knowledge production was introduced by Gibbons et al. [10] to denote '*knowledge produced in the context of application, by so-called transdisciplinary collaboration*' [2, p.740]. Transdisciplinarity is defined as a form of research that is driven by the need to solve real-world problems [4]. This is conceptualized as 'contextualized science', and explained as a situation where society 'speaks back' to science [2]. Important factors promoting this idea are the multiplication of user-producer interfaces, the introduction of new regulatory regimes, and increasing demand for innovation.

The basic claims related to the Mode 1 and Mode 2 knowledge development concepts can be summarized in table 1. As can be seen from the table, Mode 1 is used to denote the result mainly of work in scientific institutions, while Mode 2 knowledge is shaped by broad specters of intellectual, social, and also commercial needs. Mode 2 knowledge production can therefore be understood as being more complex than a traditional Mode 1 knowledge production. It should be emphasized, however, that Mode 1 knowledge production is not viewed as a perspective of the past. Rather, the concepts of Mode 1 and Mode 2 knowledge production are interpreted as concurrent processes.

Table1.Mode 1 and Mode 2 knowledge production [10]

Mode 1	Mode 2
Academic context	Context of application
Disciplinary	Transdisciplinarity
Homogeneity	Heterogeneity
Traditional quality control (peer review)	New forms of quality control
Autonomy	Reflexivity

As shown in the table, Mode 2 knowledge production is characterized by five main attributes. The first two are already mentioned, and include knowledge being generated in a context of application, by the collective effort of transdisciplinary teams mobilizing a range of theoretical perspectives and practical methodologies to solve problems. Next, knowledge production and resulting practices are heterogeneous. This involves the emergence of a new challenge, which is the problem of determining what 'good science' is. Thus, the fourth attribute is the need for new approaches to quality control, including additional criteria of economic, political, social and cultural nature. The final attribute is reflexivity, which points at the researchers' awareness of the potential societal consequences of their research, and the implication of this for their choice of research objectives, methods and approaches.

Table 2 illustrates important differences between basic and transdisciplinary research. Mode 1 can be compared with basic research, while Mode 2 represents transdisciplinary research [4]. Applied research could be seen as an intermediate state towards Mode 2.

Table 2. Basic and transdisciplinary research [4]

	Scientific disciplines	Problem fields	Communities
Basic research	Economics Politics Thermodynamics Business …	Environment Climate CCS Energy …	Private sector Public sector Civil society …
Transdisciplinary research	Economics Politics Thermodynamics Business …	Environment Climate *CCS* Energy …	Private sector Public sector Civil society …

In table 2, scientific disciplines are exemplified by economics, politics, thermodynamics and business, while the communities each comprise a range of institutions. The problem fields indicated are just a few examples of relevance to the empirical example used in the paper. The arrows point from the knowledge bases to the problem fields. In transdisciplinary research, any scientific discipline or actor in the life-world may initially provide relevant knowledge [4]. This is indicated by broken arrows pointing from all knowledge bases, and by brackets indicating the integration of knowledge. Note that basic research is seen to be an important approach to investigate concrete problem fields even in transdisciplinary research.

Although Gibbon et al.'s [10] ideas about Mode 2 knowledge production is used as basis for the discussion in the present paper, alternative accounts of current changes in scientific practice exist which also represent interesting approaches to illuminate contextualized knowledge production. An example is the concept of 'strategic research' [16], which focus knowledge production as the combination of relevance with scientific excellence. Here, relevance means application possibilities in (industrial) innovation or in (governmental) decision making [2]. In their account of 'academic capitalization', Slaughter & Leslie [17] take as their starting point that increasing globalization enhances the pressure on industry to innovate, causing corporations to turn to universities for assistance, while at the same time, the flow of public money to universities recede. Taken together, this makes universities more willing to engage in 'capitalist' activities. A final example is 'post-academic science' [18]. These ideas refer to a radical, irreversible, worldwide transformation in the way science is organized, managed and performed [2], and build on the view that science is a collective activity, that the growth of scientific activities has reached a financial ceiling, that the demand for knowledge 'usability' is increasing, that competition for resources is strengthened, and that science become 'industrialized'.

3 Managing transdisciplinary research consortia

Innovation can be seen as an act of creation, implying a break with a habitual idea or action, because a new one is discovered and implemented in use. The nature of innovation is such, however, that in the early phases ideas about opportunities and directions for innovation and change more often than not are based on assumption or vision, rather than on established knowledge. This means that innovation inherently involves conflicting views and interests. And, as Thamhain puts it [19, p.297], '*deriving competitive advantages from innovation is a highly intricate process that involves technical complexities, functional interdependencies, evolving solutions, high levels of uncertainty, and highly complex forms of work integration*'. The management of innovation thus requires an understanding of the constituting processes as complex social processes, '*interrelated to the way in which individuals interpret, act, and ascribe meaning to the world*' [20, p.829].

As indicated, the overall objective of transdisciplinary research is to respond to perceived needs for new solutions and applications in society. Management of transdisciplinary research therefore means managing a range of partners, employed by different organizations [6]. Implicitly, a potential challenging characteristic of such collaborations is the fact that the social reference and control system of partners, as well as expectations about the handling of intellectual property rights, is anchored within their home institutions and not within the transdisciplinary team. Another challenge is that participating organizations and disciplines may vary over time, depending on the nature of problem definitions and research focus. Accordingly, the different requirements, values and demands of collaborating partners must be taken into account. In our case, an issue of relevance is to what extent consortium partners consider the innovation potential of research results generated in BIGCCS, and how this affects the overall priorities of the research consortium.

One way to depict transdisciplinary collaboration is proposed by Gray [3], who conceptualizes such collaboration as innovation networks. She particularly underscores the need for network stability, knowledge mobility and innovation appropriability (which is the different means an economic agent may use to profit from its inventions or innovations by temporarily enjoying some kind of monopolistic power over the knowledge it creates). In line with this, Wiesman et al. [6] suggests that managing transdisciplinary projects primarily implies finding a satisfactory balance between periods of intense collaboration with clearly defined joint outputs and periods where deepened disciplinary and multidisciplinary contributions can be elaborated. According to Wiesman and his colleagues, this balance is best supported by management services that simultaneously ease administrative tasks for participants, provide clearly structured and timed means of communication, integration and reflexivity, and support internal and external recognition of all contributors, i.e. the latter through providing access to extended peers. Apparently, Klein et al. [5] think along the same lines when suggesting that evaluation of transdisciplinary research teams must include how well the organizational structure fosters communication, including networking, among subprojects.

The above suggestions indicate that managing transdisciplinary research efforts involves structural and process-related tasks. According to Gray [3], the challenges inherent in the transcending of established disciplinary boundaries, is to '*open all disciplines to that which they share and to that which lies beyond them*' [3, p.124]. Accordingly, she suggests that structural and process-related management tasks need to be accompanied by a third area of management attention, which is a cognitive task.

4 Research approach

The intention in this paper is to use the claims of the Mode 1 and Mode 2 concepts as an approach to discuss the knowledge production processes in R&I consortia, exemplified by BIGCCS. As indicated, experience from the BIGCCS Centre is explored from 'within' the development processes [8]. The highly participative research situation made it possible to adopt a theoretical perspective focusing on 'real time' human interaction. Accordingly, the perspective used as the methodological basis in this study, is the complex responsive processes perspective [21]. The basic idea of this perspective is the importance of taking the details of human action and interaction into account [21, 22]. As explained by Aasen and Johannessen [23], the distinguishing features of this perspective are that all human relating is seen as fundamentally communicative, and that reality is seen to develop because of social interaction. Furthermore, ideas of the autonomous individual and the objective observer/manager are replaced by assumptions of the simultaneous social construction of group and individual identities. In consequence, the source of creativity and innovation is seen to lie in the transformative potential of the continuous mutual adjustments of meaning between people doing whatever they do during their working days [9]. Incidentally, this idea is in line with the notion of cognitive leadership suggested by Gray [3]. Note that from the complex responsive processes perspective people are always seen to be in practice, and practice is experienced through participation. Retrospective reflection, then, is the 'structuring' of experience [9]. Furthermore, experience is understood as *personal experience* of interaction. Consistent with these ideas, the present study was carried out with an explorative attitude referred to as *emergent participative exploration* [9, 24]. The term *emergent* is conceptualized to represent the formation of meaning for the participating researchers from the exploration of activities or situations. Characteristic of this approach is the connection made between research and identity, implying the view that researchers, as participants in organizational everyday life, influence the processes studied. Even more importantly, it is assumed that the researchers may see things in a different light as a result of the same process.

The approach of emergent participative exploration implies the active participation of the researcher in experiencing everyday social processes in organizations. Accordingly, it can be placed within the tradition of ethnographical research, or fieldwork [9]. Note that in the process of developing new meaning, it can be seen as appropriate to apply different qualitative methods as we know them traditionally. The analytical method used is that of intentionally reflecting on the details of own experience of processes in the BIGCCS research centre, as basis for new insights and practices. As BIGCCS is a very rich example, in the process of going through the partners' and our own experiences we have intentionally picked out themes to support the communication of our present understanding of the innovation processes we are part of. Our analysis could therefore be seen to be our understanding of the particular and general themes discussed by the BIGCCS Centre management group, and by people with whom we interact. An objection to this research, as it may be to all participative research methods, is the biased subjectivity of the approach by which the results are obtained and presented. In line with Peller [25], we argue, however, that in the end, research results always depend on the subjective choices of the researcher about what to do, how to do it, and how to interpret, analyze, and present the material. In our view, this represents a valuable basis for discussion, association, and new insight.

5 The CEER scheme and BIGCCS International CCS Research Centre

The Norwegian scheme for Centres for Environment-friendly Energy Research (CEER) is a direct follow-up of the broad-based political agreement on climate policy achieved in the Norwegian Parliament in 2008, and of the national R&D strategy for the energy sector, Energi21, of that same year [26]. Energi21 is based on the assumption that Norway has the natural resources, community of experts, and social framework to become Europe's leading energy and environment-conscious nation. To obtain this, Norway is suggested to move towards a situation of being a society of close-to-zero greenhouse-gas emissions, a major supplier of environment-friendly power to Europe, and a favorable location for the world's foremost energy and technology companies, among other fields in CO_2 management. According to the Research Council of Norway, the objective of the CEER scheme is to establish temporary research centres which seek to develop expertise and promote innovation through focus on long-term research in selected areas of environment-friendly energy, transport and CO_2 management [27]. The overall objective of the CEER centres is to contribute to the ambitious targets in the Norwegian Climate Agreement. This agreement is based on broad political agreement to reduce greenhouse gas emissions in Norway by 15–17 million tonnes CO_2 equivalents by 2020. Specifically, the centres are expected to stimulate active cooperation between innovative industry, public administrative bodies, and prominent research institutions to promote the development of application-oriented research communities which lie at the forefront of international research and which participate in dynamic international networks. The centres are also expected to enhance researcher training in areas of importance for user partners, and to generate research-based knowledge and technology transfer.

Eight CEER-centres were established in 2009, three more were approved in 2011. The centres were selected primarily on the basis of their potential to generate innovation and value creation within the CEER scheme's thematic priority areas, and on the scientific merit of their research and will be financed for eight years. The condition for public support within the CEER scheme is that research is carried out in close cooperation between research communities and industrial actors entering into long-term binding consortium agreements. The intention is to provide companies and public administrative bodies with the opportunity to take on a longer-term perspective, as well as enhance the continuity and reduce the risk of their research initiatives. For the research institutions, the ambition is the facilitation of long-term competence-building through high-quality research in close cooperation with user partners. In sum, the main expectations are that the CEER scheme will 1) enhance technology transfer and innovation, 2) encourage internationalization, and 3) promote researcher training.

The CEER Centre BIGCCS is headed by SINTEF Energy Research. It involves 22 partners from industry and academia, and administers a budget amounting to 45 million € over 8 years. Partners include twelve universities and research institutes, and ten industrial companies, which primarily represent end-users. The specific target for BIGCCS is to enable sustainable power generation from fossil fuels based on cost-effective CO_2 capture, and safe transport and underground storage of CO_2. This will be achieved by building expertise and closing critical knowledge gaps of the CO_2 chain, and developing novel technologies in an extensive collaborative research effort.

6 Innovation-directed knowledge production in practice

The present extraordinary injection of public funding of environmental-friendly energy research, combined with the general growing sense of urgency that the climate crisis must be met, set the CEER Centres in a somewhat different position than previous climate-related projects and research projects in other fields. In line with the ideas of Mode 2 knowledge production, the CEER scheme defines a clear context for the research. It further reflects a generalized expectation about research-based innovation as a means of vital importance to control the increasing climatic imbalances. Seen together, research in the CEER centres can pave the way for a broad range of technologies and processes promoting the development towards a greener economy.

According to the CEER scheme, the primary focus in the thirteen research areas of the BIGCCS Centre is on long-term, basic research, yet innovation oriented activities are also integrated as part of the work. The intention of these activities is to increase the consortium partners' attention towards collaboration and innovation, and to support them with knowledge about how to handle such processes, including the authors' own part in it. The expectation is the establishment of a close dialogue between the research communities, industrial partners, and also legislative authorities, and that this will promote the development of commercially and socially valuable knowledge and technology.

6.1. Mode 1 and Mode 2 induced innovation

The research in the BIGCCS Centre is legitimized among other factors by the global focus on climate challenges, the need for alternative energy forms, and the national CEER scheme. As indicated, the research is mainly of a precompetitive nature, developing at a stage where a Mode 1 approach to research seems appropriate. According to Gibbons et al. [10] Mode 1 knowledge production can of course result in practical applications, but as opposed to the ideas of Mode 2 these will be separated from the actual knowledge production in space and time. Seen from a Mode 1 perspective, the role of the BIGCCS Centre in innovation thus is as an arena for knowledge transfer from research to industry [2], independent of the level of interaction between the two parties. This is supported by the mutual consortium agreement, which allows all partners' equal access to the knowledge produced in the centre, meaning that each partner is free to exploit and capitalize on BIGCCS results. A potential challenge related to this is that different target groups are likely to make use of knowledge in ways unknown at the start of a research project [34], although this may also induce innovation in unforeseen areas.

If, however, BIGCCS knowledge production is interpreted from a Mode 2 perspective, BIGCCS can be seen as an arena for joint production and sharing of knowledge. In this case, innovation could be understood as communicative processes influenced by, but also influencing, the BIGCCS partners engaged in the development, exploration and exploitation of CCS-related knowledge and technologies. Such processes do not evolve in a vacuum, but will be affected by external factors such as public opinion, political discourses, and scientific breakthroughs. Implicitly, all partners, whether researchers or representatives from private or public organizations, need to engage in joint scientific discussion as basis for the co-production of knowledge and innovation, as two aspects of the same process. Seen from the perspective of innovation, this also makes demands on the framing of research consortia deliverables, which should both be countable for the sake of reporting, and at the same time reflect a movement from basic research towards demonstration of the potentiality of the new knowledge in solving life-world challenges. This claim supports the Mode 2 call for additional ways of evaluating research quality.

Apparently acknowledging the above challenges, the CEER scheme involves the expectation that CEER centres are composed of partners from several research institutes, universities, and industrial companies. This is also in line with the nature of the challenge of climate changes, which is of global concern, and seen as such requires coordination and collaboration for innovation across national, cultural and professional borders. The CEER scheme can therefore be seen as an example of a trend towards increasing complexity, size, and contextual demands on research programs, encouraging a change towards heterogeneous multipartner research consortia and Mode 2 knowledge production. As pointed out by Boix-Mansilla [28] and Sand et al. [29], impacts of collaborative research programs are however often diffuse, delayed in time, and dispersed across diverse areas of study and patterns of citation practice. This view is supported by Defila & DiGiulio [30], who admonish that many long-term effects cannot be predicted or checked in five-year periods, let alone annual measures. This indicates that even in Mode 2, the realization of innovation depends on the fruitful interaction of many different kinds of processes, of which Mode 1 research is one. Therefore, the CEER scheme expectation about long-term academic research and relevant innovation suggests that the two modes of knowledge production cannot be seen as separate approaches, but should be perceived as concurrent, potentially intertwined paths towards the realization of the BIGCCS Centre ambition.

6.2. Transdisciplinary research is a collective endeavor

The transdisciplinary nature of the activities within the BIGCCS Centre can be understood in at least two dimensions. Seen from an innovation perspective, transdisciplinarity implies a need to develop the current predominantly disciplinary research towards a more integrated research situation, with a focus not only on scientific excellence, but also on the combined commercial and social value of research results. A characteristic of Mode 2 knowledge production standing out as particularly interesting seen from this perspective is the focus on research teams' awareness of their contribution in a broader, social context. The Norwegian (and international) debate on CCS is a complicated debate, with diffuse stages between facts and feelings, differing opinions about the significance of these technologies, and unclear incentives of technology implementation and use [32]. At the time being, the debates on climate and CCS serve as legitimizing factors for environmental-friendly energy research, but less as a guideline for evaluating and prioritizing of research. As a consequence of new initiatives, such as, the EU Strategic Energy Technology (SET)-plan research initiative [35], this may change. According to the SET-plan, twelve CCS demonstration sites will be built by 2015. This will probably generate research problems which are not addressed today, such as environmental, safety, and efficiency considerations, as well as current research problems in need of new angles. In BIGCCS, an important tool to turn researchers' attention towards a more reflexive work approach is the development of roadmaps for each of the research tasks. Although in an early stage, the roadmaps support the introduction of conscious reflection on assumed future implications of research for innovation and indirectly, for the realization of the national research strategy, Energy 21.

Another dimension related to transdisciplinarity, is the demands advanced by national authorities 'on behalf of society' that the climate crisis must be solved, presenting a substantial challenge to industrial, political, and individual will and ability to adapt. Thus, problem solving within CEER Centre BIGCCS could be seen to involve the 'overall coordination of science, education and innovation towards a specific societal purpose' [15, p.47]. To assign to a research program the responsibility for innovation could, however, be seen as problematic. Being on the 'offerer-side', research partners' freedom of action is limited to substantiate value creation by seeking to make available knowledge anticipated to support the process of capturing, transporting, and storing CO2 in a safe and efficient way. The actual realization of CCS technologies and processes is contingent on the positive evaluation of the innovation potential of new knowledge by the industrial partners. To further complicate the picture, the outcome of such evaluations depends on prevailing political regulations. At present, the Norwegian CCS-related processes are politically driven in the main, and important factors for bringing about innovation, such as a clear regulatory framework and predictable market conditions, are not established.

Independent of perspective, transdisciplinarity is about collective efforts to solve problems in the life-world [15]. As pointed out by Hadorn et al. [4] transdisciplinary research is called for in cases where knowledge is uncertain, the concrete nature of the problem is disputed, and there is a great deal at stake for those concerned by the problem in question, which is indeed the situation within the field of CCS. Moreover, the collective nature of Mode 2 problem solving means that research can no longer build on clearly defined knowledge bases in science. Instead, shared ideas about the nature and complexity of the problem at hand, including the need to blend disciplinary paradigms, appears to be an essential condition for joint action. This brings up a question about BIGCCS partners' reasons for entering into the partnership. Through interviews with representatives for all partners, diverging views concerning the overall ambition of BIGCCS and about the roles of the partners were, however, identified. The main motivations for joining the centre were pointed out by the industrial partners to be access to high-quality research-based knowledge, innovation potentiality, and social responsibility. Not unexpectedly, the social value of research was seen as important, yet even more important for future investment in research and innovation in the field would be indications of commercial value and political decisions concerning CCS. These elements of uncertainty were not mirrored in the answers given by representatives for the BIGCCS researchers, who explained their main reasons for participation in the BIGCCS Centre to be the advantage of long-term financing of research and education, recognition, and knowledge and technology development in a real life context. The latter reason points towards a Mode 2 mindset. However, explanations about BIGCCS as a framework for research and innovation diverged not only between industrial and research partners, but also within the partner groups. A relevant observation in this connection is made by Pohl, who find that partners participating in projects funded by transdisciplinary programs are not inherently co-producing knowledge [15]. He argues that while some researchers acknowledge their role in initiating such co-production (Mode 2), others focus on the presentation and communication of knowledge according to their academic culture (Mode 1). Worth noticing is that although innovation appears to be the expected end result of Mode 2 knowledge production, the roles of industrial partners is not discussed. The theory indicates that the joint participation of scientific disciplines and actors in the real-world having concurrent interests will facilitate innovation, but appears limited by a lack of focus on individual actors and their motivation for contributing to new knowledge and innovation.

6.3. Managing innovation as concurrent processes of Mode 1 and Mode 2 knowledge production

The CEER scheme frames and structures research in a way that creates expectation not only about excellent academic performance but also about new knowledge exploitation and innovation. So far, experience indicates that although these are important ambitions, the goals set for the CEER centres also lead to diverging ideas among BIGCCS members and other parties concerned about centre priorities and targets. Among the ongoing discussions in BIGCCS is for example the question whether the future ambition should be to broaden the basis of fundamental understanding of relevant mechanisms, to prioritize strands of research appearing more promising seen from an exploitation perspective, or both. The problem is similar to that discussed by Pohl [15], which is the difference between creating knowledge about a problem, and solving the problem. The combined attributes of Mode 1 and Mode 2 knowledge production display the complexity of the management challenge inherent in the CEER scheme, and direct attention towards innovation management as the integration of different 'worlds of relevance'. In practice, this implies that members of different partner organizations may look at the same situation and come to differing conclusions of what are the problems, and what has to be done, based among other factors on their cultural norms, knowledge, and practices. Accordingly, in collaborative research consortia like BIGCCS there is a need for abundant information exchange and careful coordination within and between research activities. These can be seen as structural tasks [3] prerequisite for the optimal performance of the centre. Implicitly, research managers need to take the role as brokers, both of knowledge and paradigms, to bridge the gap between expectations framed within a context of science, and those defined in the context of application. In consequence, managing Mode 2 knowledge production appears as a more complicated task than the management of Mode 1 knowledge production, and the concurrent management of the two modi of knowledge production, which currently is the challenge in the BIGCCS Centre, even more so.

According to Gray [3], structural-leadership tasks address a team's need for coordination and information exchange. Her research indicates that such tasks are necessary, but not sufficient, to succeed with transdisciplinary research. Another important task is process leadership. The intention of these activities is to ensure that interaction between cooperating partners is constructive, trustful, and productive. This is in line with Wiesman et al. [6], who emphasizes that the management of transdisciplinary research is a question of dealing with the production pressure, on one hand, and on the other, to provide adequate time, space and resources for mutual learning and recursive research processes to take place. In the BIGCCS Centre, various arenas for interaction and information are established, such as technical meetings, work-shops, consortium days, and e-room and strategies for exploiting the arenas are described in a separate document. Still, experience indicates that the provision of time and space is not sufficient. In practice, there is an additional challenge related to the priorities of individual partners concerning participation in the different arenas. In consequence, moving from disciplinary research towards real-life solutions not only demands a broad engagement among partners, but also within the partner organizations. This includes the continuous evaluation in the individual partner organizations about participation in joint processes on different arenas; who needs to meet who, with which knowledge, and on which level of authority.

A third way to approach transdisciplinary leadership is to capture it as the creation of a mental model, or mindset, to which followers must adhere [33]. Implicitly, leading heterogeneous, multipartner research consortia involves the 'management of meaning' [3]. Seen this way, management is a cognitive task, where the development of a joint vision will support the movement of research towards one direction rather than another. This means that the development of a roadmap for research should at the same time be seen as the process of developing a shared mental map of desired goals among collaborating partners. Another aspect of this has to do with the actual processes of collaborate working. It is reasonable to believe that leadership skills needed in transdisciplinary research teams are similar to those suggested in other forms of cross-disciplinary teamwork, such as listening ability, conflict-handling, bridge-building capability, and the development of a common language. In BIGCCS, the CEER scheme's expectation about innovation calls for all of the preceding characteristics.

7 Conclusion

The CEER-scheme can be understood as a way to organize markets for knowledge production and knowledge brokering. The concurrent expectation about high-quality research and innovation inherent in the scheme makes current the ideas of Mode 1 and Mode 2 knowledge production as an approach to broaden the understanding of how new knowledge and innovation evolve and diffuse in innovation-oriented research consortia for those charged with the responsibility of coordinating and managing such complex forms of co-operation. Application of the attributes of Mode 1 and Mode 2 knowledge production, in particular the emphasis on transdisciplinarity, heterogeneity, reflexivity and context, elucidates well the challenges and opportunities of heterogeneous, multipartner research collaborations. Yet, the concepts do not focus the specific aspect explored in the present paper, which is the concurrent expectation about academic excellence and commercial and societal value creation. Apparently, there is a need to perform leadership according to Mode 1 and Mode 2, at the same time. Accordingly, the management of heterogeneous research consortia like BIGCCS means managing diverging expectations. This involves a need to direct managerial focus not only on structures for information and knowledge transfer, but also on the development of multidisciplinary co-operation, and a shared sense of meaning and ownership among BIGCCS Centre partners .

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