This paper was presented at ISPIM *Connects* Fukuoka – Building on Innovation Tradition, Fukuoka, Japan on 2-5 December 2018. The publication is available to ISPIM members at www.ispim.org.

Exploring university-industry-collaboration-networks from German battery research – An innovation-ecosystem perspective

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Abstract: With university-industry collaborations gaining relevance as a suitable approach to realize interdisciplinary research, modern research management reaches new levels of complexity. Drawing on the concept of innovation ecosystems, we explore the collaborative structure of the German battery research landscape based on university-industry collaboration networks. We rely on a comprehensive project database which offers information on 809 publicly funded individual and subprojects. Evaluation-wise, we transformed the project data into a network structure and calculated centrality measures such as "Eigenvector" and "Betweenness". Our study reveals that it is possible to attribute roles to actors within innovation ecosystems, aiming at indicating their suitability for various research management tasks, based on the position they take within it. These findings have important theoretical and practical implications, since they allow for synergies to be exploited and the efficiency of interaction within the innovation ecosystems to be increased.

Keywords: Innovation Ecosystem; University-Industry Collaboration; Ecosystem Management; Social Network Analysis; Knowledge Transfer; Interdisciplinary Research Management; Battery Research; Network Approach; Collaborative Research.

1 Introduction

Interdisciplinary research is becoming increasingly prominent in today's research landscape as increasing numbers of initiatives and calls aim to promote knowledge generation by fostering the collaboration of various disciplines. While interdisciplinary initiatives provide ideal conditions for the emergence of close university-industry collaborations, their interdisciplinary research context places high demands on research management in terms of higher coordination, translation and knowledge management efforts (König *et al.*, 2013). This complexity impedes not only the understanding and investigation of resulting collaborations but also of the research landscape as a whole.

An important example is the research on lithium-ion batteries (Golembiewski *et al.*, 2015). The field has high relevance for tackling the major issue of energy transition due to its role as key technology for enabling electric vehicles and further mobile applications as well as appropriate integration of renewable energy into energy infrastructure by pursuing research on stationary energy systems (Struben and Sterman, 2008). Yet, while anticipated to make significant contributions to the sustainability of energy supply and carbon emission reduction, a concise investigation of emerging university-industry collaborations is still lacking in literature. This is partly attributed to its highly dynamic character, where multiple technological trajectories are pursued simultaneously. Particularly affected by this are companies and policy makers in countries where the automotive industry is a key economic sector, such as Germany.

In this context, the concept of innovation ecosystems provides valuable insights into underlying dynamics by reframing collaborations as group of partners who interact to pursue shared value creation (Adner, 2016). By adopting this perspective, existing collaborations can be utilized to derive an interaction network, which does not claim to represent the entire innovation ecosystem, but is suitable to convey a uniform impression of research-intensive collaborations within it. Previous studies within this context mainly took the perspective of innovation ecosystems to discuss dynamic roles of universities, various forms of collaboration between universities and industry, or transition of innovation ecosystems (Chen and Lin, 2017). However, despite considerable relevance for theory and practice, the extent to which structures of innovation ecosystems can be inferred about the suitability of an ecosystem considering specific needs, roles, functions and tasks of successful interdisciplinary research management has not yet been sufficiently studied.

Therefore, this paper aims to explore the collaborative structure within the innovation ecosystem of battery research in Germany as an exemplary interdisciplinary research field by drawing on university-industry collaboration networks. Specifically, following questions are subject of investigation within this study: Who are the key partners? What roles are taken by partners in the network and what does this imply? Do universities and corporations differ in their roles within the ecosystem? If so, how can these differences be explained?

We extend the discussion on management needs of interdisciplinary research projects by giving reason to consider structural components of respective innovation ecosystem. Practical implications such as the possibility to assign management tasks according to the positions within the network more needs- and competence-based follow out of this. This allows synergies to be exploited and the efficiency of interaction within the network to be increased.

The remaining article is structured as follows: Section 2 discusses the origin of ecosystem research as well as recent publications on innovation ecosystems and aligns this study's approach by e.g. distinguishing between networks and collaborations. Section 3 describes the process of data collection and analysis, while results and discussion are presented in section 4. Finally, section 5 highlights the most important contributions and limitations as well as recommendations for future research.

2 Theoretical background

2.1 Research on Innovation Ecosystems – Fundamentals and peculiarities

The great interest in research on ecosystems can be explained by the theory of "relational view". This theory reveals that relationships between firms or within a network of firms can lead to competitive advantages (Dyer and Singh, 1998), and extends the resource-based view with the consequence that the nature of relationships in networked environments can be even more important than the nature of available resources (Lavie, 2006). In this context ecosystems are considered as a concept for networked environments, being able to contribute decisively to gaining a deeper understanding of how to improve or create new value propositions without neglecting the challenges, which are related to creating increasingly complex products and services that require the collaboration of multiple parties (Adner and Kapoor, 2010; Chesbrough, 2003). Thus, the ecosystem concept provides new perspectives on interdependency between involved actors and their respective potential to contribute to value proposition (Dattée *et al.*, 2018).

Originally from the field of biology, the scientific literature comprises a considerable number of publications in which the term "ecosystem" is often interpreted ambiguously and used to describe different things. Current studies are therefore attempting to structure the basic concepts and refine terminology (Adner, 2016; Jacobides et al., 2018; Scaringella and Radziwon, 2018). A current definition that emerges from these efforts and is widely accepted in the scientific literature describes ecosystems as *"the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize"* (Adner, 2016).

Business ecosystems are a subtype of ecosystems frequently discussed in scientific literature (Moore, 1997). By using this term, a firm-centric perspective is adopted which, regarding the multilateral set of partners, includes all those who have an influence on the firm itself as well as its customers and supplies to formulate a value proposition (Jacobides *et al.*, 2018).

In contrast to business ecosystems, the subtype of innovation ecosystems does not focus on a single company and its environment, but on a specific innovation. The relatively new field of research (Wright, 2014; Carayannis and Campbell, 2009) therefore includes actors contributing to value propositions resulting out of a respective innovation (Jacobides *et al.*, 2018). An earlier definition (Adner, 2006) describes innovation ecosystems as *"the collaborative arrangements through which firms combine their individual offerings into a coherent, customer-facing solution"*. To extend this definition, not only firms but rather a *"network of diverse actors, including emerging young firms, as well as established medium-size and large enterprises, NGOs, and government"* contribute to a value proposition within the context of corresponding innovations (Carayannis and Campbell, 2009; Wright, 2014).

According to Adner, no company can accomplish the task of contributing to a value proposition as explained above on its own (Adner, 2006). This reveals a peculiarity in research on innovation ecosystems, namely the emphasis on understanding how interdependent actors interact to create and commercialize innovations for the benefit of the end customer. The mandatory aspect of interaction within innovation ecosystems therefore requires coordination efforts, which – if carried out incorrectly – can even lead to the failure of innovations (Adner and Kapoor, 2010; Kapoor and Lee, 2013).

Taking the points mentioned above into consideration, we perceive research on innovation ecosystems as a suitable basis for integrating this study into the scientific literature. We investigate the collaborative structure of interacting research partners using the example of research on energy storage technologies. These are highly technical and complex systems which, due to their high research intensity, justify approaching research from an innovation ecosystem perspective. Furthermore, collaboration represents a key activity within innovation ecosystems, which makes our study to appropriately fit into the corresponding context as we approach investigating collaborative links between research partners.

2.2 Networks, Collaboration and Roles in Innovation Ecosystems

Recent studies emphasize that the degree to which actors interact through different arrangements will affect their capacity to create value for the end customer (Adner, 2016). This degree of interlinkage is measurable and is reflected in the literature by various concepts (networks, platforms, multisided markets), which are sometimes difficult to distinguish and require a more nuanced clarification. In his study, Adner thus highlighted the advantages of taking the perspective of achieving a defined value proposition on ecosystems. What consequently follows from this point of view is the task of identifying the group of actors who must interact in order for this goal to be achieved (Adner, 2016).

Corresponding studies on networks in innovation ecosystems regard these as *“virtual networks”* (Iyer *et al.*, 2006) or *“complex entities of group-related actors”* (Brusoni and Prencipe, 2013) and focus on their ability to contribute to the progress of innovation in a value-creating matter. However, we adapt Adner’s perspective and regard networks not as equivalent to ecosystems (Iansiti and Levien, 2004), but rather as a form of representation in which a certain group of actors and their interactions can be visualized as a data set in a suitable way.

Proceeding from the discussion on innovation ecosystems, it is often complex technical innovations which have the potential of substantial influence on business models, strategy development, and major economic and social changes. Driven by this insight and taking into account coexistence of both public and industrial research, the vivid and diverse field of technology transfer research deals with challenges related to interlinking public research and industrial application (Lee, 1996; Siegel *et al.*, 2003; Bozeman *et al.*, 2013). However, there are various appearances for the transfer of technology or technological knowledge which are the subject of various publications (Bekkers and Bodas Freitas, 2008; D’Este and Patel, 2007). As one of these, joint research collaborations between public research institutions and industry can be highlighted as particularly important for the generation of technological spill-overs

(Galán-Muros *et al.*, 2017; Ranga *et al.*, 2017). Such research collaborations make a positive contribution not only to steering innovations through intense interaction between the actors involved, but also to generating returns from invested research funds through increased probability of outcomes (Martin and Scott, 2000; Siegel and Zervos, 2002). Recent studies attribute a special role to universities in promoting technology transfer. It is frequently observed that universities are not only entrusted with the dissemination of knowledge, but also often play a key role of mediating knowledge to industry partners (Chen and Lin, 2017).

The idea that specific roles, which indicate function and thus responsibility for progress of respective ecosystem, can be attributed to actors within ecosystems, has already been subject of various publications (Adner and Kapoor, 2010; Moore, 1997; Adner *et al.*, 2013). Exemplarily various terms such as orchestrator, hubs, stewards, or keystone company are used interchangeably within innovation ecosystem literature, usually describing a coordination function (Adner, 2006; Dobson, 2016). Current studies are furthermore concerned with linking roles according to innovation processes with those within innovation ecosystems that are of particular importance for gaining understanding of ecosystem development processes (Dedehayir *et al.*, 2018). When choosing a network format for representation purposes of innovation ecosystems, roles can also be attributed based on computational determination, e.g. so-called centrality measures. These can provide information about structural composition as well as peculiarities of ecosystems (Bonacich, 2007; Freeman, 1978). Current studies put effort into investigation of these network structures for industrial sectors within the framework of business ecosystems (Aaldering *et al.*, 2018). However, studies of this kind which deal with the analysis of innovation ecosystems are very rare, although they are of promising potential for the development of more suitable strategic measures.

The identification of roles within ecosystems can have implications for the allocation of responsibilities regarding a managed coordination of ecosystems. Hence, reference can be made to the "competing values framework" (Quinn and Rohrbaugh, 1983), which presents itself as a suitable framework for management needs within joint research projects – a common form of university-industry collaboration as already explained. With regard to the points previously mentioned, we perceive a need to apply network analytical methodology to identify roles within innovation ecosystems. Considering the growing interest in interdisciplinary research for solving complex social and economic problems (Borge and Bröring, 2017), discussing these roles, in the light of e.g. the extended competing values framework, would provide valuable starting points for the development of more needs-based strategic measures based on innovation ecosystem structure (König *et al.*, 2013).

3 Methodology

A common approach for the realisation of interdisciplinary and multisided research objectives are university-industry collaborations, which are tendered, initiated and managed in the form of joint projects (König *et al.*, 2013). The German battery research landscape is particularly suitable for the analysis of such projects, as the promotion of collaborative battery research is a central focus of the German government as part of the European funding initiative "Horizon 2020" (European Commission, 2017).

We base our analysis on a comprehensive project database published and updated by the German industrial alliance "Competence Network Lithium Ion Batteries" (KLiB), which summarizes valuable information (e.g. technologies, type of research institution, field of application, type of project, implementing institution, project funding) on 809 individual and subprojects that are funded by federal ministries. Since our research focuses on the interaction of collaboration partners, we eliminated all individual projects from the data set and aggregated the subprojects to their corresponding joint projects, resulting in a set of 171 collaborative projects.

In this work we explore these collaborations by adopting an innovation ecosystems perspective. To reveal the ecosystem within the selected projects we used a network-based approach. For this purpose, we defined German battery research landscape as a large network in which each participants of these projects acts as a node, while the joint participation in projects serves as an edge, connecting these nodes. We propose that the resulting network acts as a valid representation of the underlying innovation ecosystem. While this approach can be used to analyse the whole battery research ecosystem at once, it can also be utilize to analyse the innovation ecosystem of specific technologies.

For our analysis, we focused on the entire battery research ecosystem, as well as the innovation ecosystem of specific battery technologies, such as metal-air or metal-sulphur. Towards this, we first constructed the networks by transforming the project data into an network structure using the Python language software package NetworkX (Hagberg *et al.*, 2008). Next, the resulting networks were visualized using the open-source visualization platform Gephi (Bastian *et al.*, 2009). The subsequent evaluation is based on a social network analysis utilizing prominent centrality measures such as “Eigenvector” and “Betweenness” to structure actors in networks according to their position and interrelation to others. Afterwards, we assign and discuss roles of actors within respective networks based on a classification scheme by (Aaldering *et al.*, 2018).

4 Results and Discussion

Our project is based on publicly funded 171 joint research projects, forming the German battery research landscape. A total of 279 participants interact in these projects, 168 companies, 111 public research institutes and 41 service providers. To analyse how these participants interact, we visualized joint project participation using a network approach (Figure 1).

The visualization reveals that participants in these publicly funded projects form a coherent network, in which both companies and public research institutes are equally distributed. The high degree of interconnection among the participants and the lack of large inert clusters suggest that this field of research represents an interactive ecosystem.

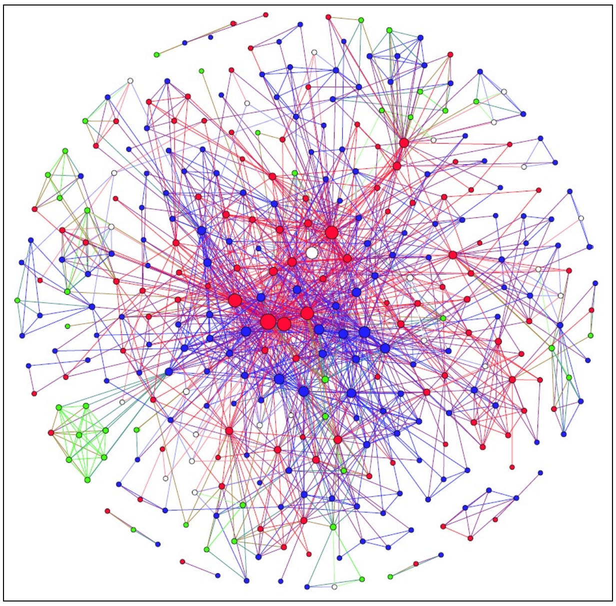

Figure 1 Network representation of research collaborations in the German battery research landscape. Shown are interactions between public research institutes (red), companies (blue), service providers (green).

The number of connections to others differs strongly among respective actors within the network, implying varying levels of actors' impact on the ecosystem. Focusing on the degree of interconnectedness solely (Table 1), it becomes evident that public research institutions and companies might differ in their role within the ecosystem as 8 out of the 10 most interconnected actors are public research institutions.

Table 1 Overview of the most interconnected participants

Participant	*Number of connections*
Westfälische Wilhelms-Universität Münster	77
Rheinisch-Westfälische Technische Hochschule Aachen	64
Technische Universität Carolo-Wilhelmina zu Braunschweig	61
Technische Universität München	59
Karlsruher Institut für Technologie	59
Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg	52
Varta Microbattery GmbH	47
Litarion GmbH	40
Thyssenkrupp System Engineering GmbH	39
Bayerische Motoren Werke AG	37

Drawing on this finding, we further investigated specific roles assumed by the participants within the ecosystem by performing a social network analysis in accordance to the proposed analytical framework of (Aaldering *et al.*, 2018). We altered the framework to fit in the context of innovation ecosystems by adjusting the descriptions of the proposed roles and focused only on three main roles: Key Player, Dominator and Bridge, without distinguishing between local and global variants (Table 2).

Table 2 Definition of specific roles within an ecosystem.

Roles	*Description*
Key Player	The key player connects with other influence actors within the innovation ecosystem and thus serves as an innovation-wide hub. This position is advantageous as it can control the knowledge flow within the system.
Dominator	The dominator is instrumental in creating value, but relies on others to appropriate its value. This position can have a significant impact on the ecosystem.
Bridge	The bridge connects multiple and otherwise disconnected innovators. This positon mediates the knowledge transfer within the ecosystem.
No Role	Innovators that have no role are actors within the network, however, the calculated centrality values do not reveal any special functions.

Source: Adapted from (Aaldering *et al.*, 2018).

Our analysis revealed that all roles, Key Player, Dominator and Bridge, are represented within the German battery research landscape. While most participants assume no special role within the ecosystem (No Role), the role of Bridge or Dominator are both assumed by 5% of all participants (Table 3). With 6,4 % of participants assuming the role of Key Player, this role is the most prominent within the ecosystem. Since only a few actors might have an actual impact on a network, percentages of this magnitude reflect a realistic assessment of the reality of the innovation ecosystem. This also coincides with observations from earlier studies (Dobson, 2016; Adner, 2006).

Table 3 Occurrence rates of different roles.

Role	*Number of occurrence*	*Rate of occurrence*
Key Player	18	6,4 %
Dominator	14	5,0 %
Bridge	14	5,0 %
No Role	148	83,6 %

However, we found that the specific rates of the roles distribution differ between public research institutions and companies (Figure 2). In general, public research institutions account for roughly 40% of all participants. Hence, the proportion of universities in the roles of Dominator (35,7 %) and Key Player (44%), as well as the assumption of no role (36,5 %), corresponds to expectations.

A comparable assumption rate of the role of Key Player, compared to the overall distribution of public research institutions and industry in our data set, can be explained by the fact that battery research is carried out in parallel. Due to the enormous importance of energy storage technologies for the future, industrial companies as well as public research institutions have a share in research and thus in value creation in the context of the innovation ecosystem.

The dominator role is primarily value-adding, as such, it does not contribute to the overall connectedness of the network. In the context of knowledge transfer this translates to a focus on knowledge generation rather than knowledge dissemination. Both companies and public research institutes fit this research intensive role, however, public research institutes in this role do not strictly pursue knowledge transfer. This can either be explained by the often close proximity to basic research in the context of battery technologies or a lack of proper technology transfer capabilities.

In contrast to the other roles, the role of Bridge is mostly (92,9%) taken by public research institutions, indicating a coherence between this role and their characteristics. By definition, this role mediates knowledge transfer between multiple and disconnected actors within an ecosystem. Even if the clarity of this finding is surprising, a similar trend can also be reconciled with earlier studies (Chen and Lin, 2017). The extension of the traditional academic tasks of teaching and research with commercialisation of knowledge describes the so-called “third mission” of public research institutions (Etzkowitz *et al.*, 2000). Whilst considering this study’s specific database, this finding suggests that foremost public research institutions facilitate the process of mediating the knowledge flow within the German battery research landscape.

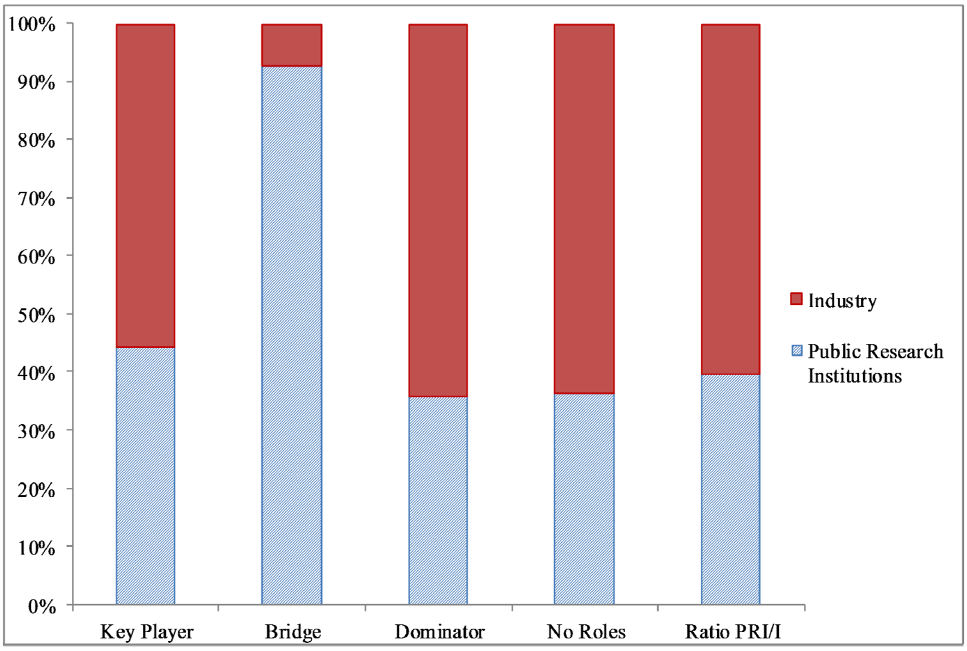

Figure 2 Adoption rate of specifics roles within the German battery research landscape.

Having examined the entire collaborative network on German battery research, we focus in the following on three selected battery technologies in order to assess how the degree of technological development and thus the proximity to basic or applied research affects the position of actors in the network (Figure 3).

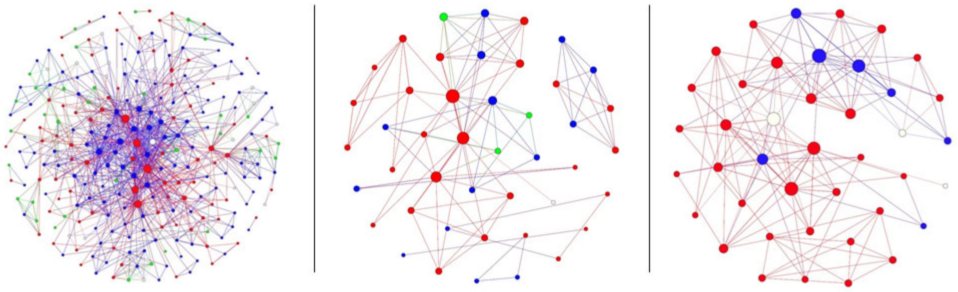

Figure 3 Network representation of research collaborations in the German battery research landscape, separated by different battery technologies. From left to right: Metal-Ion, Metal-Sulfur and Metal-Air.

While metal-ion technology comprises established battery systems that are already used in end products such as electric vehicles, metal-sulphur and metal-air, on the other hand, are classified as so-called post-metal-ion technologies which, due to their promising chemical properties, are subject of intense current research but have not yet found their way into mass production (Placke *et al.*, 2017).

The network visualizing metal-ion technology is at first glance comparable with the overall network. We recognize an equally high degree of networking which indicates advanced maturity of the network. A difference can also be seen in the increased share of industrial companies in the center of the network. However, this was to be expected, since Metal-Ion is an established technology, which leads to a higher activity in applied research areas and thus to a closer proximity to industry.

In comparison, the networks on metal-sulfur and metal-air have a different appearance. The net is much coarser meshed, which indicates a generally lower collaboration activity. Within the network of metal sulfur deficits in the homogeneity of the cross-linking can be observed. Thus, some areas are not connected to the main network - i.e. isolated - and the main network is strongly centered on a few actors, which also indicates an imbalance. Metal-Air has a more homogeneous network, but the proportion of industrial companies involved is quite small, so that a proximity to basic research can be inferred.

In summary, it can be assumed that the proportions of roles assigned to actors change according to the degree of technological development. Further studies, however, would be necessary to substantiate this effect.

Finally, we discuss our findings and suitability for the role distributions within collaborative networks by referencing to specific management needs of interdisciplinary research projects (König *et al.*, 2013).

The formation of a common, interdisciplinary culture is linked to the development of a common vision and a common language and serves to bridge internal conflicts and focus the research goal. Units entrusted with this task must use their structural leadership to legitimize necessary activities on this path (Adler *et al.*, 2009). This task can therefore be clearly assigned to the role of the Key Players, since only they can exert enough influence on their environment.

Another special feature of interdisciplinary research management is the necessity to actively balance between disciplinary and integrative research work. While the individual researcher usually draws his motivation from disciplinary research, the achievement of the project goal is often associated with a corresponding performance in integrative research work. Therefore, we consider a responsibility spread over two roles. On the one hand, the assertiveness of Key Players is necessary to define in the planning phase of the project how the work packages of disciplinary and integrative research are structured. On the other hand, one should take advantage of the good interlinkage of actors attributed to the Bridge Role in order to relieve the Key Players during the course of the project and provide regular feedback in order to ensure a balance between the research types. With a view to our results from the field of German battery research, public research institutions are mostly suitable for this task.

In interdisciplinary projects, research management is also faced with the challenge of balancing routine project management with the freedom related to creativity and application efforts. With regard to the roles within the network, the influence of Key Players are able to establish routines and coordinate them by resorting to internal stability. Detailed execution, i.e. measuring and documenting the project plan, requires organizational capacity as well as the ability to combine contentual issues with planning efforts. Due to their important role in value creation, actors in the Dominator role are well-suited using their competences. A division of tasks is also an appropriate way of further relieving the Key Players in this respect.

5 Conclusion

This study reduces complexity of interdisciplinary research management by disclosing the suitability of actors within collaborative networks for performing such management tasks. Based on an analysis of the network structure from interdisciplinary research projects, we were able to successfully identify roles of actors and assign them to needs- and competence-based management tasks.

We contribute to the so far limited body of research management literature within interdisciplinary settings and enter a novel theoretical discussion of the field by aligning our study with the concept of innovation ecosystems. We are thus answering the call for more research in the field of innovation ecosystem collaboration and follow the proposed research agenda by (Jacobides *et al.*, 2018). Furthermore, we make use of network analytical methodology and demonstrate its suitability to investigate collaborative structures within innovation ecosystems. Based on the position taken by the actors within innovation ecosystems, it is possible to attribute roles to them that, for example, indicate their suitability for various research management tasks.

Practical implications such as the possibility to assign management tasks according to the positions within the network more needs- and competence-based follow out of this. This allows synergies to be exploited and the efficiency of interaction within the network to be increased. External research management can be relieved accordingly, since institutions supervised with research are suitable to take over some management tasks themselves. By disclosing the structure of the collaboration network and relying on insights from actors' network-related roles and technological competences, research managers from industry and research institutions get an adequate overview on the innovation ecosystem enabling them to find suitable collaboration partners or refine their competition analysis. Policy makers involved in conceptualizing collaborative research projects will find the results out of network analytical methodology particularly useful since these might lead to facilitated decision-making processes and more needs-based project initiating or terminating measures. With regard to transition our use of energy, this study contributes to an increasing efficiency in resource allocation from public funding as well as industrial expenditure, resulting from improved transparency.

Public research projects reflect only part of the innovation ecosystem. Industrial research in particular can only be depicted peripherally. Also, our dataset just considers research in Germany – which of course goes hand in hand with local research culture that may not be comparable with that in other countries. In selecting the research topic of battery research, we have paid great attention to its representative character for interdisciplinary research. However, an inevitable transferability to other interdisciplinary research areas cannot be guaranteed.

Investigations in other interdisciplinary research areas as well as in other countries would allow a statement on the generalizability of the results found here. A dynamic change in the distribution of roles according to technological development could also be substantiated by further studies.

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