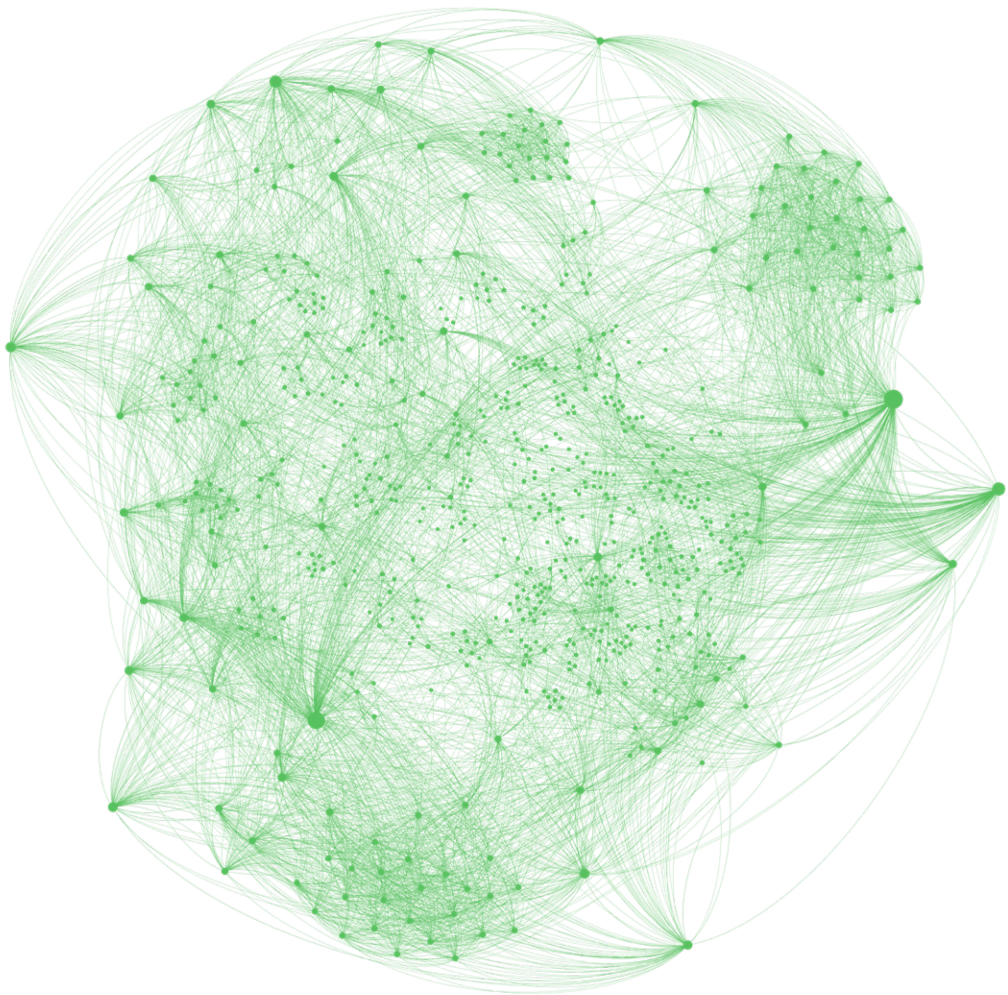
I / 2021 ▪ Study

Battery cell manufacturing ecosystem in Europe

Network structures as a basis for knowledge transfer and value creation partnerships

Publication of the Accompanying Research for the funding programme for Battery Cell Production on behalf of the Federal Ministry for Economic Affairs and Energy



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Accompanying Research
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LIST OF ABBREVIATIONS

ACEA: European Automobile Manufacturers Association

BAJ: Battery Association of Japan

BDE: Bundesverband der deutschen Abfall-, Wasser- und Rohstoffwirtschaft (Federal Association of the German Waste, Water and Raw Materials Management Industry)

BEM: Bundesverband der Elektromobilität (Federal Association for Electric Mobility)

BEV: Battery Electric Vehicle

BMWi: Bundesministerium für Wirtschaft und Energie (Federal Ministry for Economic Affairs and Energy)

BVES: Bundesverband Energiespeicher (German Energy Storage Association)

CLEPA: European Association of Automotive Suppliers

CNESA: China Energy Storage Alliance

DIN: Deutsches Institut für Normung e. V. (German Institute for Standardisation e. V.)

EBA: European Battery Alliance

EBRA: European Battery Association

EGVI: European Green Vehicle Initiative

ERTRAC: European Road Transport Research Advisory Council

EUCAR: European Council for Automotive R&D

EUROBAT: Association of European Manufacturers of automotive, industrial and energy storage batteries

FCEV: Fuel Cell Electric Vehicle

FuE: Forschung und Entwicklung

GBA: Global Battery Alliance

IPCEI: Important Project of Common European Interest

IPR: Intellectual Property Rights

KLiB: Kompetenznetzwerk Lithium-Ionen-Batterien (Competence Network Lithium-Ion Batteries)

KMU: Kleine und mittelständische Unternehmen

LIB: Lithium-Ionen-Batterie

PHEV: Plug-In Electric Vehicle

SDO: Standards Developing Organisation

VDA: Verband der Automobilwirtschaft (German Association of the Automotive Industry)

VDMA: Verband Deutscher Maschinen- und Anlagenbau (German Engineering Federation)

EXECUTIVE SUMMARY

The formation of actor networks is essential for the establishment of a sustainable and closed battery value chain in Germany and Europe. The sum of these connections between the actors is called an **ecosystem**. By actively building this ecosystem, existing competences in research and industry can be networked and synergies can be created. In this way, networking leads to the establishment of value added partnerships and the improvement of knowledge transfer.

This study focuses on the analysis of relationships between actors and the resulting network structures in the field of batteries. This approach, **complementary to market and technology studies**, leads to a better understanding of the battery cell production ecosystem.

These structures arise from current, completed or potentially possible joint activities in relation to a common goal in the context of battery cell production. The activities take place **within the value chain of battery cell production**, from the handling of resources (e.g. resource extraction or recycling) to production (e.g. component or module production) to the application of battery cells. These structures consequently "carry" the **knowledge** transfer for which joint activities are the basis. At the same time, these structures also point to connections that can be used for **potential value-added partnerships** and show initial approaches to this. The focus of this study is thus on three different types of connection:

- research cooperation,
- cooperation for the purpose of pure economic value creation and
- cooperation in the pursuit of common strategic interests.

Therefore, this study does not focus on just one form of activity, but equally considers research, value creation (here in the form of joint ventures) and strategic cooperation in order to take a look at the common basis for knowledge transfer and value creation. In this respect, it takes a **holistic, structural view of the battery cell production ecosystem**.

The **objectives of this study** are, to

1. structure the battery cell production ecosystem,
2. provide an overview of relevant stakeholder categories in the field of battery cell production along the value chain,
3. demonstrate the involvement of the different actors in the ecosystem, and
4. identify possible gaps in the ecosystem.

This creates a **fundamental understanding of the ecosystem**, on the basis of which recommendations are formulated as to how connectivity within the ecosystem can be specifically improved and existing gaps closed.

Key findings of this study:

- *Networks*: Many actors are only well connected within institutionalised networks such as associations. They lack connections to other parts of the ecosystem.
- *Interfaces*: Comparatively few key actors take on an interface function and establish connections between different parts of the ecosystem.
- *Key actors*: Due to their central role, key actors can steer topics and networking. This offers potential for the expansion of the ecosystem, but also gives them great creative power.
- *Specialised knowledge*: There are companies in the poorly connected, weakly integrated part of the ecosystem with specialised knowledge to develop innovative products and processes. These are therefore very important for the overall ecosystem.
- *Circular economy*: The strategic role of the research actors in terms of linking the activities that are important for a circular economy calls for focusing research, but also for a lower level of involvement of industry.
- *Research structures*: At European level, the focus on industry-related development projects with a thematic focus on production is less pronounced compared to the German level. On the other hand, large-scale demonstration projects with many actors at European level offer a high networking potential.

The findings result from the assumptions, the data and the chosen methodology. The classification and evaluation of these findings is commented on at the appropriate place in the study.

1 INTRODUCTION

The future is electric, but the transformation into the post-fossil age cannot succeed without the ability to store electrical energy. For many applications such as smartphones, power tools or stationary power storage, but especially for electric vehicles, batteries are already a key technology today. Currently, lithium-ion batteries (LIB) are most widely used due to their high energy and power density as well as their cycle stability and service life. According to a recent study, the global demand for LIBs was around 200 gigawatt hours (GWh/a) last year, more than 80 percent of which was covered by Asian production[1]. Based on the forecasted increase in demand to about 1,200 GWh/a in 2030, the annual market volume is estimated at the equivalent of about 117 billion euros.

The production capacities currently available in Europe can cover about six percent of the current global demand for LIB. The political goal is to cover around 30 percent[2] of the global demand for battery cells from German and European production by 2030. To this end, the Federal Ministry for Economic Affairs and Energy (BMWi) is funding the establishment of industrial battery cell production in Germany with almost three billion euros[3], thus laying the foundation for the development of a European battery cell industry together with other European member states. Due to the European dimension of this project, support is being provided by the European Commission within the framework of an Important Project of Common European Interest (IPCEI)[4]. The Commission coordinates and checks the compatibility of national support with EU objectives and international trade rules. The pan-European funding is intended to bundle innovations, jointly acquire technological expertise in the field of battery cells and establish large-scale production facilities throughout Europe.

Battery cell production ecosystem

In this study, the term ecosystem encompasses all actors and the structures resulting from their relationships that are involved in maintaining or building battery cell manufacturing. In this sense, the ecosystem can be outlined as a network of actors, with the connections being the focus of this study.

The development of an ecosystem in which existing industrial competences and value creation potentials in Germany and Europe are profitably networked is essential in order to advance the development of a German and European battery cell production, taking into account a sustainable and closed value chain in the sense of a circular economy. This requires precise knowledge of this ecosystem, both of its strengths and weaknesses, as well as of structural gaps.

As part of the accompanying research in battery cell production commissioned by the BMWi, this study is being prepared to[5] analyse the battery cell production ecosystem in Germany and Europe.

Aim of the study

Most studies usually look at the topic of battery cell production from a market perspective (e.g. market potentials and framework conditions) or identify product- or process-related research needs. Often, the topic of knowledge transfer and networking emerges as a recommendation of these studies, without specifically naming with whom networking should take place, be it to improve knowledge transfer or to establish value creation partnerships. This study therefore focuses on the analysis of relationships between actors and the resulting network structures in the field of batteries. This approach, **complementary to market and technology studies**, leads to a better understanding of the battery cell production ecosystem.

These structures arise from current, completed or potentially possible joint activities in relation to a common goal in the context of battery cell production. The activities take place **within the value chain of battery cell production**, from the handling of resources (e.g. resource depletion or recycling) to production (e.g. component or module production) to the application of battery cells. These structures consequently

1 Avicenne, 2020

2 BMWi, 2018

3 BMWi, 2020

4 BMWi, 2020

5 The study outlined in this concept builds in parts on a predecessor study of the scientific monitoring that was not published.

"carry" the **knowledge transfer** for which joint activities are the basis. At the same time, these structures also point to connections that can be used for **potential value-added partnerships** and show initial approaches to do this. The focus of this study thus is on three different types of connection:

- research cooperation,
- cooperation for the purpose of pure economic value creation and
- cooperation in the pursuit of common strategic interests.

Therefore, this study does not focus on just one form of activity, but looks equally at research, value creation (here in the form of joint ventures) and strategic cooperation in order to take a look at the common basis for knowledge transfer and value creation. In this respect, it takes a **holistic, structural view of the battery cell production ecosystem**.

The **objectives of this study** are, to

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3. demonstrate the involvement of the different actors in the ecosystem, and
4. identify possible gaps in the ecosystem.

This creates a **fundamental understanding of the ecosystem**, on the basis of which recommendations are developed as to how networking within the ecosystem can be specifically improved and existing gaps closed. In this sense, a **"map of the battery cell production ecosystem"** is also shown.

In the context of the analyses for this study, the accompanying research in battery cell production is currently developing a web-based tool that enables collaborative, individual analyses of the ecosystem. Available tools for analysing networks, such as the tool used in this study[6], have very extensive analysis options, but are also very complex in their application, which requires specific prior knowledge. The tool developed by the accompanying research therefore focuses on ease of use and also allows collaborative work through simultaneous access to a common database. The knowledge and experience gained in the course of this study therefore also serve to improve the precision of the tool and optimise it in terms of usability.

In the analysis of the structures of the ecosystem, the connections between the actors at different levels are considered and the cooperation within the framework of the following activities is examined:

- value creation cooperation (here: joint ventures[7]) (who generates value with whom?)
- research cooperation (who generates knowledge with whom?)
- networks and interest groups (who can exert strategic influence with whom?)

The study answers the following **four central questions**, which pay into the objectives of this study:

What **roles** are there in the ecosystem and what are the **interfaces** to other roles?

Goal 1 and 2

I

Which **networks, cooperations and thematic clusters** exist at European level and in Germany?

Goal 1 and 3

II

Where are there **structural gaps** in the battery cell manufacturing ecosystem?

Goal 1 and 4

III

What is the **state of development** of the battery cell production ecosystem in Europe?

Goal 1, 2, 3 and 4

IV

Figure 1: Central questions of the study

6 See also Chapter 2.3

7 Due to the accessibility of the data, this study only considers public funding as well as joint ventures, which are also easily accessible. In the case of knowledge generated in the context of industrial cooperation, for example, this study assumes that this occurs in the context of value-added cooperation.

In addition to a description of the approach pursued and the methodology used (*Chapter* 2), this study is structured according to the following **focal points**, which build on each other and are based on the aforementioned questions. *Chapter* 3 provides an overview of the background and market potential of battery cell production in Germany and Europe. *Chapter* 4 will describe the status quo of the ecosystem in Germany and Europe, and *Chapter* 5 will look at the network structures in terms of roles, thematic clusters, stakeholder involvement and overall networking. Finally, *Chapters* 6 and 7 analyse the strengths, weaknesses, opportunities and threats in relation to the actors and roles as well as the networking of the ecosystem and derive recommendations for action.

This study shows where there is a need for action on the part of politics and business in order to advance the development and expansion of the ecosystem for battery cell production in a targeted manner. Accordingly, this study is primarily aimed at decision-makers from both politics and business.

2 METHODOLOGY AND APPROACH

This study follows an explorative, highly data-driven approach in order to be able to capture the ecosystem on the largest possible scale, i.e. to take into account a large number of actors and their possible relationships with each other. To analyse the data, an extensive database was created with information on actors and identified connections, which was examined using network analysis methods.

2.1 Data acquisition and processing

Network or interconnection levels: Data on activities in the three areas of value creation, research and strategy, which represent the networking levels of the ecosystem, serve as the basis for the analysis of the battery cell production ecosystem. In addition to desktop research, an automated query of various databases was also used. Relevant activities in the field of (lithium-ion) batteries were identified at these three levels. In order to achieve the greatest possible coverage of relevant activities at the various levels, news reports were evaluated in addition to publicly accessible, thematic databases. For the network level, a pre-selection of networks and associations was made and available data from preliminary work was used. The selection was based on an expert assessment with regard to the expected weight and relevance in the experts' community in relation to the value creation levels considered in this study. Overall, activities have been recorded for all levels since 2014[8] (see table 1).

From the data collected, all stakeholders involved in the identified activities were extracted. These form the basic population of the stakeholders under consideration. Obvious duplicates were automatically removed. In the case of activities of different subunits of an organisation, for example different institutes of a university, these were also treated as separate stakeholders[9]. It was assumed that these actors also have a connection to each other or to the respective parent organisation, provided that it can be identified. The networks considered also have a "double role", since they occur both as a networking level and as an independent actor. This is methodologically justified. Only directly possible connections are recorded as connections in the sense of this study. Networks are usually represented in R&D projects as an independent actor, not by the totality of their members. In other words, just because a network participates in an R&D project, this does not necessarily mean that there is a connection between the actors in the project and the network.

Actor classification: The identified actors are assigned to the actor categories considered in this study (companies, research institutions, networks / interest associations,

Networking level	Subject ("identified activities")	Data basis
Value-added level	Value-added cooperation: Joint ventures [I]	Own research based on news reports on news portals, daily newspapers etc.
Research level	Research cooperation: Research projects, scientific publications	CORDIS database of the EU, funding catalogue (based on the edited version of the project database of the Battery Foru[II]), literature database SCOPUS
Strategic level	Strategic cooperation: Interest groups, initiatives, networks, etc.	Own research on relevant associations based on information from the network/association websites

I On the topic of coverage, see also the comments in the section "Limitations of the study".
II KLiB, 2020

Table 1: Objects of the levels of analysis and respective data basis

8 Deadline for data collection: July 2020

9 See also the section „Limitations of the study".

Technical basics

The basis for the creation and analysis of the database is a data science toolkit developed by VDI/VDE-IT. Its elements and mechanisms, which were used for this study, are briefly outlined here.

Data warehouse: In order to enable a search across several data sources in a performant and automated way, the data sources mentioned were stored in a common database in which the entries are mapped to common categories.

Automatic recognition of actor duplicates: The naming of actors in the data sources is done according to different rules and is associated with input errors. Therefore, duplicates are automatically searched for by similarity measures on names, legal forms and organisation types.

Preparation of text data: In order to address the variability in language use and thus create comparability between different texts, words without information content are removed and the remaining words are reduced to their basic form.

Keyword extraction: In order to be able to classify the processed text data, words that describe these texts particularly well were automatically extracted from reference texts describing the categories. These were determined via statistical metrics that compare the use of the words in the reference text with those in general, extensive text corpora.

Classification by keywords: The extracted keywords are searched for in the processed texts and, in addition, an information content of the terms for this text is determined via statistical metrics. In this way, it is possible to determine whether a keyword in the text under consideration is relevant and should be included in the classification.

standardisation organisations [SDO] and others). In order to be able to capture the large amount of data, a pragmatic approach was chosen for this classification: All actors that could be identified as such were grouped as companies based on the designation of the legal form (e.g. “GmbH” or “AG” or international designations such as S.L., S.A.U. or SE). The assumption here is that these actors primarily pursue value-creating activities. All actors that are designated as “university” or “institute” were grouped together as research institutions. The bridging hypothesis here is that these actors primarily serve to generate knowledge. Actors that are recognisable as “association” or “federation” or under related designations were recorded as networks. Analogous to the other two categories, the assumption applies here that these actors primarily serve to represent interests. Since standardisation organisations have a superordinate role in the ecosystem and norms and standards are also an important basis for the emergence of closed value chain cycles, these actors were considered separately. All actors that could not be classified in this way were grouped under “Other”. The selection was checked on a sample basis, validated and misclassifications adjusted.

Classification of the connections: Based on the data basis, an overview of the interconnectedness between the actors was created. The unit of analysis used in this study is the connection between two actors, the so-called edge. These connections “arise” from the implementation of joint activities. These activities can be the joint implementation of a research project, participation in an interest group or in a joint venture. The assumption is therefore that each actor within one of the activities under consideration has a connection to every other actor involved in these activities[10] – regardless of whether this connection is actively used. The sum of all possible activities of one type (research project, interest group, joint venture) and the resulting connections in turn represents the respective networking level (see table 1). All identified activities were examined in this way for possible connections. A classification of the connections according to content-related focal points was made on the basis of the content-related description of the activities considered. These focal points correspond to the individual stages of the value chain (see figure 2), which are summarised in the superordinate categories of ***production*** “P” (component production, battery cell production, module and system

10 Example: In a research project there are three project partners P_1, P_2 and P_3. This results into following connection possibilities: P_1-P_2, P_2-P_3, P_1-P_3. Accordingly, there are three possible connections in this research project.

assembly, battery production[11]), *application and use* "U" (product integration[12]) and *resources* "R" (recycling[13], raw material extraction, material production). Due to the large amount of data, the research projects were classified using a data science-based approach (see info box on "technical basics").

Often, themes cannot be clearly assigned to a category. For connections where two or more topics have a similar scoring value, calculated using statistical metrics, the topic with the highest value was assigned to the connection. The results of this automated classification were spot-checked. Obvious misclassifications were corrected to increase the quality of the classification. In the case of networks and joint ventures, a manual allocation was made on the basis of expert assessment. In cases where a clear allocation to a focal point was not possible or several stages of the value chain were equally relevant, the category was indicated as "cross-value chain".[14]

2.2 Assumptions about roles and interfaces

The following chapter shows the basic structure of the battery cell production ecosystem considered. This serves to clarify the understanding of the battery cell production ecosystem underlying this study as well as the roles and interfaces contained therein (see figure 3).

The abstract form of representation is based on the assignment of the actors in the battery cell production ecosystem to the three areas of politics, research and industry. In this abstracted representation, the ecosystem has a circular structure, with the categories of politics, research and industry each taking up one third of the circle's area. In the centre of the circle are all the identified actors who come from the three categories mentioned.

On the first circle, which directly surrounds the centre, the **actor categories** (see Actor Classification) are arranged. In

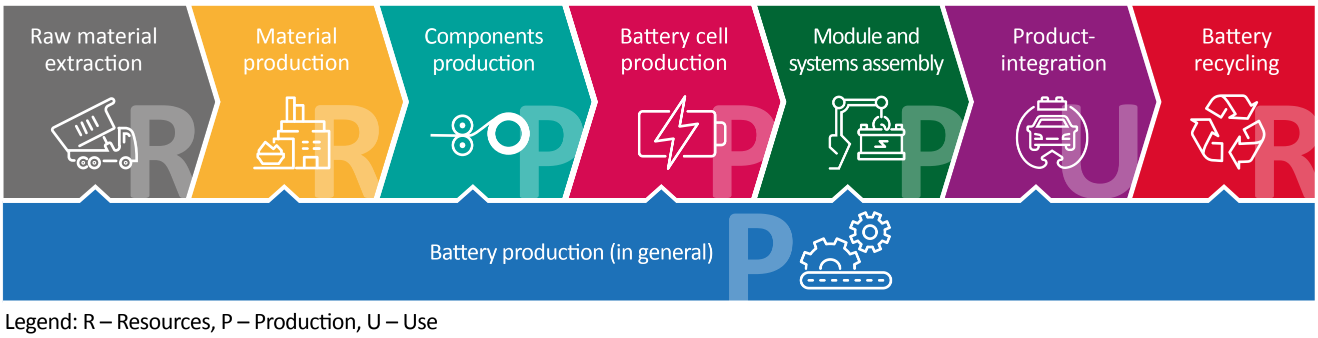


Figure 2: Stages of the battery cell production value chain with colour coding and classification of the individual stages into the main categories of resources, production and use.

11 Without aspects of use/application and resources. This refers to production topics that cannot be assigned to a specific value creation stage. These include, for example, additive manufacturing methods or the production of machinery and equipment.

12 For analytical reasons, a broad understanding of product integration is used in this study. This includes not only the production-related integration into the product, but also application possibilities (excl. 2nd use).

13 Similar to product integration, a broad understanding of the topic of recycling is also used here, which also includes the topic of 2nd use.

14 This is the case with many networks. The European Battery Alliance, for example, covers practically the entire value chain in its activities.

addition to the companies and research institutions that can be assigned to the industry category and the research category respectively, networks are listed here. The networks form an interface between industry, research and/or politics, so that actors from all three areas can be represented here. The actors in the SDO category are located at the interface between politics and industry. The actor category "Other" is not listed here because it cannot be clearly assigned to one of the three areas due to the indeterminacy of the actors it contains.

The circle with the next largest radius represents the **networking level**, which represents which types of networking between the actor categories are considered in this study. In the area of industry, joint ventures between companies are considered. In addition, networking via research projects and networks are taken into account. These are arranged on the interfaces between the individual areas, as they are established by actors from at least two categories. Purely industrial research projects are not considered.

The outer circle shows the stages of the **value chain** under consideration. This illustrates that companies from different stages of the value chain can be involved in joint ventures, or that the core business of the joint venture can be assigned to different stages of the value chain. Since the value-added stages can primarily be transferred to companies, they are all located in the industry sector.

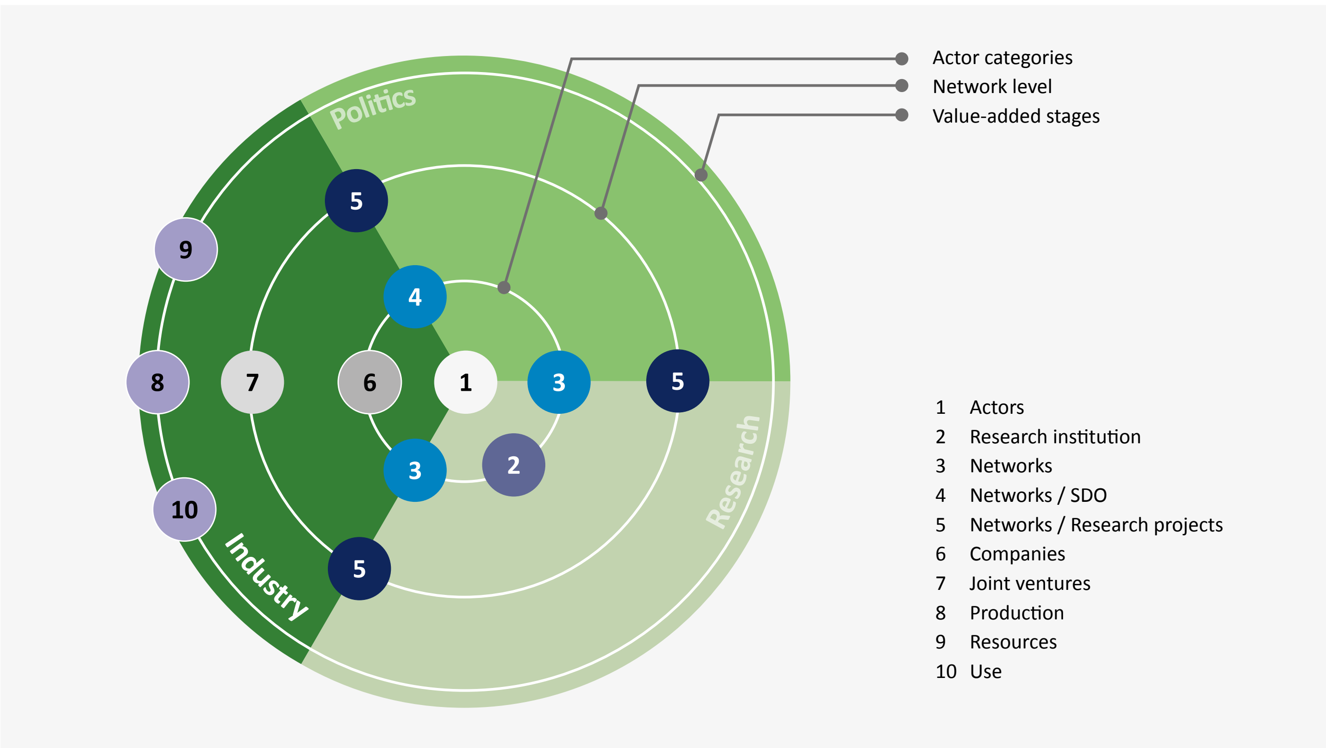


Figure 3: Overview of the most relevant networks of the considered ecosystem

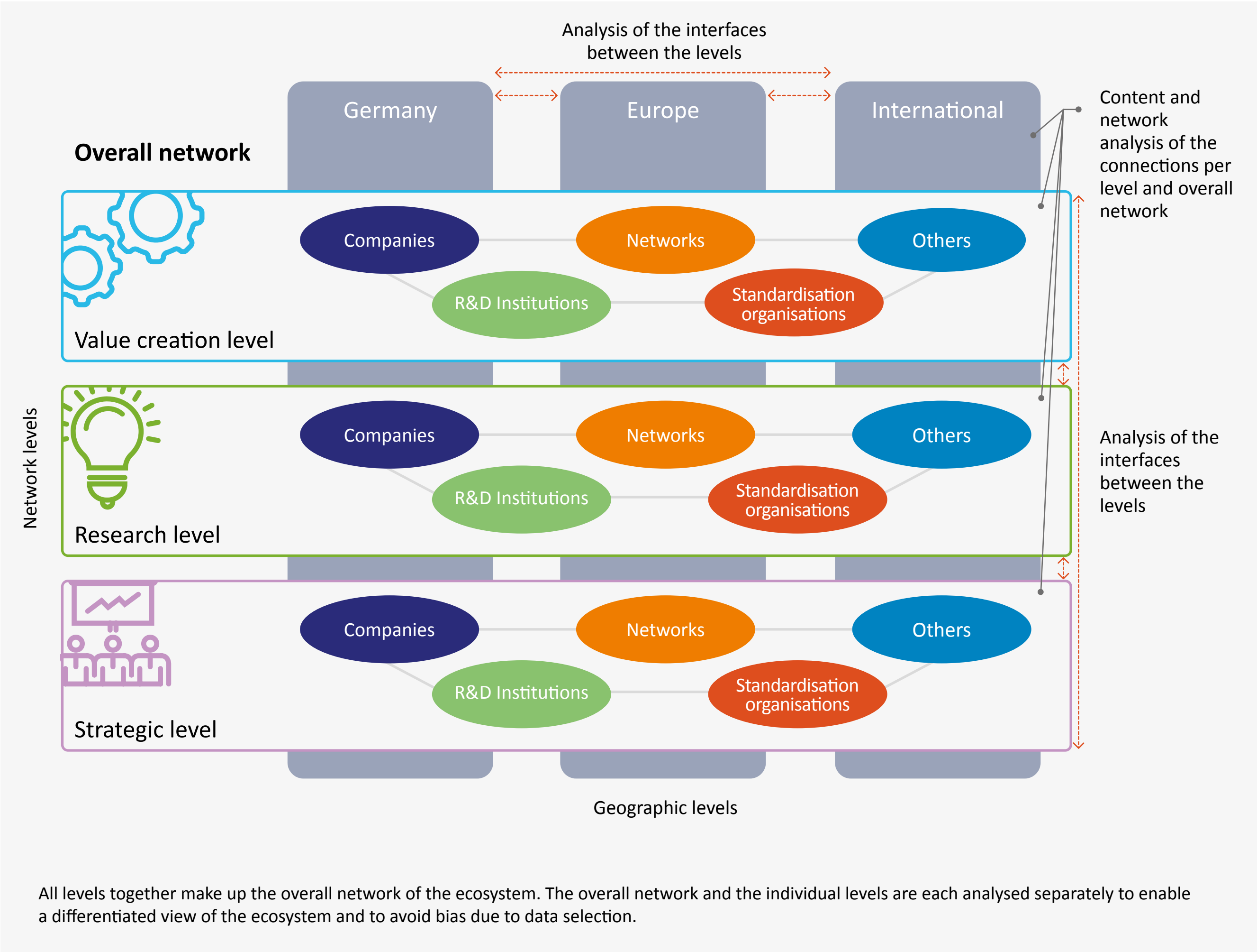
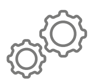


Figure 4: Analysis scheme of this study along the different networking levels to structure the approach

2.3 Analysis

The basic scheme followed by the analyses in this study can be seen in figure 4. This forms the framework for the analysis of the identified individual connections, which is carried out on the basis of various criteria. The identified individual connections form the basic population of connections in the battery cell production ecosystem. The presentation of the status quo and the further analyses were carried out for the networking levels of value creation, research and strategy as well as for the overall network. In each of these levels, the geographically differentiated analysis is carried out according to the levels in Germany and Europe. Depending on the networking level, the international level is also included. In addition, the interfaces between individual levels are identified. Interfaces are actors who have activities on more than one of the geographical or networking levels considered in this study. They therefore have the opportunity to address topics, concepts or issues that they deal with at one level also to address with other actors at another level. In this sense, they can disseminate these topics across several levels. The following criteria form the basis of the analysis:

Weighting of the linkages: The weighting is done on a scale of 1 to 3 in order to be able to represent a stronger differentiation between the individual linkage levels.



- Value-added level links are assigned a value of 3, as it can be assumed that they are **particularly resilient and long-term**. There is also a special form of reciprocity here, i.e. all partners involved in such a link receive a concrete, usually contractually defined consideration for their activities (e.g. the supplier receives money for parts produced, the

OEM the parts for vehicle construction). Thus there is a strong interest on both sides in the continuation of the link.

- Connections at the research level are assigned a value of 2, since cooperation in research projects can be quite intensive, but the **continuation of the connection is linked to the processing of research topics**. If a topic is no longer pursued, for example because it has not proven to be sustainable, the chance of further cooperation is also reduced.
- Connections at the strategic level are assigned a value of 1. Networks and interest groups offer good networking opportunities, **but no guarantee for a close, reciprocal connection of their members**, especially since competitors are often active in the same networks and interest groups. Furthermore, the chance of finding cooperation partners for exchange or even cooperation without suitable matching measures is relatively low in very large networks, such as the VDMA. Therefore, networks are classified as the "weakest" type of connection. In an ecosystem, they are nevertheless relevant because they offer a high reach through the multitude of networking possibilities. As independent corporate actors, networks and associations also bundle and represent the interests of their members.

Differentiation by geographical level (see table 2): Based on the data, the activities were assigned to the geographical levels of Germany, Europe and internationally, which allows a geographically differentiated presentation within the networking levels of value creation, research and networks. The origin of the connection served as an allocation criterion. In the case of networks, the decisive factor is whether it is primarily a European-led initiative, and at the research level, whether funded projects are financed by federal or European funds, for example.

	Germany	Europe	International
Value creation level	Kion Battery Systems, JT Energy Systems, Digital Energy Solutions, VW-VM Forschungsgesellschaft mbH & Co. KG (4 joint ventures)	Automotive Cells Company (ACC), Coulomb, Hydro Volt AS, Joint Venture between Iveco, Nikola & FPT Industrial, Joint Venture between VW and Northvolt, Joint Venture between Eneris and Leclanché (6 joint ventures)	Further joint ventures and value creation cooperation (40 joint ventures, see full table in the annex)
Research level	Funding catalogue (109 joint projects)	CORDIS (92 projects)	SCOPUS.[III] (1,240 publications)
Strategic level	BDE, BEM, BVES, KLiB, VDA, VDMA Battery Production (6 associations/networks)	ACEA, ALISTORE, CLEPA, CNESA, EBA, EBRA, EGVI, EIT InnoEnergy, EIT RawMaterials, ERTRAC, EUCAR, EUROBAT, EUROMETAUX, RECHARGE (14 associations/networks)	BAJ, CNESA, GBA (3 associations/networks)

III SCOPUS data are not systematically included in the analysis, so they are greyed out in the table. See the note in the section "Differentiation by geographical level" on the use of SCOPUS data.

Table 2: Allocation of data sources by geographical level

This criterion is not useful for value creation cooperation due to the strong reciprocity of the relationship, so that the decisive factor for classification is whether the actors involved are located internationally, in Europe or in Germany.

Despite the focus on Germany and Europe, the international level served as a reference partially, since most of the activities considered at the value creation level take place in the international area and organisations important for the development of battery cell production, such as the Global Battery Alliance, are also active internationally. For the analysis at the research level in the international area, the SCOPUS database was used. Since the focus of the database is strongly on the European area[15] and publications are often written within the framework of research projects, an intersection with the CORDIS or funding catalogue data is to be expected. In order to avoid bias, the international level is not systematically included in the consideration of the links, but only as a supplement.

Content analysis of the connections: A content analysis of the networks and interest groups, joint ventures or research projects was carried out on the identified connections. The basis for this was the previously described classification of individual connections according to value creation stages in the simplified classification shown in figure 2 according to materials (material extraction and production), production (production of components up to product integration) and recycling (incl. second life approaches).

Network analysis: The relevance of actors and their position in the network was assessed by analysing the network underlying the ecosystem according to various parameters of a network analysis[16]. Among other things, the degree of interconnectedness, the degree of proximity and the degree of "betweenness" of individual actors were considered. The degree of interconnectedness is the set of all edges of an actor and thus indicates how many connections an actor has with other actors[17]. It is therefore a simple measure of the centrality of a node[18]. Proximity indicates the distance[19] of a node to all other nodes and shows which nodes are in the "centre" of the network. It is therefore less dependent on mediation by other nodes when reaching other nodes[20]. Betweenness indicates how often an actor is on the shortest path to other actors. This provides a measure of the structural dependence of a pair of nodes on a third node, i.e. how many nodes a node connects with each other[21]. While the degree of interconnectedness is a local measure, since it only measures the number of "immediate neighbourhoods" of a node, proximity and betweenness are so-called global measures. This is because they always relate individual nodes to the entire network. For the network analysis, as well as for the creation of the network graphics shown in this study, the tool Gephi[22] was used.

2.4 Limitations of the study

Analysis of actually "active" connections: In the study, connections between actors are considered that can be "activated" by the actors in the sense of this study. With regard to future cooperation, the assumption is that connections that already exist through joint activities can be reactivated for future activities. Whether the connections are actually actively used by the actors cannot be proven on the basis of the data used, with the exception of active joint ventures and ongoing research projects. In this sense, the ecosystem outlined in this study should be understood as a "possibility space" of usable connections.

Distortions due to data quality: In the data cleansing, renaming of actors, e.g. as a result of company restructuring, was taken into account as far as possible. It was not checked whether individual players still exist or have already

15 cf. Elsevier, 2020, p. 19

16 A discussion of the various measures of network analysis cannot be undertaken here. For this, please refer to the relevant literature, e.g. Stegbauer, C. (ed.), 2010 and Stegbauer, C., & Häußling, R. (ed.), 2010.

17 Mutschke, 2010, p. 367

18 „Node" is a term from graph theory and denotes a connecting point of at least two edges.

19 The distance refers to the graph-theoretical distance, which is to be understood as „the number of edges of the shortest path connecting [two nodes]." (Mutschke, 2020, p. 367)

20 Mutschke, 2010, p. 367

21 Mutschke, 2010, p. 370

22 https://gephi.org/

disappeared from the market (e.g. as a result of being bought out by other companies, insolvency, etc.). Furthermore, the data sometimes show different aggregation levels of companies (e.g. group – subsidiary, research company – institute, university – department). It is not always clear which part of the company is involved in a cooperation. In addition, some companies have national offshoots in different countries with their own legal form. In order to obtain the greatest possible depth of detail, especially in the geographical analysis (e.g. regarding the application for national funding, integration into local structures)[23], these different levels are broken down as far as possible. If there is no more detailed information on the part of the company or the organisational unit, the connection is attributed to the respective parent organisation. Due to the different aggregation levels of the data sources considered, distortions may occur in the network representation.

Bias due to the restriction to publicly available data: Cooperation at the level of value creation is exclusively represented by publicly disclosed joint ventures. Supplier relationships or other forms of business cooperation are only made public in exceptional cases. Therefore, there is an undetermined number of connections that are not recorded in this study. In addition, some of the networks considered have several hundred members. If no structured lists of members were available in a machine-readable format for easy processing (e.g. as an Excel file), these can only be presented in excerpts due to their size (see overview in the appendix). Therefore, only individual particularly relevant initiatives and interest groups (e.g. GBA and EBA) are fully mapped in this study. Furthermore, when considering the research level, no research projects from national funding of the European member states are taken into account[24], but only projects from the CORDIS database. Therefore, the networking at the research level in relation to the entire European area is probably also greater than shown in this study.

Technical limitations of data science approaches: Due to the large amount of data used in this study, it was processed using data science approaches. Data science approaches can facilitate many processes and support the content analysis of large amounts of data. Very good results were already achieved with the methods used in the run-up to this study. Nevertheless, false positives cannot be ruled out, for example in the automated classification of data at the research level.

23 This applies, for example, when a company sets up a subsidiary in another country in order to gain access to national funding there.

24 Germany is considered separately from the European level in this study due to the focus on Germany in the ecosystem as its own level.

3 DEVELOPMENT OF BATTERY CELL PRODUCTION IN GERMANY AND EUROPE

Key findings

- Expected increase in **global market demand for** lithium-ion batteries from 200 GWh/a in 2019 to approximately **1,200 GWh/a by 2030**.
- According to the manufacturers, **battery cell production capacity in Europe** (incl. IPCEIs) will increase to **up to 595 GWh/a** by 2030, and globally to up to 2,100 GWh/a. This ideal case assumes that all production facilities are built as planned and produce at full load without rejects.
- The **share of European cell manufacturers** in production capacities in Europe will grow to **about 50 percent** by 2030.
- The IPCEIs will ramp up European cell production, introduce substantial innovations to the market and create a strong actor network along the entire value chain.

The EU sees the **development and production of batteries in Europe as** a **strategic necessity**[25] for the competitiveness of its automotive sector. According to an internal market analysis by the accompanying research group Battery Cell Production commissioned by the BMWi, the automotive sector is already the clear lead market for lithium-ion batteries. About two out of three LIB cells were needed for automotive applications in 2018.

In the coming years, the demand will increase significantly. Vehicle manufacturers must reduce the average carbon dioxide (CO_2) emissions of their fleet and **accelerate** the **introduction of low-emission and zero-emission vehicles** in order to avoid high fines. Plug-in hybrids (PHEVs) and battery electric vehicles (BEVs), and thus batteries, play a central role in this[26]. While the EU-wide CO_2 emission targets for vehicle fleets envisage a significant reduction in emissions as early as 2020[27], the average emission of passenger cars registered in

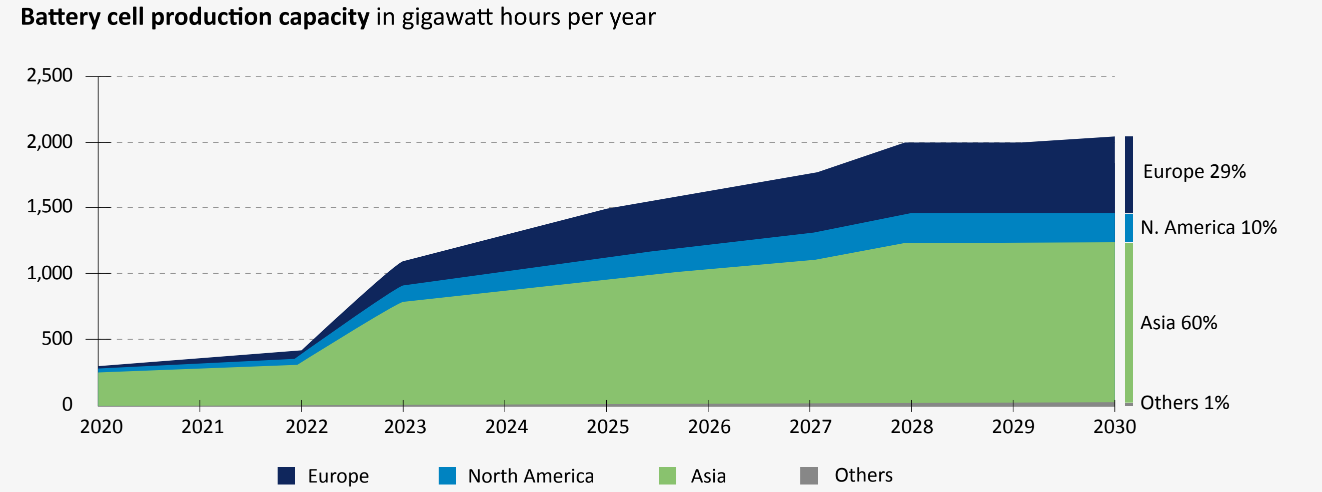


Figure 5: Development over time of the annual production capacity of battery cells in Europe. Source: Analysis of the scientific monitoring of battery cell production based on publicly available information sources.

25 European Commission, 2018

26 Transport and Environment, 2019

27 European Commission,2019b

the EU[28] in 2019 was 122.4 grams of CO_2 per kilometre, well above the stricter limit of 95 g CO_2 / km that came into force in 2020. As a result, after several years of tentative growth, the **number of EV models produced in the EU** (and thus available on the market) is rising sharply, according to a study by T&E[29]: Starting from around 60 BEV, PHEV and fuel cell (FCEV) models available at the end of 2018, this is expected **to rise to 214 models in 2021**. In combination with rising registration figures, a significant increase in the demand for battery (cells) is emerging.

According to the forecast of a recent study, the global market demand for LIBs is expected to increase to about 1,200 GWh by 2030[30]. In the same period, global battery cell production capacity will reach 2,100 GWh / a, according to manufacturers. The prerequisite for this ideal case is that all production facilities are built as planned and produce cells at full capacity without rejects. Figure 5 shows the increase in **production capacity in Europe** from currently about 20 Wh / a to about 595 GWh / a in 2030. According to this, production facilities for battery cells will be built primarily in Germany, Poland, Sweden, UK and Hungary. **European manufacturers** are also **significantly involved** in this. While they do not currently have any significant production capacities in Europe, their **share will grow to about 50 percent by 2030**.

Driven by the EU's CO_2 targets for vehicle fleets, **carmakers and others invested about 3.5 times as much in electric mobility in Europe as in China**, with 60 billion euros in 2019, according to T&E[31]. Given the scale and speed of the investments made and the continued need for them, this strategic challenge cannot be addressed in a fragmented way. Therefore, the **IPCEI on battery cell production** will promote **cross-border work** in the four areas of raw materials and advanced materials, cells and modules, battery systems, and repurposing, recycling and refining. Thus, not only the **European cell production will be ramped up**, but also a European concept will be implemented that covers the **entire value chain of the battery ecosystem** and focuses on sustainability. To successfully build a sustainable and vibrant battery ecosystem, it is necessary to have a basic overview of the current state of development of the ecosystem.

28 EU-27 plus UK, Iceland and Norway

29 ibid.

30 Avicenne, 2020

31 Transport & Environment, 2020

4 STATUS QUO OF THE ECOSYSTEM IN GERMANY AND EUROPE

Key findings

- The **ecosystem is strongly dominated by companies**, as companies represent the largest group of actors in the ecosystem under consideration at every networking level, followed at a great distance by research institutions.
- Among the **TOP 10** most networked actors, across the various networking levels, are **predominantly large internationally active** companies.
- The topic of **production** occupies a **focal point in the ecosystem at European level** due to the large share of network connections.
- The identified connections at the research level can be assigned primarily to the aspects of utilisation and production, whereby regional differences between Germany and Europe can be observed here. In **Germany**, the topic of production is dealt with more strongly in research than in Europe.
- The actor category of **companies** represents the **most interfaces** (actors with activities on several levels) between different levels compared to the other categories.
- Compared to the basic population (n=3,178) of the actors considered, there are **comparatively few actors** who act **as an interface between German and European activities** (approx. five percent).

For successfully establishing the key industry of battery cell production in Germany and Europe, it is necessary, among other things, to build up a dynamic and well-networked ecosystem in which this key industry is “embedded”. In Europe, there are already many actors with suitable competences that are necessary for the establishment of battery cell production. Examples include the strong research landscape and the competences of German mechanical and plant engineering companies. Nevertheless, there are also obvious weaknesses along the value chain in Europe, such as the poor access to strategically important raw materials. Before looking at the gaps in Chapter 5, the following section first shows the “status quo” of the ecosystem as it appears on the basis of the data used in this study.

4.1 Actors and drivers

The battery cell production ecosystem contains **a large number of different** actors, which are classified **into the five categories “companies”, “research institutions”, “networks”, “standardisation organisations” and “others”**. Figure 6 shows the number and distribution of the individual categories for the entire ecosystem as well as per networking level. Overall, companies are the dominant group (81 percent) in all the connections considered. This in particular results from the large number of companies in the networks considered. But companies also dominate at the research level with a share of 67 percent of all actors at this level. As expected, it is primarily research institutions that are represented at the research level.

A wide range of different actors can be found in the categories of actors considered. The group of Companies includes both internationally active large companies and corporations as well as small and medium-sized enterprises (SMEs). The former often belong to the particularly strongly networked companies. In terms of content, the activities of the participating companies cover the entire value chain (see also Chapter 4.2 and Chapter 5). The Research Institutions range from universities, sometimes represented by several institutes, to large research organisations and to public and private research institutes. In the category of Networks, there are above all numerous large interest groups. Pure automotive associations as well as battery- and storage-centred associations, networks and platforms are represented here as independent actors[32]. Furthermore, there are numerous actors in the battery cell production ecosystem that cannot be assigned to any of the three aforementioned categories and are therefore grouped under Others. This category mainly includes municipalities and cities, but also public institutions such as the Physikalisch-Technische Bundesanstalt (National Metrology Institute of Germany). The European Commission is also directly involved in the ecosystem through various Directorates-General and their participation in networks. Chambers of commerce or donors (e.g. the European Fund for Strategic Investments) can also be found in this group. It should also be emphasised

32 These are to be distinguished from networks and interest groups, which are considered at the networking level. See also the methodological notes in Chapter 2.1.

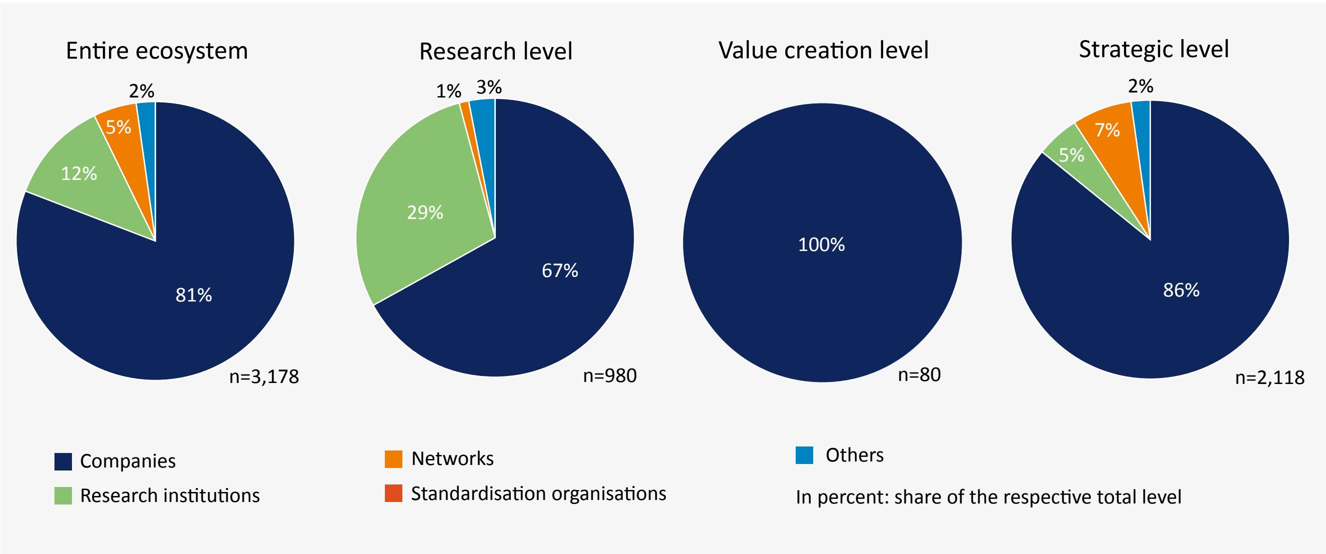


Figure 6: Number of actors per connection level

that four standardisation organisations, DIN, DKE, CEN, CEN/CENELEC and the Spanish standardisation and certification body, Asociación Española de Normalización, are involved in the identified activities. These are presented as a separate group due to their particular importance for standardisation and certification in the ecosystem, despite their very small number.

Considering all networking levels together, the **most networked actors**, i.e. the actors that have particularly many connections to other actors, are predominantly large internationally operating companies[33]. Thus, in the top 5 of the most networked actors, there is only one larger research organisation that also operates throughout Europe. With the restriction that the international level was only considered to a limited extent in this study, it can be seen that the most networked actors (top 10) are almost exclusively German actors.

A different picture emerges when looking at the research or value-added level alone: At the research level, it is mainly research institutions from the European region that are strongly networked – there are two larger German research organisations among the top 5 here. Due to the high proportion of international activities, the top 5 at the value-added level are exclusively large internationally active companies, of which only one is from the European region (excluding Germany). Here, a strong Asian presence can be seen in the activities considered. If the circle is extended to the top 10, two German companies are also among the most strongly networked players at the international level of the value chain.

If the ecosystem is looked at differentiated only by geographical level, i.e. without differentiating between the value-added, research and strategic levels, here too, with the exception of the European level, almost exclusively internationally active large companies are to be found among the most strongly networked players. The European level is an exception. Here, not only is the share of research institutions in the top 5 or top 10 significantly larger, but there are also actors who are not among the most networked actors at other levels, including a larger, European OEM. This is mainly due to the large share of network connections, which also offer these actors the opportunity to link up with many other actors. Overall, however, the data selection made in this study must also be taken into account in the preceding considerations with regard to the significance.

4.2 Interfaces and connections

The network representation of the battery cell production ecosystem considered in this study provides an **overview of**

33 Since the focus in this study was primarily on Germany and Europe and corresponding data basis was used, a certain bias is to be expected here.

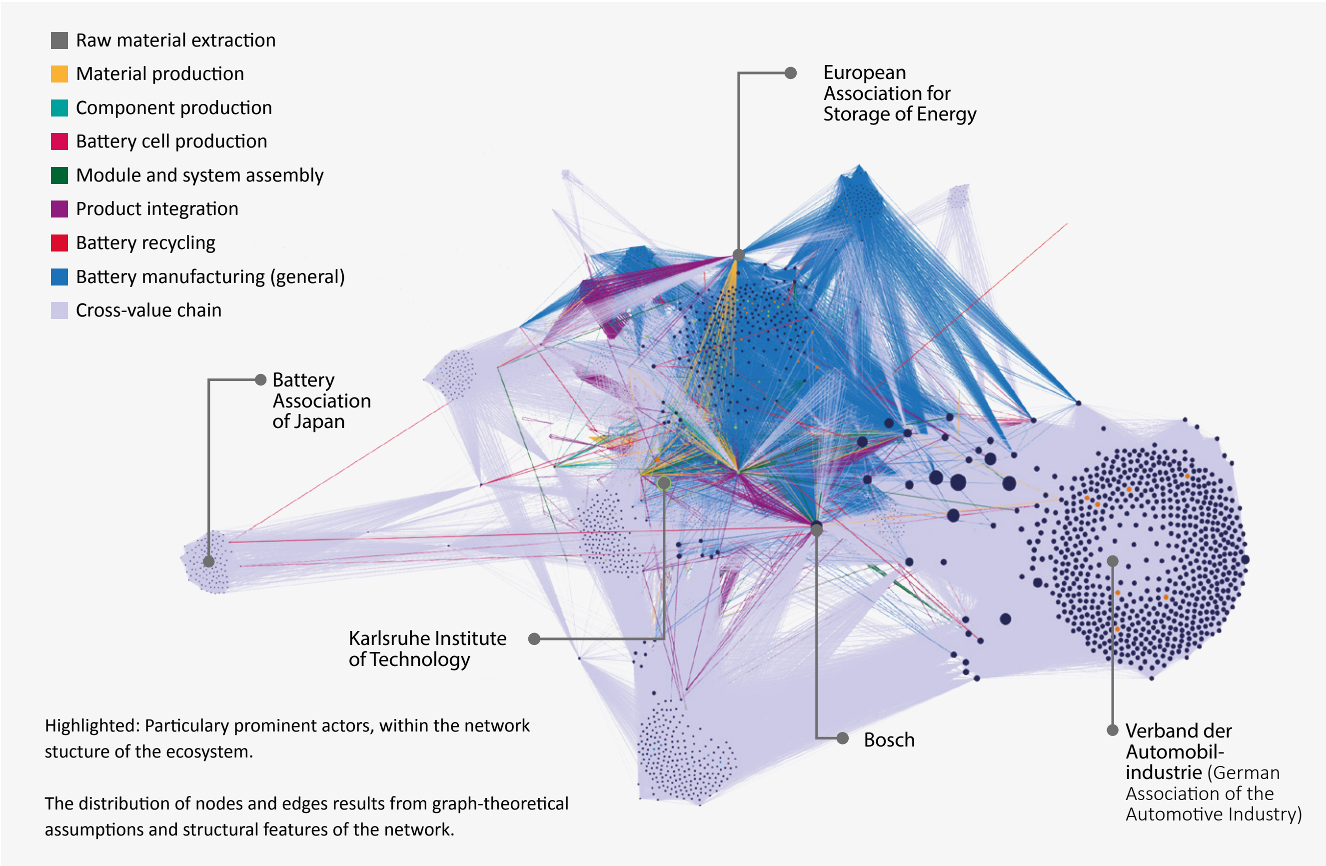


Figure 7: Overview of the entire ecosystem across all levels according to value creation stages

its structure and interconnections in figure 7. All identified actors are represented by a node whose area is proportional to the number of connections. Actors with numerous connections in many areas of the ecosystem are represented by comparatively large nodes in an exposed position. Those actors who have few connections are represented by comparatively small nodes that often agglomerate. Several agglomerates are conspicuous[34], which are collections of actors that are all connected within this agglomerate, but have few or no connections to actors outside the respective agglomerate. In the ecosystem under consideration, it is mainly the members of networks and interest groups that form agglomerates. Examples highlighted are the VDA, on the right, and the Battery Association of Japan (BAJ), on the left. Although the VDA, for example, has a particularly large number of members, only a few members could be identified who are also connected to actors from other contexts of the ecosystem, e.g. other associations or research projects. A similar picture emerges for other associations and networks, such as VDMA Battery Production or CLEPA. This means that within the networks there are very many access points to other actors (members), but only few connections to the rest of the ecosystem. Thus, these associations and networks have a certain internal effect. Despite this internal effect, this does not mean that associations and networks are not relevant for the overall ecosystem of battery cell production, but rather that many members with relevance for the ecosystem do not currently network appropriately with other actors outside the associations and networks in which they are members[35].

34 This and the following network graphs do not show a geographically correct distribution of actors. Rather, the figures show how the actors are distributed based on graph-theoretical premises and structural properties of the network.

35 This is subject to the restriction that, as explained at the beginning of Chapter 2, only publicly accessible connections are presented in the context of this study.

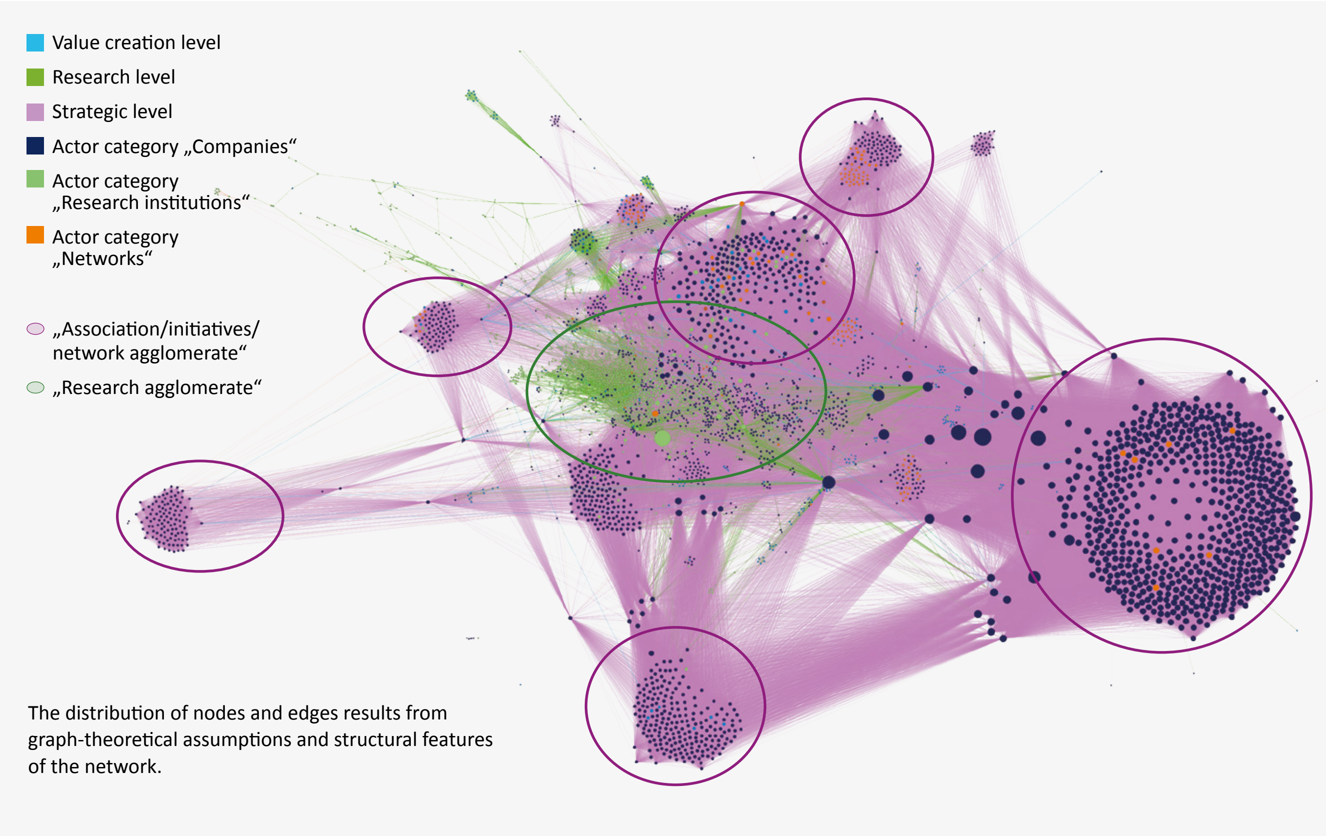


Figure 8: Overview of the entire ecosystem by connectivity level with exemplary highlighting of individual agglomerates.

Within the ecosystem there is also an **agglomeration** of research projects (see figure 8), whose boundaries are less sharp compared to those of the networks. Accordingly, the actors from research are more heterogeneously networked in the ecosystem. On the one hand, this is due to the smaller number of actors per research project compared to interest groups; on the other hand, there are also several intersections across research projects. Therefore, the agglomerate of research projects is quasi "drawn out" across the board, which is why individual research projects have a smaller internal effect than networks. Figure 9, which only shows networking via research projects, illustrates the heterogeneous distribution of actors in the ecosystem.

The number of joint ventures considered in this study is small compared to the number of research projects or networks. Consequently, relatively few actors are involved, so that no agglomeration can be detected at this level. This also means that the joint ventures are hardly networking with each other, for example through intersections among the actors involved, and they therefore tend to stand alone. Since the actors involved in joint ventures are also involved in networks or research projects, they function as interfaces to these agglomerates here (see next section).

If one analyses the **ecosystem differentiated according to the individual levels**, it becomes apparent that the majority of the connections identified in this study are realised via networks, regardless of the region under consideration (figure 10). A connection always indicates direct contact between two actors. The number of connections is therefore not identical with the number of activities in the sense of research projects, networks or joint ventures.

Compared to research projects or joint ventures, networks and associations usually have a larger number of members and can thus generate a **greater reach**. It should be noted, however, that only publicly known joint ventures could be taken into account in this study. Other value creation cooperations, such as strategic cooperations or supplier relationships, which are likely to account for a not insignificant share of connections between the actors under consideration and beyond, were not taken into account.

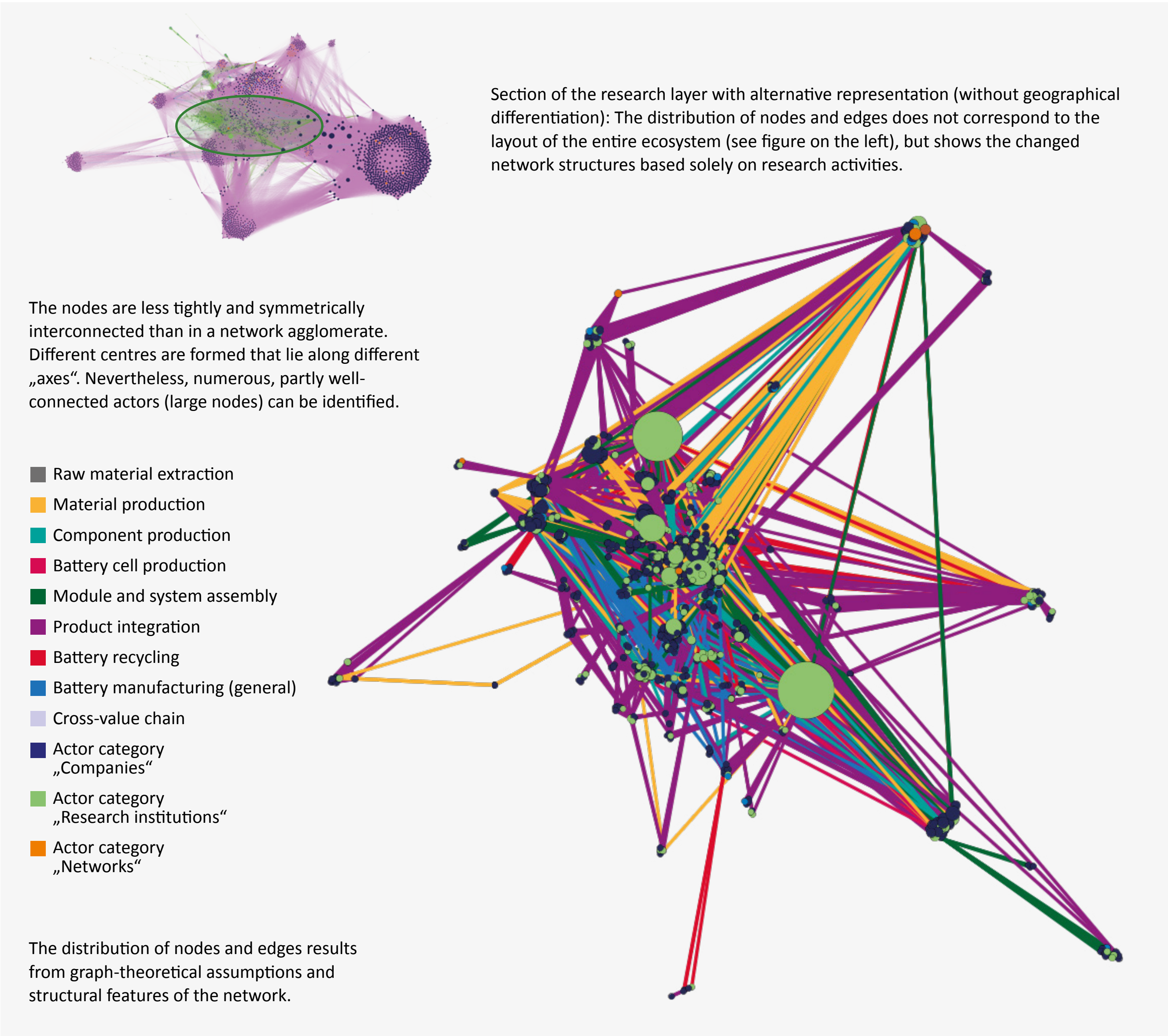


Figure 9: Focus on the research level: networking via research projects and distribution of actors

A differentiated consideration of the activities identified in this study according to the regions of *Germany and Europe* as well as the levels of *value creation*, *research and networks* proves the **dominance of networks** in connecting actors. It should be noted, however, that at the research level only the German and European levels were included in the analysis[36]. At the level of **German activities** in the field of battery cell production, almost all of the identified connections (approx. 99 percent) are realised via networks. About one percent of the connections exist through research activities. At *European level*, about 86 percent of the connections exist through joint memberships in networks and about 14 percent through research activities. At the *research* networking level, 15 percent of the activities take place in Germany and 85 percent in Europe. The international level was not considered here. At the networking level of *value creation*, 17 percent of all connections in the field of battery cell production are found at European level and six percent

36 See the note on the data basis in Chapter 2.

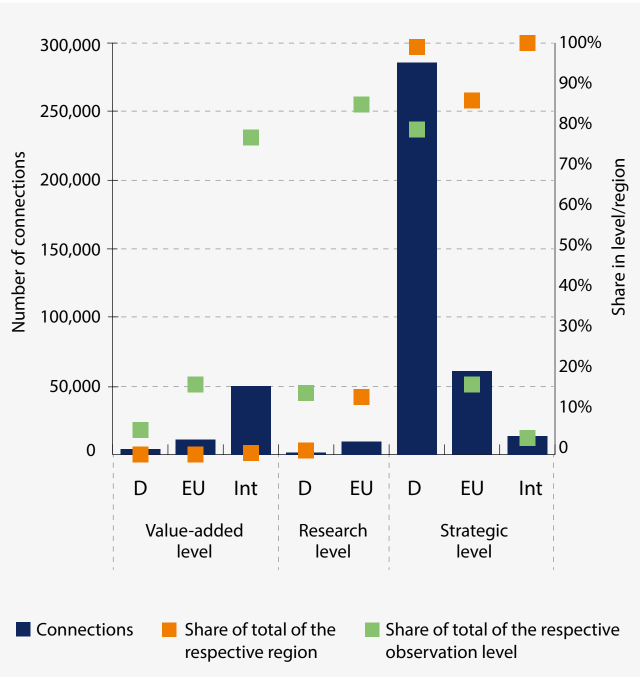


Figure 10: Number of connections of the overall network according to level. For classification purposes, their respective share of all connections of the respective networking level and the respective geographical level is shown in percent.

at German level. Most of the actors connected at this level via joint ventures are found at the international level.

At the research level, most connections exist due to activities that focus on the aspect of the use of battery storage, closely followed by the thematic focus on *production* (see figure 11). However, regional differences are evident here. In **Germany, production is addressed more strongly in research** than at European level. Use is primarily addressed by projects in the field of electric mobility, in which the battery is only one aspect of the project. Frequently, battery performance parameters are investigated that influence the range of electric vehicles and thus also the development of charging technologies. On the basis of identified research cooperation on the topic of resources, slightly fewer connections can be found compared to the other two topics. There are hardly any connections on the topic of material extraction.

Across all networking levels, ***production*** is a **thematic focus in the ecosystem**, which is in particular due to the large proportion of network connections on this topic. This is why it says nothing about the actual production capacities in Germany. In particular, the assignment of large networks – dealing with battery cell production across the board – to

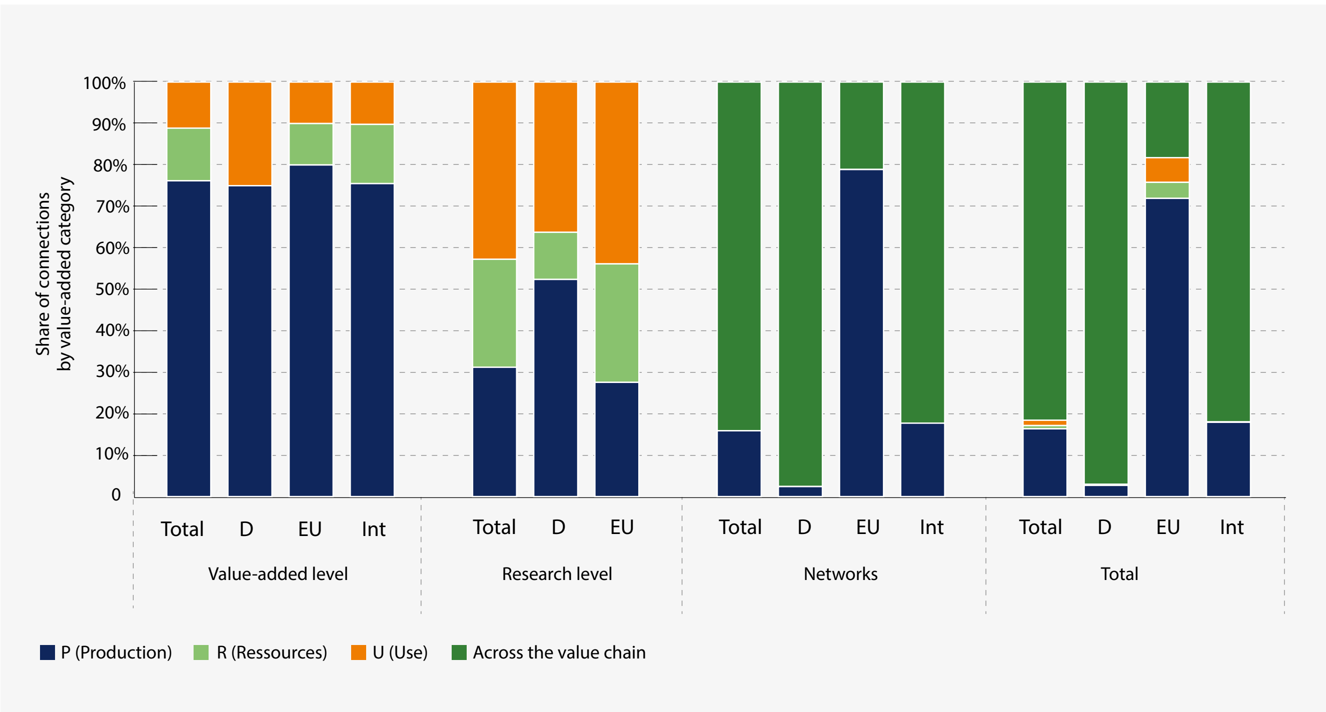


Figure 11: Thematic focus of the connections according to the superordinate value creation categories

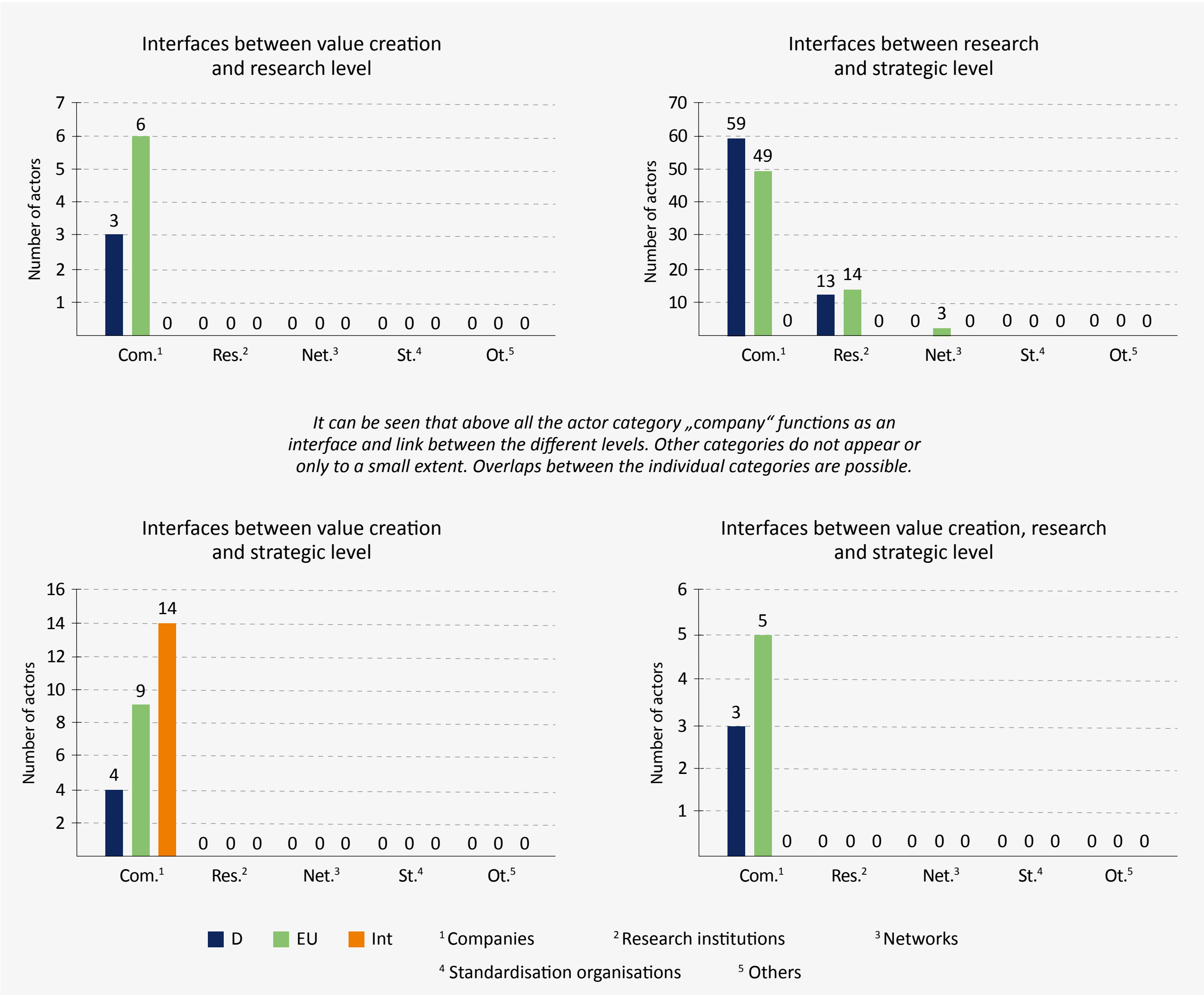


Figure 12: Interfaces between the different networking levels according to actor type

a thematic focus distorts the picture, as some of these also cover other topics. At the level of value creation, the focus is also on the topic of production, both in Germany and in Europe. On the topic of resources, which includes recycling, only a comparatively small number of links could be found.

Some actors in the ecosystem considered have a comparatively large number of connections to other actors, in some cases at several or all levels (figure 7). **Companies** are the only category of actors considered that are **represented at all three levels**. These widely networking actors have different types of connections on different thematic focal points, ranging from close cooperation at the value-added level to loose connections via networks and interest links.

However, the overall view of the ecosystem presented at the beginning of Chapter 4.2 also shows that in relation to the total number of actors, only a few occupy multiple interfaces (cf. figure 7 and figure 8).

Due to the large number of actors in networks and research projects compared to joint ventures, the intersection of these two levels is the largest (figure 12). About **five percent of all actors in the ecosystem considered** are active in **both, research projects and networks**. These are predominantly larger companies and universities at German and European level (figure 13). The exception is a testing and certification company that is involved in German and European research activities as well as networks.

About **five percent of the actors are** involved in **both German and European activities**. At this interface there are to be found predominantly companies, but also research institutions and organisations and, to a small extent, networks.

Compared to the total number of actors in the ecosystem, relatively few actors are active in several or all levels. In addition to the most strongly networked actors per networking level, the ecosystem also includes a number of companies that have hardly networked so far, but whose activities (e.g. raw material supplier or recycling specialist) give them a relevant role in the value chain of sustainably produced battery cells and thus also in the ecosystem. This also includes important networks and interest groups that act as independent, corporate actors. For the establishment of a circular economy, there is a lack of such actors and organisations that could be important promoters for the topic.

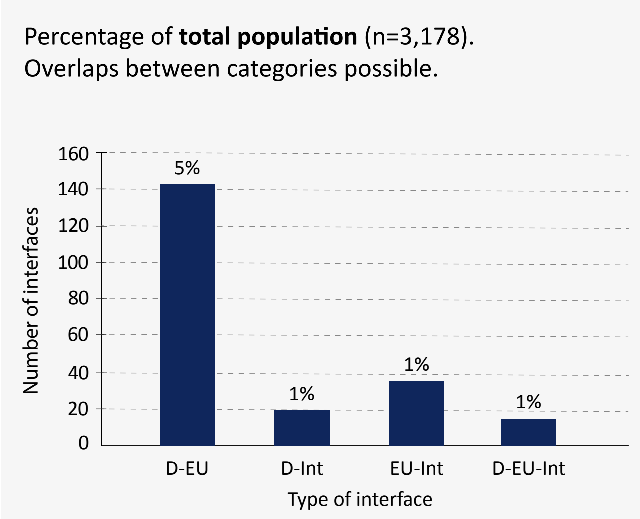


Figure 13: Number of actors with activities in more than one geographical region

5 ANALYSIS OF THE NETWORK STRUCTURES OF THE ECOSYSTEM IN GERMANY AND EUROPE

Key findings

- Many actors in the battery cell production ecosystem considered here are **well networked within organised groups and associations, but** beyond that have **few external contacts** to other parts of the ecosystem.
- Some **key actors**, few in relation to the total number, form the interfaces between the levels.
- Actors who serve as interfaces between several levels have a strategic **function in the ecosystem**, as they can set impulses across different levels and steer issues due to their central role as connectors between different levels ("gatekeepers").
- In the less networked and poorly integrated part of the ecosystem, there are small companies that are only now gaining a foothold in the topic as well as thematically very focused companies and OEMs that make a major contribution with their **specialised knowledge** in the development of innovative products and processes and are therefore very important for the overall ecosystem.
- **Businesses** represent the largest category of actors in the identified multi-level interfaces and thus play a **multifaceted role in** the ecosystem, as they are not only involved in value creation but can also lead knowledge transfer in the ecosystem.
- The strategic role of the research actors in terms of linking the activities that are important for establishing a **circular economy**, like recycling and production of cells, modules, systems and/or car manufacturing, is an argument for a **focus on research**, but also for a **weaker involvement of industry**.
- At European level, the focus on **industry-related development projects** with the thematic topic production is less pronounced compared to the German level, but large-scale **demonstration projects** with many actors offer high networking potential.
- In the thematic cluster **resources**, the projects have so far been primarily dedicated to the development of new materials and not to the topic of recycling. However, new initiatives show that the topic of recycling will come more to the fore in the future.

On the basis of the explanations of the status quo in Chapter 4, this chapter provides a more in-depth analysis of the ecosystem. The focus is on identifying gaps in the ecosystem with regard to characteristic aspects such as networking and role distribution.

5.1 Roles in the ecosystem

In this section, the roles of the actor categories defined in Chapter 2 (companies, research institutions, networks, standardisation organisations [SDO] and others) are examined at the different networking levels. As presented in Chapter 4, the networking of actors via research projects, networks and joint ventures is examined in the context of this study, whereby a distinction is also made between the German and European research levels in the following consideration.

Roles in the German and European research landscape

To assess the distribution of roles within the German research landscape, 190 collaborative projects financed or partially financed by federal funds were evaluated. A total of **340 different actors** could be identified, of which almost three quarters could be assigned to the category *Company* and one quarter to the category *Research institution*. No actors could be assigned to the category *Other*, and one actor each to the categories *SDO* and *Network*. The shares of actors per defined category are shown in figure 14. All identified actors are located in Germany.

Within the European research landscape, 92 projects financed or partially financed by European funding were evaluated. Analogous to the analysis of the German research landscape, a total of 652 different actors were assigned to a category. About **two thirds of the actors could** be assigned to **the *category* Company** and about 30 percent to the category *Research* institution. The remaining actors are distributed among the categories *Network*, *Other* and *SDO*. The distribution is shown in figure 15.

The branches of the **652 EU-funded actors** are spread across 39 countries, with 80 percent of the identified actors coming from ten countries. With 101 different actors, Germany is leading the field, followed by France (90) and Spain (74). Figure 15 visualises the respective number of actors from

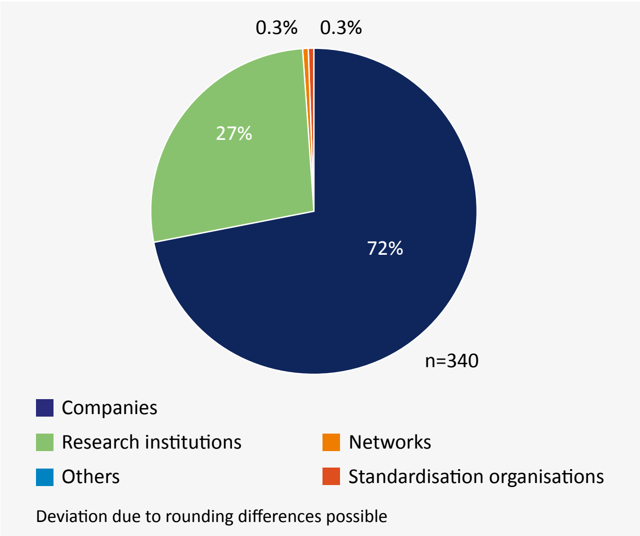


Figure 14: Number of different actors in federally funded research projects.

the ten countries and shows that with 265 actors funded at European level, about 40 percent come from the three previously mentioned countries. The allocation of the actors from these ten countries to the actor categories showed that in most countries at least 60 percent of the actors belong to the category ***Companies*** (figure 16). Only the United Kingdom, Belgium and Denmark deviate from this. While more research institutions are involved in the UK and Denmark compared to the other countries, the deviation in Belgium is due to a higher number of networks involved, which are mainly located in Brussels due to their often European orientation.

With the exception of Germany, Belgium and Austria, the ten countries under review also include actors in the ***Other*** category. These actors are often **local authorities**, but also **public authorities**, **non-profit organisations** or **agencies for urban and project development**. As in the German research landscape, the ***SDO*** category is occupied by only one actor.

Compared to the German research landscape, the European research landscape forms a **larger network of different actors** despite the smaller number of projects evaluated. This is mainly due to the fact that on average twelve partners are involved in European projects and four in German projects. Furthermore, at European level, a higher proportion of the identified actors could be assigned to the categories ***Network*** and ***Other***. In particular, the actors in the category Other, e.g. local authorities but also public authorities, non-profit organisations or agencies for urban and project

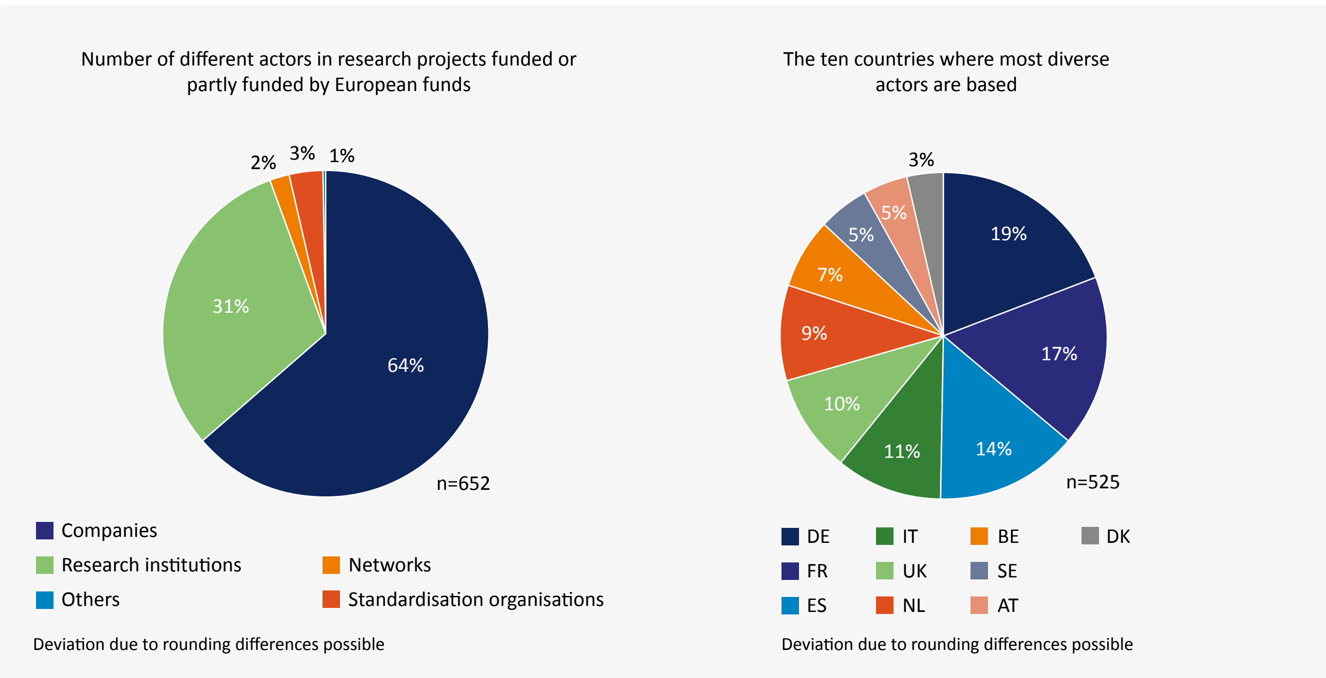


Figure 15: Overview of the actor landscape at European level

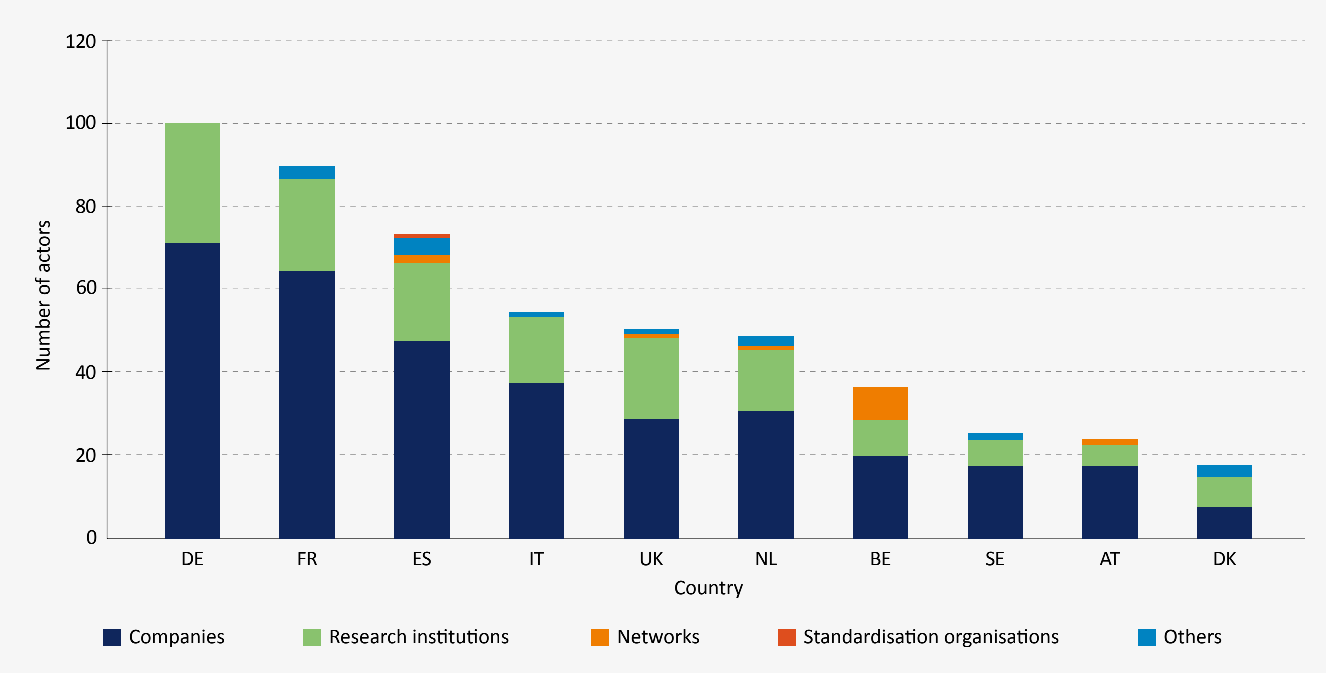


Figure 16: Classification of actors according to the categories defined in Chapter 2 for the ten countries with the highest number of different actors.

development, are often involved in demonstration projects and enable the implementation of project objectives under real conditions and in part close to the public.

The actor category *Other*, which is not present in the German research landscape, is an indication that the projects funded with federal funds are less involved with the implementation of **demonstration projects** close to the public under real conditions, but rather focus on the development of industrial solutions.

Roles in joint ventures and networks

As already explained in Chapter 4, joint ventures are cooperations between companies. Therefore, the identified joint ventures exclusively link actors from the category of *Companies*.

In contrast, all actor categories can be found in the evaluated networks (figure 6). As shown in Chapter 4.1, companies are particularly strongly represented in networks. This results, among other things, from the nature of the networks, which also include some industry associations. In quantitative terms, research institutions play a subordinate role in the networks and associations and are still positioned in third place behind the actor category *Networks*. In fourth place is the category *Other*, followed by *SDO*, in which two representatives can be found among the actors.

In addition to political institutions, the category *Other* also includes banks and other funders. Actors assigned to the category Other are particularly active in alliances that pursue the goal of establishing a sustainable battery value chain with a different regional focus. Since the establishment of sustainable value chains should be as holistic as possible, the alliances bring together a large number of different actors from the entire battery ecosystem. This illustrates that in addition to the actors primarily considered in this study, *Companies*, *Research institutions*, *Networks* and *SDOs*, there are **other actors**, such as political institutions, banks and funders or local authorities, that **can be seen as a part of the battery ecosystem**. In this study, these roles are summarised in the actor category *Other*. For future analyses, it makes sense to assign each of these roles to a separate actor category in order to specifically investigate their integration into the ecosystem.

Summary: Roles in the ecosystem

Representatives of the actor categories *Companies* and *Research institutions* can in particular be found in the German research landscape. This reflects the focus on industry-related research projects. At European level, in addition to the companies and research institutions, which are also strongly represented, there are more actors from the categories of *Networks* and *Other*. Accordingly, in addition to the industry-related research projects, supplementary demonstration projects are carried out at European level under real and partly public conditions due to the involvement of e.g. local authorities.

The actors belonging to the category *Other* indicate that in addition to companies, R&D institutions, networks and SDOs, other actors are relevant for a functioning battery ecosystem. These include, for example, local authorities, banks and other financing instruments or political institutions.

5.2 Thematic clusters

The allocation of research projects and joint ventures to the thematic clusters of *resources*, *production* and *utilisation* (cf. Chapter 2) is shown in figure 17.

In the case of research projects, a distinction is made between the German and the European research landscape. Due to the high thematic diversity of some of the networks considered, they were not assigned to thematic clusters.

Topic clusters in the German and European research landscape

The German research landscape under review comprises 190 collaborative projects financed by federal funds. With over 100 collaborative projects, the focus within the German research landscape lies clearly on the topic of *production*. With 45 collaborative projects, the topic of *utilisation* follows in second place, closely followed by the topic of *resources* with 33 collaborative projects. On average, four collaborative partners were involved in the projects in the area of resources and five in the area of *production* and *utilisation*.

The strong focus on the topic of *production* supports the thesis established in Chapter 5.1 that the projects financed with federal funds address more strongly the **development of industrial solutions for the production of batteries**. Public demonstrations under real conditions are suitable in view to their use. Contrary to the assumption formulated in Chapter 5.1, corresponding demonstration projects can also be found in this topic. However, testing under real conditions can take place without funds flowing to associated partners, such as local authorities, which is why they are not explicitly listed as project partners in the databases. Therefore, demonstration projects can be carried out under real and public conditions, although no actors are listed in the category Other.

In the field of *resources*, the projects primarily develop **new materials for lithium-ion batteries**, but also for post-lithium-ion batteries. The topic of battery recycling was only specifically addressed by a few of the evaluated projects. In order to realise closed-loop recycling as far as possible and to reduce dependence on raw materials, the topic of battery recycling should be included more strongly in the future. The first steps in this direction are already being taken.

At European level, 39 of the 92 evaluated projects are assigned to the *production* cluster. In contrast to the German research landscape, the gap between the topics of *resources* and *utilisation* is significantly smaller. The topic of resources follows in second place with 28 projects and the topic of *utilisation* in third place with 25 projects. On average, twelve partners were involved in the area of *resources*, ten in the area of *production* and 16 in the area of *utilisation*.

Compared to German research projects, **significantly more partners** are **involved in the individual projects at European level**. This is especially true in the area of *utilisation*, where on average more than three times as many partners are involved in the European projects. This is due to the fact that in the European research landscape, extensive demonstration projects are implemented with many actors, in which technologies are tested, for example, in several regions in the EU. The high number of actors involved ultimately leads to the highest number of networks in the thematic area of *utilisation*, as outlined in Chapter 4.2.

As in the German research landscape, the European projects in the thematic cluster *resources* primarily research and develop new materials for lithium-ion and post-lithium-ion batteries. The topic of *recycling* is addressed by fewer projects. However, there are institutions at European level that are specifically dedicated to the topic of *resources* and promote research projects in this area. In this context, the European Battery Alliance was founded. It is specifically dedicated to the topics of raw material supply and reduction of raw material dependency.

Thematic clusters of the joint ventures

With 34 of the 49 joint ventures evaluated, most of them are also assigned to the topic of *production*. The topic of resources follows in second place with ten joint ventures and

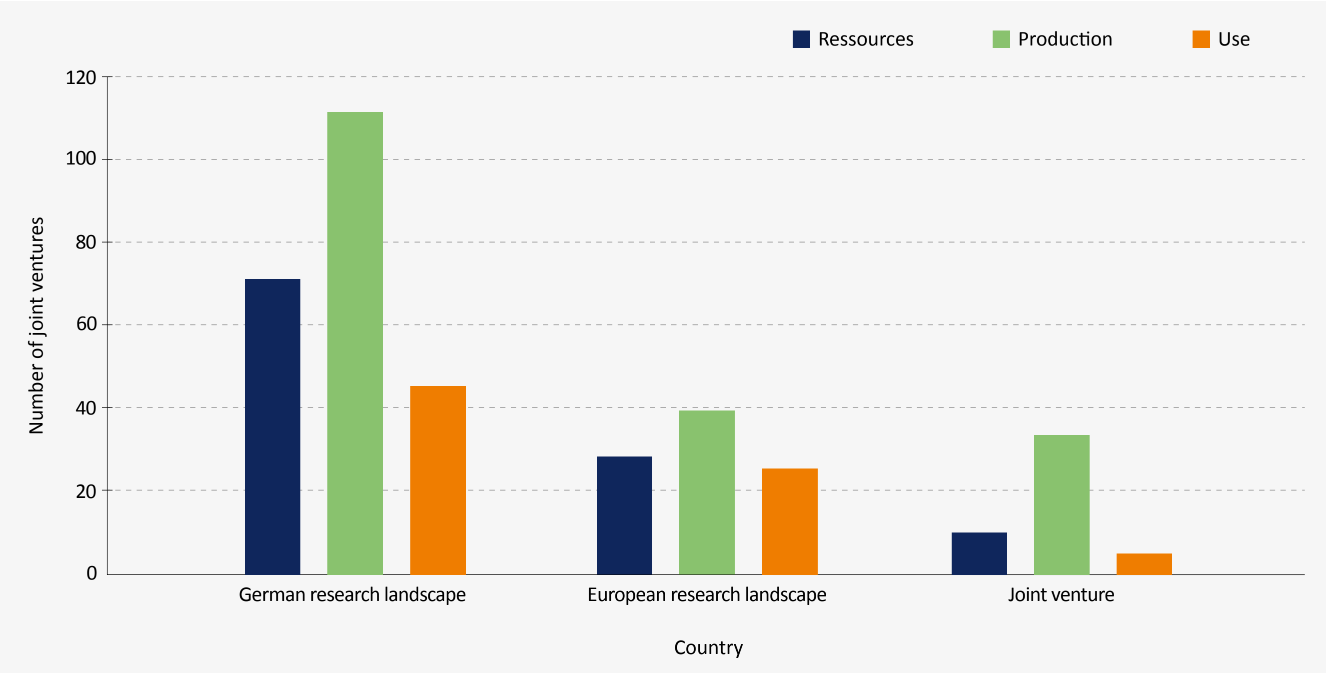


Figure 17: Allocation of the identified research projects and joint ventures to the thematic clusters of resources, production and utilisation. For the research projects, a differentiation is made between the German and European research landscape.

the topic of ***utilisation*** in third place with five Joint ventures in the field of ***production*** often exist between users, such as passenger car or commercial vehicle manufacturers, and manufacturers of cells, modules or systems and serve not only to **expand knowledge** but also to **reliably supply users with batteries**. There are also joint ventures between equipment manufacturers or suppliers of electric car components, which often serve to expand the product portfolio and open up new markets.

Joint ventures in the ***resources*** sector exist, among others, between cell and material manufacturers or raw material producers. These primarily serve to ensure a reliable supply of raw materials and materials. In addition, there are company cooperations in this area with the aim of building up recycling capacities and/or developing second life applications. Joint ventures in the ***utilisation*** field exist between car manufacturers, among others, and serve to **open up markets or the joint development of electric cars**. In addition, there are also cooperations that aim to build or develop charging infrastructure.

Summary of the thematic clusters

In the German research landscape and in joint ventures, there is a strong focus on the production theme cluster. At European level, most projects are also assigned to the ***production*** cluster, but the focus is less pronounced. At European level, extensive demonstration projects are implemented in which a large number of actors are involved. The high number of actors involved means that the ***utilisation*** theme cluster, as shown in Chapter 4.2, has the most connections. The ***production*** theme cluster follows in second place in terms of the number of connections, despite the significantly higher number of collaborative projects and joint ventures compared to utilisation overall. In the ***resources*** theme cluster, projects are primarily dedicated to the development of new materials and less to recycling. Newly founded initiatives show that the topic of recycling will be given more consideration in the future.

5.3 Involvement of the actors in the ecosystem

This chapter presents the findings of the structural analysis of the ecosystem, for which various parameters of a network analysis, such as degree of interconnectedness, proximity and *betweenness centrality* (cf. Chapter 2.3) were determined. Among other things, the results provide information on **how strongly an actor is integrated in the network** and whether an actor occupies a **central position in the network**, for example (actors of the “inner” circle of the ecosystem). It was also evaluated which actors are currently not particularly integrated into the ecosystem, although they could play an important role there, for example due to their activities or sector affiliation (actors of the “extended” circle of the ecosystem). These actors could be expediently integrated into the ecosystem through networking measures.

Special cases in the interpretation of the data: Relationship between degree of interconnectedness, proximity and betweenness

There are also special cases that need to be taken into account when interpreting the data. These include actors who are to be found in the top 10 most networked actors, although the betweenness centrality determined for them is 0. This occurs with actors who, as members of a network or an interest group, are only connected to other members of this network. These nodes (actors) thus have a high degree of networking, but no central “location” in the network, since every actor is connected with everyone. In very large networks, these actors therefore have a high degree of interconnectedness but only a betweenness value of 0. In other cases, actors with a proximity of 1 have a very low degree of interconnectedness. These actors are in a kind of very small separate network outside the rest of the ecosystem network. Within this separate network, all actors are part of as many shortest paths as possible. Due to the small number of actors in this separate network, they have few connections with other actors.

The degree of cross-linking is largely determined by the values of ***proximity*** and ***betweenness***. In general, the higher the ***proximity*** rate (value range: 0-1) and ***betweenness*** rate (value range: 0-1), the higher is the degree of crosslinking (absolute number of connections).

The analysis of cooperation within certain thematically relevant networks (see table b in Appendix II) revealed that **companies** in particular play **a decisive role** here, **regardless of the geographical level** (within Germany, Europe or internationally). In addition to the companies, one research company in Germany and two universities and one network in Europe are among the ten best-networked actors. Among 100 actors in the international area, there are 99 companies and one research institution. The advantages of networking are thus largely used by companies. There is potential here to expand the networks by integrating universities and research institutions or combining these groups of actors into networks. The few networked actors are also largely company representatives, 40 percent of which are OEMs in the European and international area.

A geographically differentiated view of the network-level population evaluated in this study shows that the **more geographically restricted the level, the higher the degree of networking**. The degree of networking (value range: 0-2,350) of the top 10 actors in Germany lies between 1,100 and 1,900 and is thus much higher than within Europe (410-560) and in international comparison (110-210). In addition, international networks are comparatively strongly shaped by Asian actors. Among the seven most strongly networked actors there are only two European actors, one of it is German. In the connections analysed in this study, it becomes clear that companies are partly focussed on Germany, Europe or the international area and are active there. It is also noticeable that less networked actors at international level have a comparatively high degree of networking within the network level (~60) and that these are mostly European actors.

The **relevant networks** in terms of actors with a high degree of networking are the German Association of the Automotive Industry (VDA) as well as the German Energy Storage Association e. V. (BVES) and the Competence Network Lithium-Ion Batteries e. V. (KLiB) in Germany, the European Battery Alliance (EBA) in Europe and the China Energy Storage Alliance (CNESA) as well as the Global Battery Alliance (GBA) at international level (see figure 18). The aforementioned networks cover many areas, so that a focus within the value chain cannot be clearly crystallised.

At the level of research and development work, cooperation and corresponding networking within the framework of research projects in Germany as well as in Europe were evaluated. At the international level, publications from the SCOPUS database were analysed again. Here, too, the correlation between the degree of networking, ***proximity*** and ***betweenness*** could be established, with ***betweenness*** having a greater influence. Comprehensive analysis results can be found in the tables in Appendix II.

Compared to the network level, **research and technology organisations** have **the greatest influence at research level**.

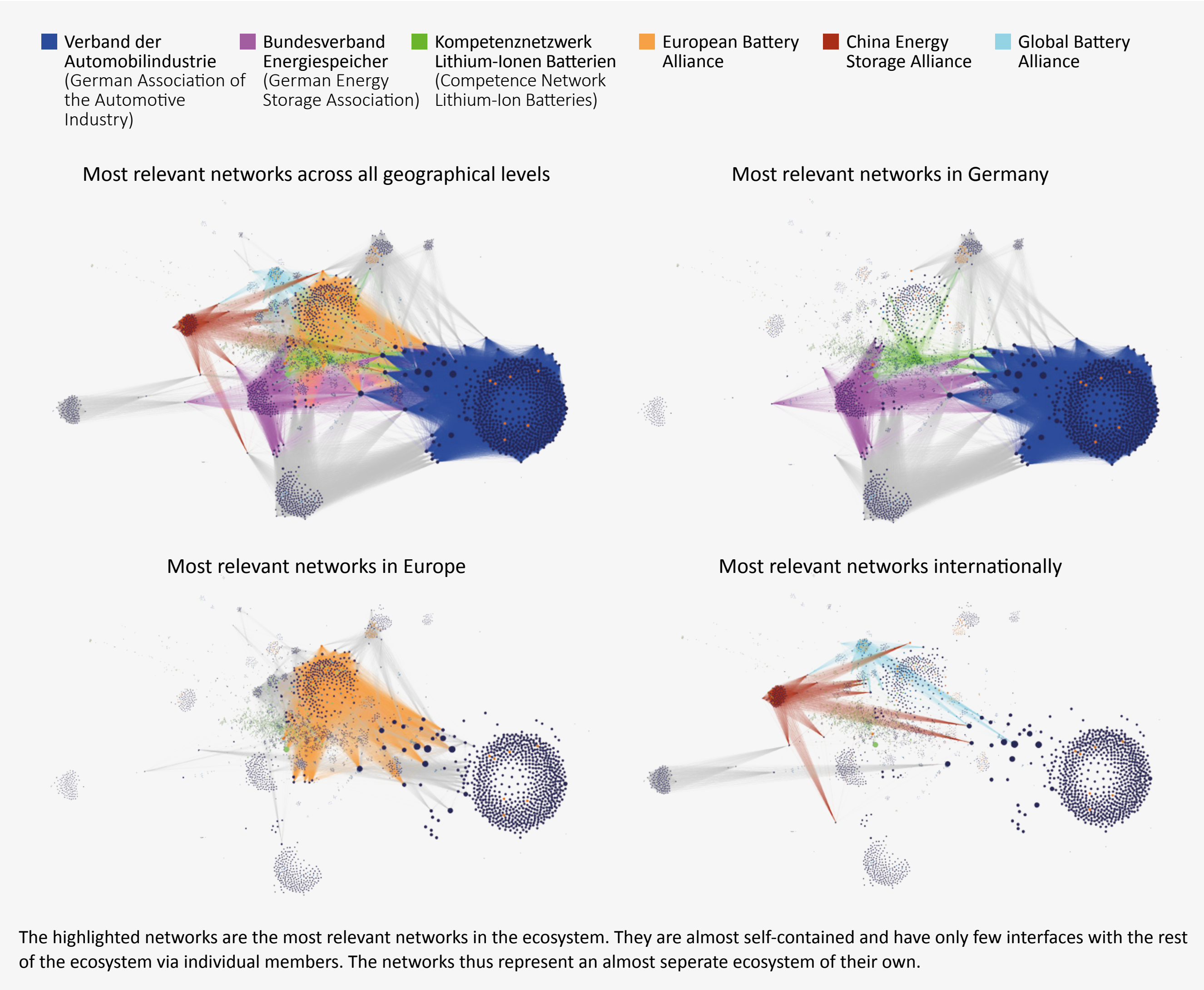


Figure 18: Overview of the most relevant networks of the considered ecosystem

Taking all geographical levels into account, only research institutes and universities are in the top 3 and a total of only five companies are in the top 10 (four within Germany and one within Europe). The low-10 actors include both research institutions and companies. Conspicuous here are actors with networking degree 1, *proximity* 1 and *betweenness* 0. These actors belong to a separate network within which they are networking without connections to the rest of the ecosystem.

The evaluation of the research-level population considered in this study according to the geographical level shows that, in contrast to the network level, the degree of networking increases as the geographical horizon expands (Germany < Europe < international). In Germany, the three actors with the most connections are large research institutions, followed by a university. The identified research projects focus on battery cells, components, production and systems, materials research and recycling as well as applications in the automotive sector and in stationary storage. The focus is on battery cells, components and production.

A strong presence of research institutions can also be discerned at European level. In addition to the research focus on battery systems, there are also many research activities in the area of materials development, which indicate a focus on basic research. Furthermore, especially **in the European**

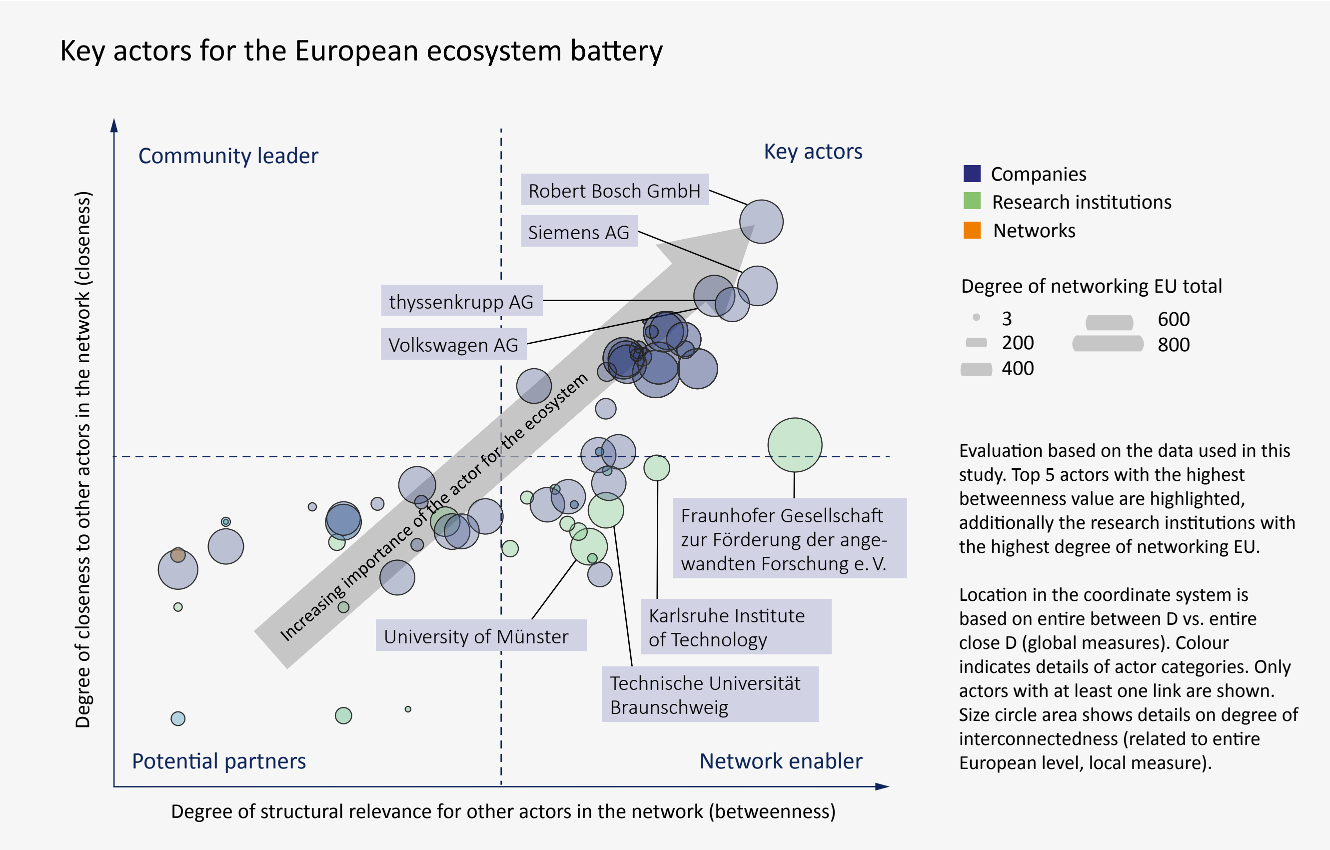


Figure 19: Key players of the entire German networking level for the European battery cell production ecosystem

region, there are **overlaps in large research projects** in which all of the top 5 players are involved. Some of these projects are carried out by more than 30 partners and thus act as promoters for networking.

The evaluation of scientific publications at international level revealed that nine research institutions and universities from Germany are within the top 10. It should be noted here that the SCOPUS database does not focus on Asian publications [37] and therefore these actors could not be sufficiently taken into account. In a European comparison, German actors published the most scientific papers and are accordingly very active in basic research in the field of battery cells.

The evaluation of the degree of interconnectedness based on joint ventures showed that it does not exceed a value of six in any of the geographical levels (see table d Appendix I). This is primarily due to the low number of identified joint ventures in battery cell production (37). In addition, only companies are linked via joint ventures and, in contrast to networks, research projects and scientific publications, mostly only two actors are involved in these. The actors represented in joint ventures are exclusively companies. At the German level, eight actors were identified in joint ventures, four of which have no other connections across all levels (networks, R&D and joint ventures) and thus represent a separate network. At European level, 11 actors are involved in joint ventures, at international level 65. International joint ventures very often show participation of Asian actors. There are three German actors among the top 25 international actors. A total of 28 actors from Europe are involved in international joint ventures, 12 of them from Germany. **Battery systems and battery cells** were identified as the **main topics of the joint ventures**. Individual joint ventures also address the areas of recycling, second use and the field of application.

37 cf. Elsevier, 2020, p. 19

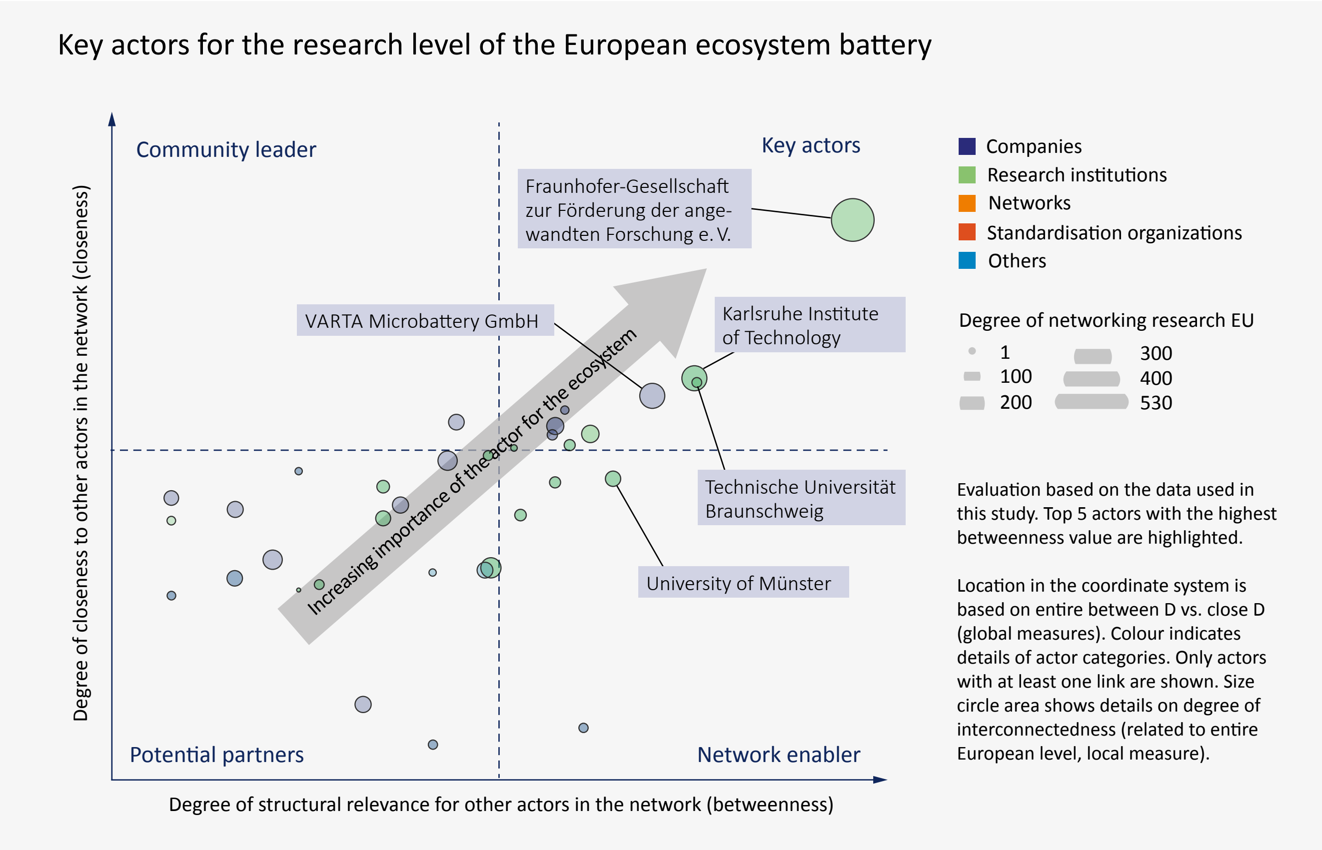


Figure 20: Key players at the German research level for the European battery cell production ecosystem

In summary, it can be said that **the well-connected part of the ecosystem** is made up primarily of **thematically broad-based large companies and larger research institutes** that are well integrated. They form the so-called *"inner circle"* of the ecosystem. **In the less networked part of the ecosystem**, i.e. the *"outer circle"*, **small and thematically very focused companies as well as OEMs** can be found that have only a few but very strong connections, for example through cooperations or joint ventures. However, these companies with specialised knowledge tend to be important for the overall ecosystem and should be integrated more strongly. It is also noticeable that networking within certain groups of actors is more pronounced than cross-linked networking. At research level, for example, there are many well-connected research institutions, while at network level it is predominantly companies that are connected. The highest degree of networking is achieved via networks. Lower degrees of networking are realised via R&D publications or projects. The lowest degree of networking is achieved through joint ventures.

Research institutions that are both active in research and involved in networks and enter into possible industry cooperations are particularly well connected in the overall network. But large thematically broad-based companies are also to be found among the strongly networked actors.

This phenomenon is further underpinned by relating the measures of *betweenness* and *proximity* within the European ecosystem in a coordinate system and at the same time looking at the degree of interconnectedness of the actors. Here, actors with a high level of *betweenness* act as connecting links that maintain the ecosystem (*network enablers*). In contrast, actors with a high degree of *proximity* have short communication channels to as many areas of the ecosystem as possible and can use this to proactively set topics and thus assume a certain leadership role (*community leader*). If an actor combines both, high *betweenness* and high *proximity*, he has the opportunity to **place thematic focal points in his networks** and to **bring together different parts of the ecosystem** via connections. These actors are seen as a kind of key player. Figure 19 shows this connection using the example of German actors and their potential for European networking. It can be seen that actors who have a high degree of *betweenness* and *proximity* at the German level and are thus well integrated into the level of German activities (top right quadrant, "key actors"), can reach many other actors quickly and directly due to a high degree of networking at European level (area size of the nodes). They are thus particularly important for knowledge transfer.

A similar picture emerges when individual networking levels are examined. Figure 20 therefore shows the previously described connection using the example of the research level. Also here it can be seen that various key actors who are well integrated in research at German level also have a high degree of networking in research at European level and are thus important for knowledge transfer. However, it is noticeable in comparison to figure 19 that there are fewer actors who have a high degree of networking. This is due to the fact that there are fewer actors at research level on the one hand, and that networking at research level is more broadly distributed on the other hand, so that there are fewer agglomerates of many actors who have a high rate of networking among themselves (cf. also Chapter 4.2 for German research level). Furthermore, it can be seen that research institutions have a much more prominent role when the research level is considered separately from the other networking levels. This is due to the great influence of large networks, as already indicated in the previous chapters.

Although German actors are already well networked within Europe, cross-level networking still appears to have room for improvement. This could be realised, for example, through university research projects with industry participation or the establishment of cross-actor networks. Thematically, ***production*** is the main focus of the activities. The evaluation of the R&D publications shows that the topic of ***resources*** (mainly material development) is also addressed here, whereas topics such as ***recycling***, ***mining*** and ***utilisation*** are rarely dealt with. The low level of addressing the topic of ***utilisation*** may also indicate a high proportion of industrial research, results of which are rarely published.

5.4 Networking

Overall, it can be said for the battery cell production ecosystem considered here that many actors are involved in large networks and associations. In these, there is a good internal network. However, the actors in these networks are often only poorly connected to other parts of the battery cell production ecosystem. This **connection takes place via few key actors** who are linked to other networks or reach other groups of actors via joint research projects (figure 12). Consequently, these actors hold strategic positions in the ecosystem and can, for example, set impulses across different levels. Therefore, they can also be seen as gatekeepers for other actors who are only active at one level. This is because networking with other levels of the ecosystem can take place via these actors and thus, for example, a transfer of knowledge can be initiated but also controlled.

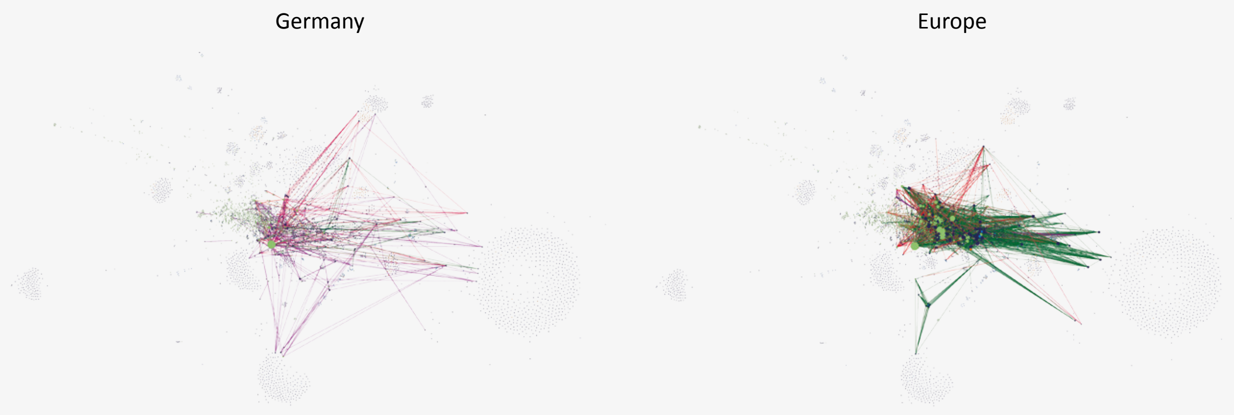
If we look at networking in the ecosystem against the background of the role model abstracted in Chapter 2.2, it becomes apparent that the majority of actors who are involved in activities at several networking levels and thus represent an **interface** are to be **found at research and strategic level**. This applies to both the European and the German level (cf. also figure 12 in Chapter 5). These are mainly companies, especially large internationally active corporations. The exception at both German and European level are some (larger) research organisations and universities. There is hardly any overlap between German and European level. With regard to the content orientation of the actors, it should be noted that many stages of the value chain are covered. Product integrators and OEMs, i.e. companies whose focus is on integrating battery packs into electric vehicles or other products, are also included. These come almost exclusively from the automotive industry. No actors could be identified as an interface from the mining sector and only a very small number from the recycling sector. However, at both European and German level, a few cell manufacturers also form an interface between the two networking levels. At European level, a testing and certification company also forms such an interface. Overall, the thematic orientation of the ecosystem is thus essentially also reflected in the composition of the interfaces between the research and strategic levels. It is also noticeable that the interfaces are predominantly served by large internationally active corporations.

In contrast to the research and strategy levels, there are virtually no interfaces between the value creation and strategic levels or the value creation and research levels. As a result, there are few actors with public research and value creation activities. Particularly with regard to **research in the area of industrial application, a need can be identified**

here. The projects of the IPCEI funding, but also the research factory funded by the Federal Ministry of Education and Research can contribute to meeting the need.

The ratio of the number of interfaces to the total number of actors in the ecosystem under consideration (see Chapter 4.2) illustrates that the cross-connectivity of the ecosystem is generated by few actors. The networking potential between the German and European levels is also very low, as figure 13 in Chapter 4.2 shows. The number of actors who are active in the ecosystem in Germany and in Europe, irrespective of the assignment to the networking levels, is low at 144 out of 3,178 actors. With regard to the role model (see Chapter 2.2), this means that **companies take on a much more diverse role in the ecosystem** and do not only have a key function in the ecosystem at the level of value creation.

The analysis of the interaction of actors in activities on different stages of the value chain, using the example of the activities on recycling and production of cells, modules, systems and/or car manufacturing in the ecosystem, which are important for the establishment of a circular economy, shows that the networking and density of activities at the European level is significantly higher than at the German level (figure 20). Contrary to the trend with regard to the role model of the ecosystem, many research actors take on a strategic role here. This speaks for the **focusing of research, but also for weaker involvement of the industry**. Furthermore, it can be seen that only a few actors cover more than one value chain level in their activities and consequently only a few actors hold an interface position from which they can pass on impulses or findings between different levels or value chain levels.



Size of the nodes: weighted degree of interconnectedness in relation to the selected activities.

Networking between actors on the topics of recycling, production of cells, modules, systems and/or car manufacturing, which is important with regard to establishing a closed value chain, is less dense at the German level than at the European level.

Figure 21: Density of networking between actors via activities on recycling and production of cells, modules, systems and/or car manufacturing in Germany and Europe across all networking levels

6 STRENGTHS AND WEAKNESSES OF THE BATTERY CELL PRODUCTION ECOSYSTEM

The previous explanations have already shown the initial strengths and weaknesses of the battery cell production ecosystem. Since the focus in this study was on the structures of the ecosystem, the following section focuses on the networking and interfaces aspects of the ecosystem when considering the strengths and weaknesses of the ecosystem. First, a brief summary of the **s**trengths, **w**eaknesses, **o**pportunities and **t**hreats from the analysis is given (see Chapter 4) and then a SWOT analysis is carried out, in which the strengths, weaknesses, opportunities and threats are considered in context. This describes the state of the ecosystem in terms of actors/roles and networking/interfaces:

- developing existing strengths to take advantage of opportunities (strengths – opportunities),
- hedging in relation to risks by using existing strengths (strengths – threats),
- the potential of opportunities to make up for weaknesses (weaknesses – opportunities) as well as
- the avoidance of dangers through risks that are reinforced by existing weaknesses (weaknesses – threats).

Finally, the recommendations for action, which are considered in the next chapter, are derived from the results of the analyses. Figure 22 summarises this procedure.

Figure 22: From analysis to derivation of recommendations for action

6.1 Consideration of actors and roles

Overview of strengths, weaknesses, opportunities and threats in relation to actors and roles

The results of the analysis of the actors and roles of the battery cell production ecosystem based on the data of this study show that actors from Germany, especially companies, are in a good position and are also well networked at European level. Some companies can act as key players here. The establishment of production sites with a high degree of innovation also appears possible. Nevertheless, this is also a weakness of the ecosystem. Apart from companies and research institutions, hardly any other actors are represented in the ecosystem. The competences along the value chain are also unevenly distributed. There are weaknesses here not only in the area of cell production, but also in the area of resources and recycling. Without actors from this area and without corresponding competences, the implementation of a closed and sustainable value chain is not possible.

SWOT analysis in terms of actors and roles

Looking at these opportunities, threats, strengths and weaknesses of the analysis in the context of a SWOT analysis, in each case, the following picture of the actors and roles of the ecosystem emerges.

Strengths – Opportunities

With regard to the entire ecosystem under consideration, there is a strong corporate base at German and European level with also internationally very active companies in key positions. These can **drive forward topics** in various areas of the ecosystem and **set impulses**. At the level of German research, there is a strong focus on the topic of *production* with a higher proportion of companies compared to European research, which enables the **establishment of production locations in Germany with a high degree of innovation**. At the level of European research, there is a high level of participation of German actors in research projects. This **European networking** can be used to **build up European value creation**.

Strengths – Threats

So far, there has been **little innovation in the field of recycling**. However, the German research landscape in particular, with its high proportion of companies, can initiate industry-oriented research projects here.

Weaknesses – Opportunities
Other actors and roles besides companies and research institutions that are important for a functioning and self-sustaining ecosystem, such as standardisation organisations, certification companies or interest groups and political institutions[38], have **hardly been integrated into the ecosystem so far**. The **competences needed** to build an ecosystem f**ocused on closed value chains** are not evenly distributed along the value chain. There are gaps especially in the area of recycling and resources.

Weaknesses – Threats
In building a closed value chain, **gaps can hardly be closed without the involvement of important actor categories** such as standardisation organisations or **certification companies**. The **supply of resources cannot yet be sufficiently** ensured **"on its own"**, i.e. through raw material supply or recycling.

Table 3 summarises these results.

	Strengths	Weaknesses
Opportunities	• Companies in key positions can drive issues in different areas of the ecosystem and create momentum. • Establishment of production sites in Germany with a high degree of innovation possible due to high company share at German research level. • Good opportunities to build European value creation through high participation of German actors in European research projects.	• Actors and roles that are important for a functioning and self-sustaining ecosystem (e.g. standardisation organisations, certification companies or interest groups and political institutions[IV]) have hardly been integrated into the ecosystem so far. • Competences with focus on closed value chains are not evenly distributed across the value chain.
Threats	• Possibility of initiating industry-related research projects on the generally understudied topic of recycling through the German research landscape with its high proportion of companies.	• Closing gaps in terms of building a closed value chain is hardly possible without the involvement of important stakeholder categories. • Securing the supply of resources has so far not been sufficiently possible "on its own".

IV The aforementioned actors and especially political institutions also participate in the development of the ecosystem without being explicitly involved in activities of the networking levels considered in this study, for example as legislators or funding bodies. See also note in previous footnote.

Table 3: SWOT in relation to actors and roles

38 It should be noted that this evaluation only considers institutions that are actively involved in the identified activities at various networking levels. This is because the actors mentioned, such as political institutions, also participate in the development of the ecosystem without being explicitly involved in activities at networking level considered in this study. For example, they have a significant influence on the development of the ecosystem as legislators or funding bodies.

6.2 Consideration of networking and interfaces

Overview of strengths, weaknesses, opportunities and threats in relation to networking and interfaces in the ecosystem

With regard to **networking and interfaces in the ecosystem**, the analysis of the data shows that the actors in the ecosystem can fundamentally benefit from the wide reach of a strong network landscape with large, thematically broad-based associations, initiatives and networks. The same applies to European research projects. The great opportunity for a transformation of the ecosystem lies in driving networking forward at other networking levels as well. This is currently a weak point. Networking beyond the networks often does not exist. Many actors are therefore not strongly integrated into the ecosystem. There is also little networking within the value creation levels, with the exception of the value creation links outside of joint ventures, which are not considered to a greater extent here. Overall, the low number of interfaces is a weakness of the ecosystem. This leads to various risks, such as a monopoly position of strongly integrated actors or more difficult market diffusion through rather very local (demonstration) projects. This can also complicate the development of a sustainable and effective battery cell production ecosystem.

SWOT analysis in terms of networking and interfaces

Looking at these opportunities, threats, strengths and weaknesses of the analysis in the context of a SWOT analysis, in each case the following picture of the networking and interfaces of the ecosystem emerges.

Strengths – Opportunities

Large networks and interest groups at German and European level as well as large European R&D projects with a potentially wide reach, are a good way **to make** many **contacts and thus gain access to other parts of the ecosystem**. Well-networked actors can be used as **promoters to build European value creation** in the field of battery cell production. A broad, interconnected research landscape in Germany and Europe, in conjunction with comparatively intensive cooperation, offers the **opportunity for actors to establish themselves in the ecosystem**.

Strengths – Threats

Possible lack of interest of actors to network outside their actor group can be compensated by networks and associations across value chains and actor groups **with low-threshold networking offers**.

Weaknesses – Opportunities

Large networks and associations are a good starting point for further networking. They **expand the circle of actors and the "radius of action" of the ecosystem** and, in part, the diversity of the actors. For example, important actors for the ecosystem, such as banks, enter the ecosystem through associations. However, there is little networking between the networks and associations and other activities[39] in the ecosystem. Many actors are not properly integrated into the entire ecosystem. Topics such as recycling, mining and use are currently still neglected. **Cross-value chain networks and associations** partly contain actors with corresponding competences. They **can therefore contribute to the networking of** these **previously neglected topics**.

Weaknesses – Threats

A **monopoly position of well-networked actors** is possible on the basis of the available data, which shows a relatively low level of networking between the different levels. These key actors or "gatekeepers" thus have control opportunities and can set and steer topics in their own interest. The **interest** of actors to **network** outside their actor group may be **limited**, as this usually results in compromises (e.g. exchange of information). Highly localised demonstration projects can make the **market diffusion of technologies** more difficult.

Table 4 summarises the results.

39 See also Chapter 2 on the limitations of the study.

	Strengths	Weaknesses
Opportunities	• Good opportunities to make many contacts and gain access to other parts of the ecosystem through large networks and interest groups in Germany and Europe. • Well-networked actors as promoters to build European value creation in the field of battery cell production. • Opportunity for actors to establish themselves in the ecosystem through broad, interconnected research landscape in Germany and Europe.	• Large networks and associations expand the circle of actors and the “radius of action” of the ecosystem to include important actors who have not been involved so far. • Contribution to networking in hitherto neglected topics such as recycling through networks and associations spanning value-added stages.
Threats	• Compensate for the lack of interest of actors in networking outside their actor group through networks and associations across value chains and actor groups with low-threshold networking offers.	• Monopoly position of well-networked actors possible due to the overall relatively low level of networking[V] between the different levels. • Interest of actors in networking outside their actor group possibly limited due to lack of willingness to compromise (e.g. exchange of information). • Very locally focused demonstration projects can make the market diffusion of technologies more difficult.

V It is important to note the underlying data basis of this study, which only considers joint ventures at the value creation level (see Chapter 2 for explanation).

Table 4: SWOT in relation to networking and interfaces

7 CONCLUSION AND RECOMMENDATIONS FOR ACTION

Despite the weaknesses identified in this study and also in other places[40], a battery cell production ecosystem basically exists in Europe. This is evidenced not only by the large number of actors with different focal points that are involved in the ecosystem at different levels, but also by the strong networking of individual key actors. These are not only active at German and European level, but in some cases also at international level. Further evidence is the thematic broad range of activities of the actors in the battery cell production ecosystem across the value chain, even if there are weak points in the areas of recycling or raw material supply, for example.

Nevertheless, there is need for action – both at content level and with regard to further networking. Many of the identified actors are, as far as can be recognised from the database, only one-dimensionally networked in the ecosystem. Consequently, they are only connected to other actors via a network or an interest group or a research project. As far as can be seen, there are hardly any interfaces between the levels considered or between the geographical levels. This is a weak point of the ecosystem. Particularly with regard to the establishment of a circular economy to reduce dependence on strategically important raw materials and the ecological footprint, no concrete integration of corresponding initiatives into research projects or activities of other networks is apparent to date. At content level, the weak points are in the area of recycling and raw material supply.

In conclusion, it can be said that the ecosystem is very dynamic and can grow rapidly if the appropriate framework conditions and support measures are created. Accordingly, the results of this study are a snapshot of the current situation.

Based on the results of this study, the following recommendations for action can be formulated:

Strengthen knowledge transfer structures between research and industry

Although companies and, to a somewhat lesser extent, research institutions represent the dominant actor categories in the battery cell production ecosystem under consideration (Chapters 4.1 and 5.1), the potential for networking between these groups of actors, as far as can be seen from the available data, is relatively low from a structural perspective. This applies in particular to knowledge transfer between research and industrial application. Targeted networking between companies and research institutions takes place, for example, within the framework of R&D activities (Chapters 4.2 and 5). However, the share of connections created through research projects is relatively low compared to the total share of all connections in the ecosystem (Chapter 4.2). Similarly, there is little evidence of strong networking between the value creation and research levels (Chapter 5.4), especially since only companies were identified at the value creation level. Considering the total number of actors, the targeted exchange of knowledge between industry and research is therefore limited.

A topic not considered in this study, but relevant to the future viability of the battery cell production ecosystem: Equality and diversity in the companies and institutions

The relevance of the topic lies in particular in securing and attracting skilled workers in industry and research as well as in the diversity of approaches, leadership styles and forms of cooperation that demonstrably increase the work results of teams. Particularly in the STEM training courses and professions relevant to the battery cell production ecosystem, equal opportunities and equality for women have so far been less pronounced than in other disciplines. In order for the battery cell production ecosystem to remain sustainable and keep pace with an equality-oriented society, existing structural inequality and options for action should be identified. Due to the lack of valid data available within the scope of this study, it was not possible to determine here how strongly and in which roles women are represented among the various actors in the ecosystem, in the different subject areas and cross-cutting issues.

40 See for example NPM - WG 4, 2019

Recommendation
Promote specific networking between industry and research actors (e.g. via networking events or specified funding programmes for knowledge transfer from research to industry) in order to harness the potential of key industry actors and to better transfer findings from research into the ecosystem.

Transfer of production knowledge from R&D to industrial application

Particularly in the German research landscape, great emphasis is placed on the area of production – know-how that is of great importance in the development of innovative European battery cell production (Chapter 5.2). Therefore, strengthening the knowledge transfer between research and industry also appears to make sense from a content perspective in order to transfer innovations more quickly from research into industrial applications. The rather strong participation of German actors at European research level (Chapter 5.2) can also be used for this purpose.

Recommendation
Production knowledge from research and development should be transferred to production sites (e.g. through appropriate networking formats, support measures with the aim of industrial application of research results) and use the potential of companies in the ecosystem to build a European battery industry.

Key actors as interfaces between different levels for the dissemination of relevant topics and important impulses

The proportion of interfaces in the ecosystem between different levels is relatively low (Chapters 4.2 and 5.4), which is one of the reasons why the systematic exchange of knowledge between the different levels considered is altogether more difficult. However, it was possible to identify a number of actors who are active at several levels and who therefore connect these levels with each other. These key actors can contribute to increasing the transfer potential.

Recommendation
Actors with an interface function should be specifically involved in networking activities (e.g. via conferences, workshops) in order to benefit from their reach into different levels and topics.

Creation of further interfaces for greater dissemination of relevant topics

In view of the relatively small number of interfaces, there is a danger of a monopoly forming here. Individual actors are in a position to determine the topics and shape them in a targeted manner. In order to ensure a diffusion of relevant topics and important impulses into the ecosystem and to avoid the formation of a monopoly, a larger number of interfaces makes sense.

Recommendation
Further interfaces should be created by networking key actors with important but less networked actors and thus also integrating these actors, e.g. in research projects or concrete network activities. This applies especially to different stages of the value chain, such as between recyclers and producers of cells, modules, systems and/or car manufacturers.

Involvement of other stakeholder groups

This study has shown that groups of actors that are important for the sustainable development of the battery cell production ecosystem are already present in the ecosystem (Chapters 5.2 and 5.3), albeit to a lesser extent. These include standardisation organisations as well as banks, which provide capital and corresponding financing instruments, and local authorities, for example with regard to the implementation of large-scale demonstrators.

Recommendation
It is recommended that further groups of actors who support the sustainable development of the battery cell production ecosystem be more strongly integrated into the ecosystem through specific networking measures (e.g. funding programmes, matching and exchange formats).

Qualitative consideration of the connections in the ecosystem

In this study, the ecosystem was examined from a structural point of view. In simple terms, it was examined where the conditions for knowledge exchange are given and where they are not. No statement could be made about the qualitative nature of these connections, i.e. “how well” or “how poorly” knowledge exchange takes place, for methodological reasons as well as for reasons of data availability. The extent to which, for example, the regulatory framework has an influence on networking was also not investigated in detail.

Recommendation

Basically, it must be examined which concrete obstacles (e.g. handling of intellectual property, lack of business models) are slowing down further networking, but also the exchange of data (e.g. with regard to the continuous traceability of battery cells and raw materials up to recycling) of actors. Here, for example, activities of the Global Battery Alliance could provide further information, who is already working on identifying such obstacles and developing corresponding solution concepts.

Strengthening the topics of recycling and the circular economy through research and accompanying measures

Some topics have so far been poorly represented in the ecosystem as a whole, but especially in research (Chapters 5.2 and 5.4). These include above all the topics of recycling and circular economy, which are important for a sustainable design of the value chain in the sense of a circular economy. The founding of the European Raw Materials Alliance shows that this topic is already moving more into focus at European level. The topic of the circular economy is also currently being flanked more strongly at both German and European level with corresponding initiatives (Circular Economy Initiative or the European Circular Economy Stakeholder Platform [ECESP]).

Recommendation

Research and development in the field of recycling and especially the circular economy should be addressed more pointedly, for example in funding programmes. Corresponding initiatives, such as the Circular Economy Initiative, should be involved at an early stage in order to support strong networking between research and industry at national and European level. This also includes supporting networking through appropriate standardisation projects.

Addressing further research topics

Some topics that are highly relevant for the sustainable success of the battery cell production ecosystem, for example in terms of competitive advantage, were not examined in detail in this study. The topic of gender equality and diversity was listed as an example (see info box p. 44). The start-up landscape and its potential for the battery cell production ecosystem was also not investigated. Start-ups in particular have great innovation potential from which the ecosystem can benefit.

Recommendation

It is advisable to take stock of topics that have been little studied so far, such as gender and diversity, in order to identify possible potential or further need for action for the battery cell production ecosystem in Germany and Europe. This concerns, for example, the availability of skilled workers in industry and research, the integration of experts into the ecosystem and making the topic more attractive to women. The start-up landscape and its potential for the battery cell production ecosystem should also be evaluated in further research studies.

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APPENDIX I: OVERVIEW OF THE NETWORKS AND VALUE-ADDED CONNECTIONS CONSIDERED

a) Networks and interest groups considered at network level

Name	Origin	Scope of consideration Members
European Automobile Manufacturers Association (ACEA)	EU	Complete
ALISTORE	EU	Complete
Battery Association of Japan (BAJ)	Int.	Complete
Bundesverband der deutschen Abfall-, Wasser- und Rohstoffwirtschaft (BDE)	D	Complete
Bundesverband Elektromobilität (BEM)	D	Complete
Bundesverband Energiespeicher (BVES)	D	Complete
European Association of Automotive Supplliers (CLEPA)	EU	Complete
China Energy Storage Alliance (CNESA)	Int.	Complete
European Battery Alliance (EBA)	EU	Complete
European Battery Association (EBRA)	EU	Complete
European Green Vehicle Initiative (EGVI)	EU	Complete
EIT-InnoEnergy	EU	Excerpt
EIT-RawMaterials	EU	Complete
European Road Transport Research Advisory Council (ERTRAC)	EU	Complete
European Council for Automotive R&D (EUCAR)	EU	Complete
Association of European Manufacturers of automotive, industrial and energy storage batteries (EUROBAT)	EU	Complete
EUROMETAUX	EU	Complete
Global Battery Alliance (GBA)	Int.	Complete
KLiB - Kompetenznetzwerk Lithium-Ionen Batterien	D	Complete
RECHARGE	EU	Complete
Verband der Automobilwirtschaft (VDA)	D	Complete
VDMA Batterieproduktion	D	Complete

b) Joint ventures[41] considered at value-added level

Name (if any) and companies involved
4R Energy: Sumitomo Corporation, Nissan
Amperex GAC Power Batterie: CATL, GAC
Automotive Cells Company (ACC): PSA, Opel, Total, Saft
Automotive Electronics Power Pvt. Ltd - AEPPL: Emberion OY, Toshiba, Denso Automotive Deutschland GmbH
Automotive Energy Supply Corporation (AESC): NEC, Nissan
BASF TODA Battery Materials LLC: BASF SE, Toda Kogyo
Beijing Benz Automotive Company: Farasis, Daimler, BAIC Group
BESK: SK Innovation, Beijing Automotive, Beijing Electronics
BMW Brilliance Automotive-BBA: BMW AG, Brilliance
BorgWarner, Romeo Power Technology
BYD Toyota EV Technology: BYD, Toyota
BYD, Changan Ford Automobile
BYD, Qinghai Salt Lake Industry Co Ltd
CATL Geely Power Battery: CATL, Geely
CATL-FAW Power Battery Company: CATL, FAW
Cinovec Lithium Project: European Metals, CEZ
Coloumb: GETEC Energie GmbH, The Mobility House
Continental AG, Chengfei Integration Technology
CNH Industrial (Iveco, FPT Industrial)
Digital Energy Solutions: BMW AG, Viessmann Group
Dongfeng Amperex: CATL, Dongfeng
Dongfeng Lishen Power Battery Systems Co.: Lishen, Dongfeng
EcoPro EM: Samsung, EcoPro BM
Eisenmann, Onejoon

41 At the time of editorial deadline, some were still strategic cooperations with the aim of establishing a joint venture.

Name (if any) and companies involved
ElringKlinger, Sichuan Chengfei Integration Technology Co., Ltd. (CITC)
Eneris, Leclanché S.A.
HL Green Power: LG Chem, Hyundai
Hydro Volt AS: Hydro, Northvolt
InoBat Auto: Wildcat, Inobat
Nikola, CNH Industrial
JT Energy Systems: Jungheinrich AG, Triathlon Holding GmbH
JV 1: LG Chem, Huayou Cobalt
JV 2: LG Chem, Huayou Cobalt
Kion Battery Systems: BMZ GmbH, Kion
Leclanché S.A., Exide Industries
LG Chem, Geely
LG Chem, VinFast
Lithium Energy and Power GmbH & Co. KG: Bosch, GS Yuasa, Mitsubishi
Morrow Batteries: Graphene Batteries, Agder Energy Ventures
Panasonic Automotive Energy Dalian Co. Ltd.: Panasonic Corporation, Dalian Levear Electric
Panasonic, Tesla
Prime Planet Energy & Solutions: Panasonic , Toyota
Primibus: SMS Group, Neometals
SAFT SA, Tianneng Energy Technology
SAIC-GM: SAIC, GM
Ultium Cells: General Motors, LG Chem
VW, Northvolt
VW, QuantumScape
VW-VM Forschungsgesellschaft mbH & Co. KG: VW, VARTA
Williams Advanced Engineering, Unipart
Yunnan Phinergy Chuang Neng Metal Air Battery: Phinergy, Yunnan Aluminium, Shangai Zuoyong New Energy Technology

APPENDIX II: VALUE TABLES

a) Top 10 total according to degree of cross-linking

Germany	EU	International
BASF SE Degree of cross-linking: 1936 Proximity: 0.650 Betweenness: 0.00106	**Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V.** Degree of cross-linking: 739 Proximity: 0.640 Betweenness: 0.00517	**Panasonic** Degree of cross-linking: 213
Continental AG Degree of cross-linking: 1738 Proximity: 0.649 Betweenness: 0.000674	**UMICORE NV/SA** Degree of cross-linking: 565 Proximity: 0.601 Betweenness: 0.0021	**NEC** Degree of cross-linking: 168
Siemens AG Degree of cross-linking: 1722 Proximity: 0.735 Betweenness: 0.00443	**GigaVaasa- Ecosystem for future batteries** Degree of cross-linking: 557 Proximity: 0.526 Betweenness: 0.000001	**Chinese Academy of Sciences Institute of Metal Research** Degree of cross-linking: 168
Thyssenkrupp AG Degree of cross-linking: 1609 Proximity: 0.714 Betweenness: 0.00308	**COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES (CEA)** Degree of cross-linking: 523 Proximity: 0.566 Betweenness: 0.00517	**SAFT Groupe S.A.** Degree of cross-linking: 163
ZF Friedrichshafen AG Degree of cross-linking: 1587 Proximity: 0.664 Betweenness: 0.00157	**Robert Bosch GmbH** Degree of cross-linking: 477 Proximity: 0.585 Betweenness: 0.00219	**Volkswagen (VW) AG** Degree of cross-linking: 156
Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V. Degree of cross-linking: 1566 Proximity: 0.570 Betweenness: 0.00764	**AIT AUSTRIAN INSTITUTE OF TECHNOLOGY GMBH** Degree of cross-linking: 474 Proximity: 0.584 Betweenness: 0.00114	**Toshiba** Degree of cross-linking: 112
Daimler AG Degree of cross-linking: 1391 Proximity: 0.644 Betweenness: 0.00187	**Vrije Universiteit Brussel (VUB)** Degree of cross-linking: 462 Proximity: 0.595 Betweenness: 0.00150	**GS Yuasa International Ltd.** Degree of cross-linking: 111
LEAR Corporation GmbH Degree of cross-linking: 1347 Proximity: 0.601 Betweenness: 0	**SAFT Groupe S.A.** Degree of cross-linking: 450 Proximity: 0.586 Betweenness: 0.00286	106 Actors with networking degree 110

Germany	EU	International
Vibracoustic Degree of cross-linking: 1344 Proximity: 0.600 Betweenness: 0	**BASF SE** Degree of cross-linking: 445 Proximity: 0.571 Betweenness: 0.000961	
Robert Bosch GmbH Degree of cross-linking: 1188 Proximity: 0.815 Betweenness: 0.00470	**University of Technology at Bel-fort-Montbéliard (UTBM)** Degree of cross-linking: 437 Proximity: 0.526 Betweenness: 0.000001	

b) Top 10 networks according to degree of cross-linking

Germany	EU	International
BASF SE Degree of cross-linking: 1910 Proximity: 0.699 Betweenness: 0.000288 Networks: VDA	**GigaVaasa- Ecosystem for future batteries** Degree of cross-linking: 557 Proximity: 0.639 Betweenness: 0 Networks: EBA	**Panasonic** Degree of cross-linking: 210 Proximity: 0.802 Betweenness: 0.00097 Networks: CNESA
Continental AG Degree of cross-linking: 1738 Proximity: 0.703 Betweenness: 0.000465 Networks: VDA	**University of Technology at Belfort and Montbèliard** Degree of cross-linking: 437 Proximity: 0.639 Betweenness: 0 Networks: EBA	**Chinese Academy of Sciences Institute of Metal Research** Degree of cross-linking: 168 Proximity: 0.608 Betweenness: 0 Networks: CNESA
Siemens AG Degree of cross-linking: 1708 Proximity: 0.820 Betweenness: 0.00318 Networks: VDMA_Batt, BVES, KLiB	**EUROBAT** Degree of cross-linking: 430 Proximity: 0.714 Betweenness: 0.000502 Networks: EBA, ERTRAC	**NEC** Degree of cross-linking: 167 Proximity: 0.713 Betweenness: 0.000273 Networks: CNESA, GBA
ZF Friedrichshafen AG Degree of cross-linking: 1587 Proximity: 0.782 Betweenness: 0.00155 Networks: VDA, BEM	**Robert Bosch GmbH** Degree of cross-linking: 428 Proximity: 0.716 Betweenness: 0.000624 Networks: EBA, EGVI, ERTRAC, RE-CHARGE, CLEPA	**SAFT Groupe S.A.** Degree of cross-linking: 162 Proximity: 0.706 Betweenness: 0.000241 Networks: CNESA, GBA

Germany	EU	International
Thyssenkrupp AG Degree of cross-linking: 1571 Proximity: 0.774 Betweenness: 0.00157 Networks: BVES, KLiB, VDA	**Renault Group** Degree of cross-linking: 427 Proximity: 0.716 Betweenness: 0.000315 Networks: EBA, ERTRAC, RECHARGE, EGVI	**Volkswagen (VW) AG** Degree of cross-linking: 155 Proximity: 0.693 Betweenness: 0.000222 Networks: CNESA, GBA
Daimler AG Degree of cross-linking: 1369 Proximity: 0.696 Betweenness: 0.00111 Networks: VDA	**Aalto University** Degree of cross-linking: 423 Proximity: 0.697 Betweenness: 0.000209 Networks: EBA, EIT-InnoEnergy, EIT-RawMaterials	**Murata Manufacturing Co., Ltd.** Degree of cross-linking: 110 Proximity: 0.542 Betweenness: 0 Networks: BAJ
LEAR Corporation GmbH Degree of cross-linking: 1347 Proximity: 0.683 Betweenness: 0 Networks: VDA	**Volvo Group** Degree of cross-linking: 418 Proximity: 0.697 Betweenness: 0.000208 Networks: EBA, EGVI, ERTRAC, EUCAR	**The Furukawa Battery Co., Ltd.** Degree of cross-linking: 110 Proximity: 0.542 Betweenness: 0 Networks: BAJ
Vibracoustic Degree of cross-linking: 1344 Proximity: 0.682 Betweenness: 0 Networks: VDA	**VITO** Degree of cross-linking: 418 Proximity: 0.682 Betweenness: 0.000261 Networks: EBA, EIT-InnoEnergy, EIT-RawMaterials	105 further entries with Degree of cross-linking 110 Proximity: 0.542 Betweenness: 0 Network: BAJ
Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V. Degree of cross-linking: 1307 Proximity: 0.540 Betweenness: 0.000158 Networks: BVES, KLiB	**Tecnalia** Degree of cross-linking: 414 Proximity: 0.697 Betweenness: 0.000208 Networks: EBA, EIT-InnoEnergy, EIT-RawMaterials	
Robert Bosch GmbH Degree of cross-linking: 1177 Proximity: 0.460 Betweenness: 0.00025 Networks: VDA, BVES, KLiB, BEM	**Eramet** Degree of cross-linking: 411 Proximity: 0.705 Betweenness: 0.000316 Networks: EBA, EIT-RawMaterials, RECHARGE, EUROMETAUX	

c) Top 10 R&D by degree of cross-linking

Germany	EU	International
Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V. Degree of cross-linking: 259 Proximity: 0.646 Betweenness: 0.001622	**COMMISSARIAT AL ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES (CEA)** Degree of cross-linking: 523 Proximity: 0.660 Betweenness: 0.00379	**Karlsruhe Institute of Technology (KIT)** Degree of cross-linking: 897 Proximity: 0.520 Betweenness: 0.00787
Karlsruhe Institute of Technology (KIT) Degree of cross-linking: 113 Proximity: 0.510 Betweenness: 0.000291	**Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V.** Degree of cross-linking: 343 Proximity: 0.595 Betweenness: 0.00156	**Helmholtz-Gemeinschaft Deutscher Forschungszentren e. V.** Degree of cross-linking: 847 Proximity: 0.538 Betweenness: 0.00943
Technische Universität Braunschweig Degree of cross-linking: 103 Proximity: 0.507 Betweenness: 0.000298	**FUNDACION CIDETEC** Degree of cross-linking: 254 Proximity: 0.547 Betweenness: 0.000488	**Ulm University** Degree of cross-linking: 259 Proximity: 0.424 Betweenness: 0.000962
VARTA Microbattery GmbH Degree of cross-linking: 64 Proximity: 0.497 Betweenness: 0.000184	**POLITECNICO DI TORINO** Degree of cross-linking: 203 Proximity: 0.545 Betweenness: 0.000379	**Technische Universität Dresden** Degree of cross-linking: 211 Proximity: 0.399 Betweenness: 0.00161
University of Münster Degree of cross-linking: 49 Proximity: 0.439 Betweenness: 0.00012	**CENTRO RICERCHE FIAT SCPA** Degree of cross-linking: 184 Proximity: 0.533 Betweenness: 0.000298	**RWTH Aachen University** Degree of cross-linking: 210 Proximity: 0.434 Betweenness: 0.00180
SGL Carbon Degree of cross-linking: 40 Proximity: 0.486 Betweenness: 0.000071	**Vrije Universiteit Brussel (VUB)** Degree of cross-linking: 170 Proximity: 0.553 Betweenness: 0.000641	**Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V.** Degree of cross-linking: 187 Proximity: 0.458 Betweenness: 0.00252
Justus Liebig University Gießen Degree of cross-linking: 39 Proximity: 0.476 Betweenness: 0.000054	**AIT AUSTRIAN INSTITUTE OF TECHNOLOGY GMBH** Degree of cross-linking: 168 Proximity: 0.529 Betweenness: 0.000315	**Justus Liebig University Gießen** Degree of cross-linking: 185 Proximity: 0.441 Betweenness: 0.00105
Litarion GmbH Degree of cross-linking: 39 Proximity: 0.451 Betweenness: 0.000019	**NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO** Degree of cross-linking: 164 Proximity: 0.541 Betweenness: 0.000492	**Max-Planck-Gesellschaft** Degree of cross-linking: 180 Proximity: 0.466 Betweenness: 0.00248

Germany	EU	International
Thyssenkrupp AG Degree of cross-linking: 38 Proximity: 0.434 Betweenness: 0.000047	**CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS** Degree of cross-linking: 163 Proximity: 0.507 Betweenness: 0.000425	**Technical University of Darmstadt** Degree of cross-linking: 149 Proximity: 0.430 Betweenness: 0.00120
Center for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW), Ulm Degree of cross-linking: 37 Proximity: 0.436 Betweenness: 0.000064	**UMICORE NV/SA** Degree of cross-linking: 156 Proximity: 0.522 Betweenness: 0.000181	**Massachusetts Institute of Technology** Degree of cross-linking: 135 Proximity: 0.402 Betweenness: 0.00074

d) Top 10 JV according to degree of cross-linking

Germany	EU	International
Jungheinrich AG Degree of cross-linking: 1 Proximity: 1 Betweenness: 0 Focus: Battery systems	**Saft Groupe S.A.** Degree of cross-linking: 3 Proximity: 1 Betweenness: 0 Focus: Battery cells	**LG Chem** Degree of cross-linking: 6 Proximity: 0.5 Betweenness: 0.000002 Focus: Battery cells
Triathlon Holding GmbH Degree of cross-linking: 1 Proximity: 1 Betweenness: 0 Focus: Battery systems	**Adam Opel AG** Degree of cross-linking: 3 Proximity: 1 Betweenness: 0 Focus: Battery cells	**Beijing Automotive** Degree of cross-linking: 4 Proximity: 1 Betweenness: 0
Viessmann Group Degree of cross-linking: 1 Proximity: 1 Betweenness: 0 Focus: Further applications	**Groupe PSA S.A.** Degree of cross-linking: 3 Proximity: 1 Betweenness: 0 Focus: Battery cells	**CATL** Degree of cross-linking: 4 Proximity: 0.458 Betweenness: 0.000002
Kion Degree of cross-linking: 1 Proximity: 1 Betweenness: 0 Focus: Battery systems	**Total S.A.** Degree of cross-linking: 3 Proximity: 1 Betweenness: 0 Focus: Battery cells	**BYD** Degree of cross-linking: 3 Proximity: 0.545 Betweenness: 0

Germany	EU	International
BMZ Batterien-Montage-Zentrum GmbH Degree of cross-linking: 1 Proximity: 1 Betweenness: 0 Focus: Battery systems	**Northvolt** Degree of cross-linking: 2 Proximity: 1 Betweenness: 0 Focus: Battery cells	**Panasonic** Degree of cross-linking: 3 Proximity: 0.545 Betweenness: 0
Varta Degree of cross-linking: 1 Proximity: 1 Betweenness: 0 Focus: Battery cells	**Volkswagen (VW) AG** Degree of cross-linking: 1 Proximity: 0.667 Betweenness: 0 Focus: Battery cells	**Huayou Cobalt, Mitsubishi , SK Innovation, GS Yuasa International Ltd., Toshiba, Beijing Electronics, Chengfei Integration Technology (CITC), Dongfeng Motor Corporation, Farasis Energy Inc., Geely, General Motors, Nissan, Phinergy, Shanghai Zuoyong New Energy Technology, Suzuki, Yunnan Aluminium, Toyota, DENSO AUTOMOTIVE DEUTSCHLAND GMBH, Robert Bosch GmbH, Daimler AG** Degree of cross-linking: 2 Proximity: 0.344-1.000 Betweenness: 0, 000000-0,000002
Volkswagen (VW) AG Degree of cross-linking: 1 Proximity: 1 Betweenness: 0 Focus: Battery cells	**The Mobility House** Degree of cross-linking: 1 Proximity: 1 Betweenness: 0 Focus: 2nd Life	
Bayerische Motoren Werke Aktiengesellschaft (BMW) Degree of cross-linking: 1 Proximity: 1 Betweenness: 0 Focus: Further applications	**Leclanche** Degree of cross-linking: 1 Proximity: 1 Betweenness: 0 Focus: Battery cells	
	GETEC Energie GmbH Degree of cross-linking: 1 Proximity: 1 Betweenness: 0 Focus: 2nd Life	
	Eneris Degree of cross-linking: 1 Proximity: 1 Betweenness: 0 Focus: Battery cells	
	Hydro Degree of cross-linking: 1 Proximity: 0.667 Betweenness: 0 Focus: Recycling	