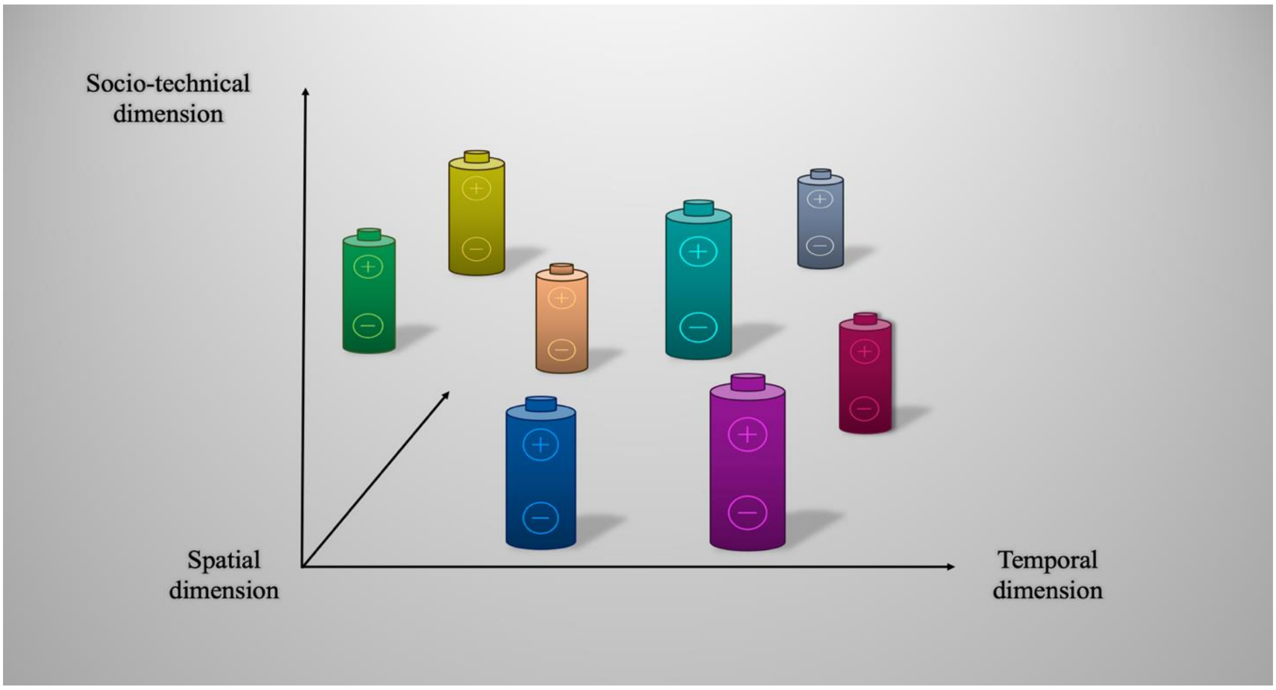

Industry formation of emerging battery technologies in Sweden

Master’s thesis in Industrial Ecology

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Cover:
Image representative of different battery morphologies and their evolution in time.

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SUMMARY

This thesis gives an overview of the current developments in rechargeable batteries researched and funded in Sweden from 2008 to 2022. The aim of this thesis is to show which rechargeable battery technologies receive research funding and which are patented in Sweden. This is important to understand what is happening in the industry to be able to predict the directionality of battery industry formation. Additionally, the thesis aims to illustrate and analyze the distribution and funding of projects along the value chain of rechargeable battery, starting with resource extraction and ending with their end of life. Furthermore, an actor analysis is performed to investigate the social dynamics of battery research and emerging battery industries. Specifically, actors involved in researching and patenting are listed and compared. The main source of data used in this thesis is the Swedish Energy Agency's project database, which contains the projects funded between 2008 and 2022. This information was complemented by the Swedish patent database and three expert interviews, which provided additional insights into actors' dynamics and interests. The results from this analysis show that the lithium-ion battery technology is clearly leading the battery research and industry in terms of funding as well as patents. However, there is a range of emerging technologies, like lithium-sulfur batteries, organic batteries, supercapacitors and sodium-ion batteries, which are starting to attract some attention from research and fundings. Regarding patents, it seems that solid state batteries, metal-air batteries and redox flow batteries are beginning to attract attention. Main actors involved in research and industry funds are identified, including the company Northvolt and the Swedish Electric Transport Laboratory (SEEL). Patent ownership lies in different hands compared to the main actors receiving funding; the distribution results in a a set of actors with similar number of patents. Along the value chain, most of the funding budget goes into developing battery chemistries or materials, and on improving the performances in the use phase.

Keywords: battery, emerging, technologies, value chain, industry, Sweden.

SAMMANFATTNING

Följande examensarbete ger en översikt över den aktuella utvecklingen inom forskning och utveckling av laddningsbara batterier i Sverige från 2008 till 2022. Syftet med examensarbetet är att visa vilka laddningsbara batterier som omfattas av forskningsfinansiering och vilka som patenteras i Sverige. Dessutom syftar avhandlingen till att illustrera och analysera fördelningen och finansieringen av projekt längs värdekedjan för laddningsbara batterier. Vidare genomförs en analys av verksamma aktörer för att undersöka den sociala dimensionen av batteriforskning och batteriindustrin. Detta utförs genom att lista och jämföra aktörer som är involverade i forskning och patentering. Den huvudsakliga datakällan som används i detta examensarbete är Energimyndighetens projektdatabas, som innehåller de projekt som finansierats mellan 2008 och 2022. Denna information har kompletterats med den svenska patentdatabasen samt tre expertintervjuer för att få en fördjupad förståelse av utvecklingen inom batteriindustrin. Resultaten från analysen visar att litiumjonbatteritet är klart ledande inom batteriforskningen och industrin när det gäller finansiering av forskningsprojekt samt patent. Det finns dock en rad nya teknologier, exempelvis litium-svavelbatterier, organiska batterier, superkondensatorer och natrium-jonbatterier som börjar attrahera viss uppmärksamhet från forskning och finansiering. När det gäller patent förefaller det som att fastfasbatterier, metall-luftbatterier och flödesbatterier börjar dra till sig uppmärksamhet. Huvudaktörer som är involverade i forskning kring batterier är Chalmers tekniska högskola, Uppsala universitet och Kungliga tekniska högskolan. Aktörer som en stor andel av forskningsbidragen har gått till är Northvolt och Svenska Eltransportlaboratoriet (SEEL). Aktörer inom patenträtt visar sig skilja sig jämfört med de huvudaktörer som får finansiering av Energimyndigheten. Längs värdekedjan går majoriteten av finansieringen till att utveckla olika typer av material till batterier och till att förbättra prestandan i användningsfasen.

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1. Introduction

According to the most recent assessment report by the Intergovernmental Panel on Climate Change (IPCC), it is undeniable that climate change has resulted in irreversible impacts as natural and human systems are pushed beyond their ability to adapt (IPCC, 2022). The impacts are widespread and beyond natural climate variability. Moreover, the assessment report shows that approximately 3.3-3.6 billion people and a high proportion of species are highly vulnerable to climate change. The current unsustainable pattern of development is increasing the exposure to climate hazards for both humans and ecosystems. The impacts of climate change are not only becoming severe but also increasingly complex and difficult to manage (IPCC, 2022). Various climate risk might occur simultaneously and interact with non-climatic risks, causing risks cascading across different sectors and regions. The assessment report further emphasizes that transformation and system transition can enable the adaptions required for achieving low global warming levels, in turn ensuring human health and wellbeing, economic and social resilience, as well as ecosystem health.

Similar to the findings of the IPCC assessment report (2022), Köhler et al. (2019) recognizes that transformation and system transitions is required in order to meet global challenges such as climate change. Unlike incremental technical improvements, these are radical shifts toward new types of sociotechnical systems. Therefore, research is needed to understand how these radical changes can develop and at the same time fulfil important societal functions.

The multi-level perspective (MLP) is a framework that can be used for analyzing transformation and system transitions. it combines ideas from different fields, including evolutionary economics, the sociology of innovation and institutional theory (Geels, 2005). 9). The main idea is that transitions occur through dynamic processes within and between three analytical levels. The first level involves niches, which are protected spaces where radical innovations can thrive. The second level is the socio-technical regime, which represent the existing sociotechnical system that is characterized by path dependency and incremental change. The third level is the socio-technical landscape, which is the exogenous environment that affects socio-technical development. Transition can occur when landscape developments put pressure on the regime, leading to cracks, tensions and windows of opportunity for radical innovations from niches to break through.

The MLP focuses on how transitions evolve, but there are other important aspects of sustainability transitions to consider. One such aspect is pointed out by Mazzucato (2018), she explains that innovations not only have a rate but also a direction. Some directions of innovations are more desirable than others since they are more likely to manage social, environmental, and economic challenges. However, not all possible directions are feasible. A variety of social, institutional, cultural and political mechanisms affect the possible directions of innovation, resulting in only a restricted number of possible outcomes (Stirling, 2009). To understand the potential outcomes of directionality, Andersson et al. (2021) have developed a framework that conceptualizes the multidimensional space in which sociotechnical systems may adopt different shapes and configurations.

To summarize, climate change mitigation requires grand transitions as well as research to understand and conceptualize these transitions. According to Köhler et al. (2019), transition is already beginning to happen in some areas, for example renewable electricity technologies and electric vehicles. These transitions create a new demand (for example batteries) which in turn causes new industries to form. The development of new industries is important to study, for example the location of the industry will affect which countries in the world that will benefit from the innovations. The battery industry formation is an interesting case for studying this. Therefore, this thesis will focus on analyzing and understanding transitions for a specific case: industry formation of emerging battery technologies in Sweden, which will be presented more specifically in the section below.

1.1 Case study: emerging alternative battery technologies in Sweden

Market prospects suggest a fivefold increase in the global consumption of lithium-ion batteries (LIBs) from 2017 to 2025 (Avicenne Energy, 2019). This fast increase is also shown in Figure 1 for the time span 2008-2021. European LIB production capacity is expected to grow to 500 GWh in 2030, fulfilling an internal demand of about 400 GWh (Avicenne Energy, 2021; EUROBAT, 2022). Sweden is part of this industry formation. During this period, there has been a replacement of the previously established rechargeable nickel metal hydride batteries with LIBs and nickel cadmium batteries (Patrício *et al.*, 2015). The battery producer Northvolt started producing its first LIB in in Sweden in the end of 2021 and their gigafactory located in Skellefteå is currently producing 2 GWh/year of batteries (Avicenne Energy, 2022). It is worth mentioning that in 2020, expectations were to get 40 GWh in 2023 (Jaani Heinonen, 2020). However, it is now forecasted to produce 32 GWh/year in 2030 and there is a plan to expand production up to 60 GWh/year (Avicenne Energy, 2022; Jaani Heinonen, 2020; Clyde Hughes, 2021). This trend is illustrated in Figure 2. In addition, Northvolt is planning another battery production site in Gothenburg, which will be begin operating in 2025 (Automotive News Europe, 2022). That planned site would be able to produce another 50 GWh of batteries per year, which corresponds to supplying about half a million cars with LIBs (Automotive News Europe, 2022). These are the production plants known to the authors, which show signs of an emerging LIB industry in Sweden.

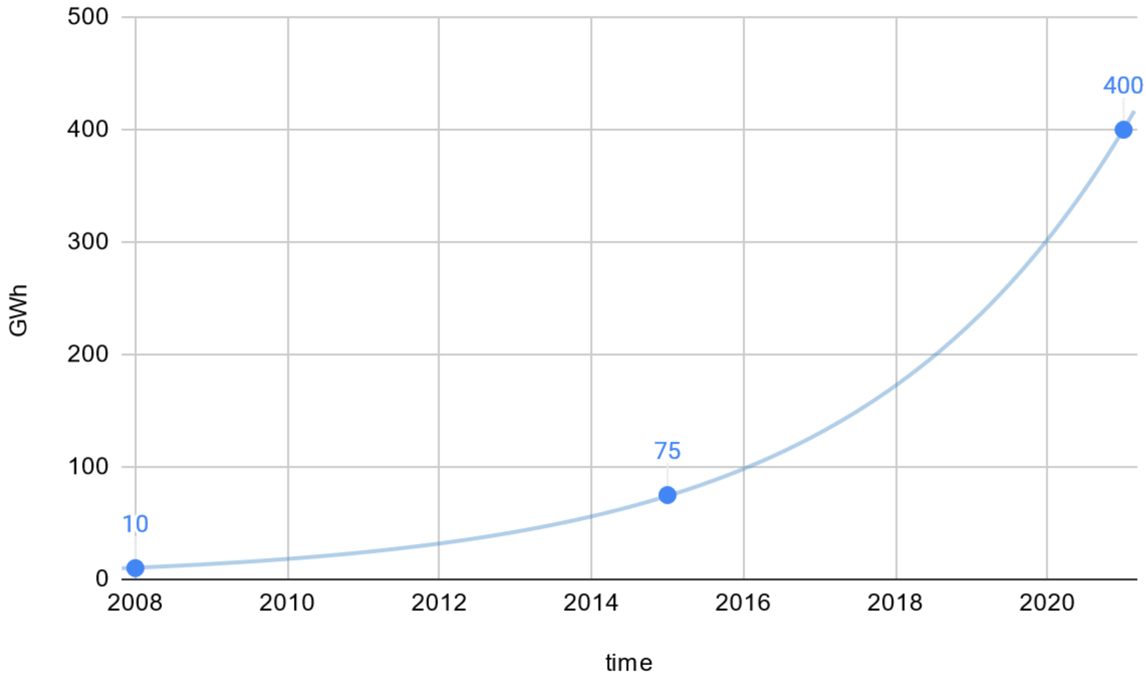

Figure 1. Global Li-ion battery consumption 2008-2021 (Avicenne Energy, 2022).

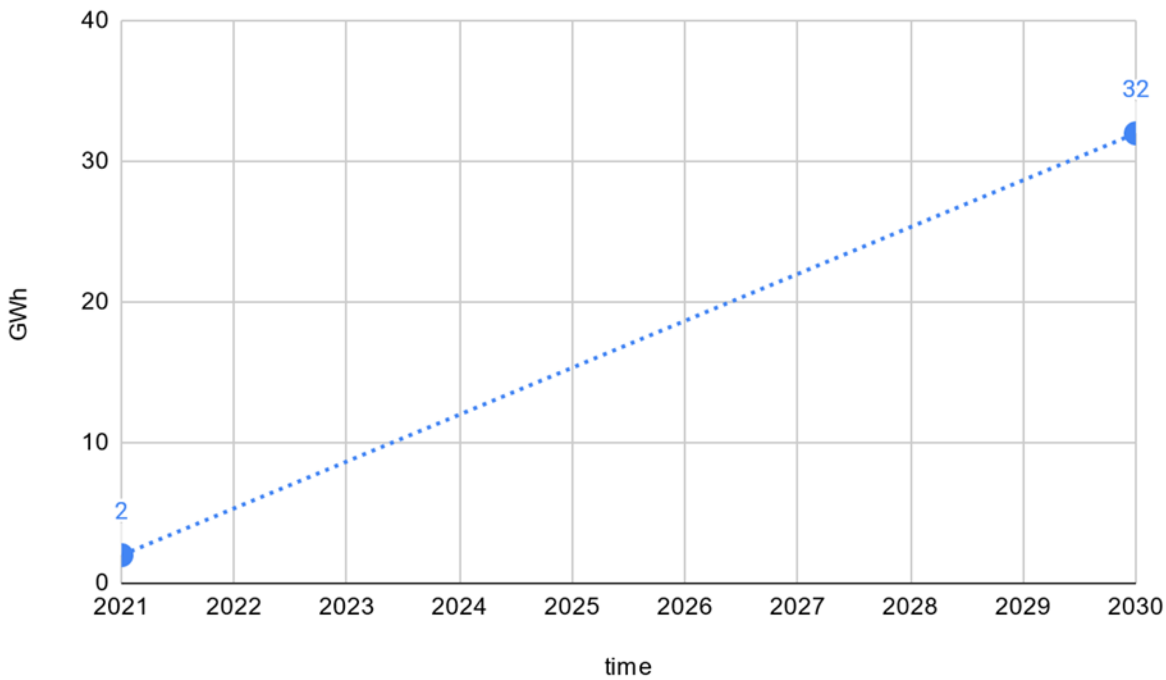

Figure 2. Sweden Northvolt Li-ion present and future production in Skelleftea industrial site (Avicenne Energy, 2022).

There is also a big interest in batteries in the scientific community. The publications of research articles in the 2000-2020 period shows an exponential increase in studies (Ma *et al.*, 2021). About 40% of them regard LIBs, while the remaining are about alternative battery technologies, mainly sodium-ion (Na-ion), lithium-sulfur (Li-S) and lithium-air (Li-O_2), which together amount to about 20% of all publications (Ma *et al.*, 2021). The remaining publications are about more minor battery technologies with publication rates below 3% each (Ma *et al.*, 2021).

1.2 Critical raw materials

Critical raw materials are materials that are economically important to the EU and show potential supply risks (European Commission (EC), 2021). Critical materials are used in most of battery technologies. For example, LIBs require cobalt and nickel, where cobalt mainly originates from a geopolitically instable region (Democratic Republic of the Congo) and nickel, which is primarily sourced from Russia. That sourcing is now becoming a concern due to the Ukraine war and possible commercial embargos. Table 1 shows the countries that account for the largest share of EU supply of some critical raw materials of relevance for LIBs. As can be seen, there are some countries with a high share of EU sourcing, which can be challenging for from a European supply risk perspective (Dorninger et al., 2021; European Commission (EC), 2021). The presence of critical raw materials in LIBs is a main motivation for transitioning towards other battery technologies (Ziemann *et al.*, 2013).

Table 1. Global producers, import reliance and End of Life (EoL) Recycling Input Rate(RIR) for relevant critical raw materials (EC, 2021, p. 21-22).

Raw materials	**Stage of evaluation of criticality in the value chain**	**Main global producers**	**Main EU sourcing countries**	**Import reliance**	**EoL-RIR**
Lithium	Processing	Chile (44%), China (39%), Argentina (13%)	Chile (78%), United States (8%), Russia (4%)	100%	0%
Cobalt	Extraction	Democratic Republic of the Congo (59%), China (7%), Canada (5%)	Democratic Republic of the Congo (68%), Finland (14%), French Guiana (5%)	86%	22%
Nickel	Not considered critical yet, by but highlighted as potentially critical				

1.3 Aim and research questions

The purpose of the thesis is to analyze the directionality of battery industry developments in Sweden during the 2008-2022 period. It is important to analyze the directionality to understand how societal challenges will be met and it is particularly interesting for the actors that are involved in this industry

Six research questions (RQs) were formulated in order to operationalize the above stated purpose:

1. Which rechargeable battery chemistries are covered by research funding in Sweden?
2. Which rechargeable battery chemistries are patented in Sweden?
3. Which parts of the rechargeable battery value chain are covered by research funding in Sweden?
4. Which actors are involved in research about rechargeable batteries in Sweden?
5. Which actors are involved in patenting rechargeable batteries in Sweden?

Three main methods are applied in this study to answer the RQs. RQs 1, 3 and 4 are mainly answered by analyzing data from battery projects funded by the Swedish Energy Agency, which is a major funder of battery research in Sweden. RQs 2 and 5 are mainly answered by consulting a patent database. In addition, a limited number of interviews with Swedish key battery experts are conducted in order to verify the results from the two other methods. The methods of this study are described in more detail in Section 3.

1.4 Limitations

The study will mainly rely on data from funding records, patenting trends and expert interviews. It would have benefitted from additional approaches, e.g. more deep interviews with developers of specific battery technologies and bibliometric studies. For example, some companies may not have filed patents or participated in publicly funded research projects related to all their research and development activities.

2. Theoretical framework

This section presents theoretical frameworks that will function as a basis for this study. A framework is developed to study industry formation and is influenced by the multi-level perspective (MLP) and a framework developed by Andersson et al. (2021) regarding directionality. These frameworks will also be described further in detail.

2.1 Multi-level perspective

The first theoretical framework is the MLP, which provides an explanation to how technological transition occur (Steward, 2012). It combines concepts from evolutionary economics, sociology of technology, history of technology and innovation studies (Geels, 2005a). The MLP framework is based on three conceptual levels: niche, socio-technical regime, socio-technical landscape (Geels, 2005b). The relationship between these levels is described as nested hierarchy, which means that socio-technical regimes are embedded within socio-technical landscapes and niches within socio-technical regimes (Geels, 2005a).

At the micro level, technological novelties emerge in niche markets (Geels, 2005a). The technologies are in an early phase of development and exist in various shapes. They emerge in so called “protected spaces”, where there is no market selection or competition. Since there is no selection, there is room for radical innovation in different niches, which is important to support learning processes.

The meso-level contains socio-technical regimes (Geels, 2005a). Regimes are actively maintained and created by different social actors and it is difficult for novel technologies to enter the regime level due to its stability. Even if the stability is dynamic, the changes that occur are often incremental, resulting in path dependency. This implies that it requires more than new competitive technologies to create new regimes. According to Geels, changes at the landscape level are also necessary to open up for novel technologies to enter the regime level.

The macro-level contains the socio-technical landscape, which is the exogenous environment that affects socio-technical development (Geels, 2005a). The term “landscape” implies a stability of that level. The landscape is normally beyond direct influence of individual actors and there are thus few possibilities to strategically change the landscape. The MLP framework can be illustrated graphically as in Figure 3.

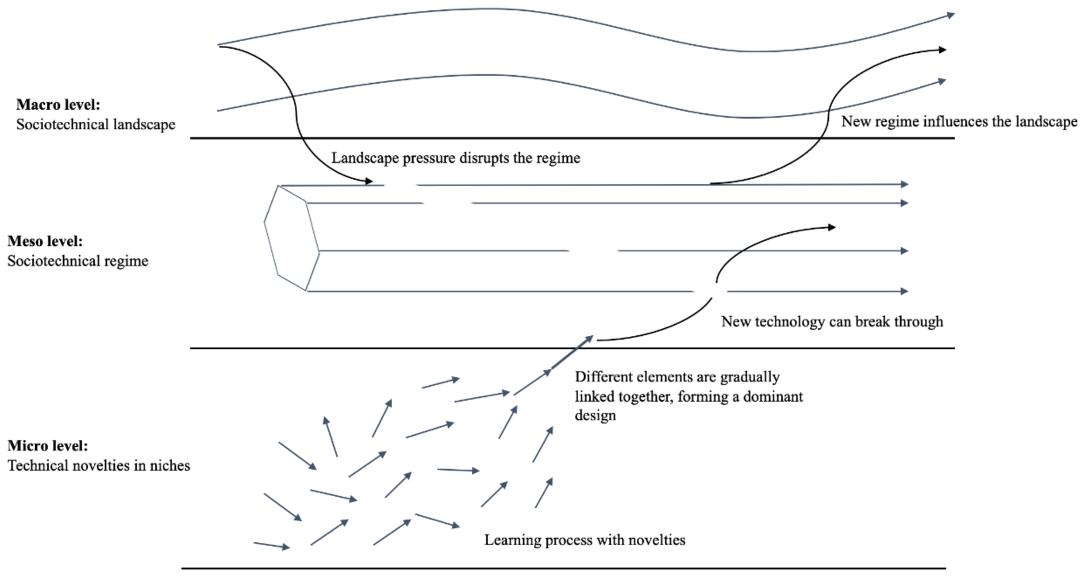

Figure 3. A graphical illustration of the Multi-Level Perspective. Modified from Geels (2005).

Geels (2007) describes four general transition pathways for niches to enter the regime. It is important to understand these pathways when studying industry formation, since it can suggest how certain batteries can enter a regime role. The first pathway is called transformation. Transformation occurs when there is a moderate landscape pressure and niche innovations have not been fully developed. As a result, regime actors will shape the direction of development and innovation. The second transition pathway is re-alignment and de-alignment. This can occur when the landscape pressure is divergent, large, and sudden. As a consequence, regime actors lose their legitimacy, which leads to de-alignment and dissolution of the regime. If niche innovations are not developed enough, it will create space for the emergence of multiple niche innovations to co-exist and compete. Eventually, one of these innovations will become dominant, shaping the core for the re-alignment of a new regime. The third pathway is technological substitution, which occurs when landscape pressure is strong and niche innovations are sufficiently developed. This allows the niches to break through and replace the existing regime. The last possible pathway is reconfiguration. This pathway occurs when the radical innovations that are developed in niches have symbiotic relationships with the regime. In a symbiotic relationship, these innovations can function as add-ons or component replacements of already existing technologies to solve local problems. Subsequently, the innovations will cause further adjustments to the regime, resulting in new socio-technical construction of the regime. In addition to these four transition pathways, there is also a possibility of a sequence of different pathways. For example, if there is heavy landscape pressure, the pathway can begin with transformation, followed by reconfiguration and then substitution or de-alignment and re-alignment.

Table 2. Characteristics of transition pathways.

Transition pathways	**Characteristics**
Transformation	•Moderate landscape pressure •Niche innovations not fully developed → Regime actors will shape the direction of development and innovation.
Re-alignment and de-alignment	•Divergent, large, and sudden landscape pressure → Regime actors lose their legitimacy causing de-alignment. •Niche innovations not fully developed → Niche innovations will compete until one become dominant. Shaping the core for the re-alignment of a new regime.
Substitution	•Strong landscape pressure •Niche innovations sufficiently developed → Niches can break through and replace the existing regime
Reconfiguration	•Radical innovations in niches have symbiotic relationships with the regime → Subsequently, the innovations will cause further adjustments to the regime resulting in new socio-technical construction of the regime.

2.2 Directionality

This section describes the second framework, which is based on research regarding directionality of technological innovation. Some directions of change can be perceived as more desirable considering the potential effects on the environment and human health, while others are more likely since sociotechnical change is usually path dependent (Andersson et al., 2021). Thus, it is important to investigate the possible directions of innovation and to characterize their potential outcomes.

According to Andersson et al. (2021), technological innovation can follow different trajectories that can result in different levels of diffusion and have different configurations. The authors have proposed a distinction between the pace and the direction of innovation, where the pace determines the level of diffusion, and the direction affects the shape of the sociotechnical system. They have chosen to investigate in the directionality of innovation and created a framework to identify the different configurations in a sociotechnical system. The framework is built on three fundamental dimensions of a sociotechnical system: temporal, spatial and socio-technical, which are illustrated in Figure 4. These dimensions act as boundaries that define the space of the system analyzed. It is necessary to specify the temporal and spatial dimensions of a certain study, since it is not possible to consider all past and future times, nor all geographical spaces. The boundary in the socio-technical dimension is derived from the definition of a technology, which can be either broad or narrow.

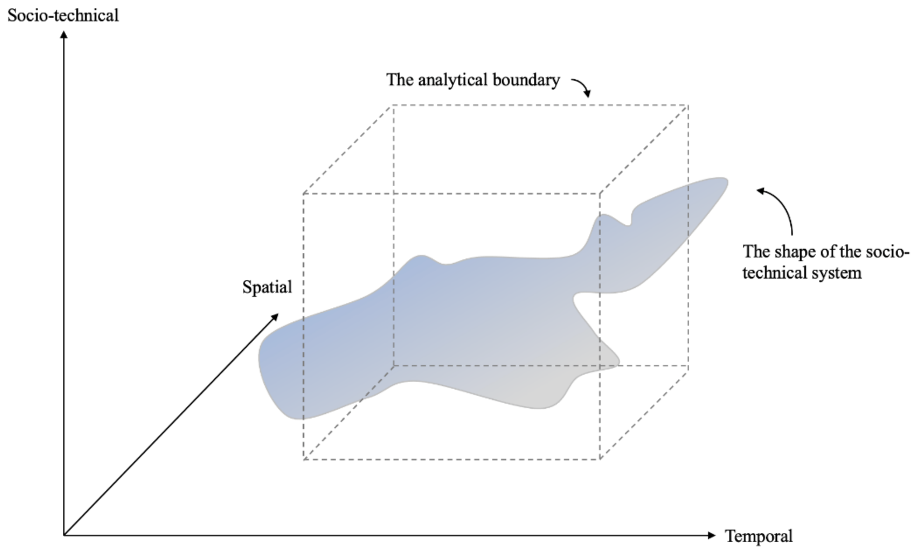

Figure 4. Illustration of the three fundamental dimensions. Modified from Andersson et al. (2021).

The characteristics of the three fundamental dimensions describe the innovation system. To describe the configuration of the system, the fundamental dimensions are divided into new categories: technical, social and spatial. The technical and social categories are distinctions of the sociotechnical dimension and the spatial dimension remains the same.

The technical configuration derives from the relation between artefacts and processes within a socio-technical system. The framework by Andersson et al. (2021) has identified five different configuration scales: technical diversity versus standardization, physical distribution versus concentration, technical specialization versus integration, physical separation versus integration, and technical completeness.

The social configuration is based on the actors involved in the socio-technical system and how they interact. The framework from Andersson et al. (2021) has identified five different configuration scales for this dimension as well. These are: operational distribution versus concentration, ownership distribution versus concentration, operational specialization versus integration, ownership specialization versus integration, cognitive alignment versus misalignment, and normative alignment versus misalignment.

Lastly, the spatial configuration describes the geographical location of the socio-technical system. The framework from Andersson et al. (2021) contains four different configuration scales: Formal regulation versus de-regulation, type of spatial localization, regional distribution versus concentration, and regional specialization versus integration.

Andersson et al. (2021) has also included a multi-dimensional configuration in their framework, where all three – technical, social and spatial – configurations can be combined.

In addition, one can also include the temporal dimension to observe how these three different dimensions change over time.

The MLP and the framework on directionality will in conjunction form the theoretical foundation that will be the basis of this thesis. It can enable forecasts on the possible outcomes of the battery industry formation. The MLP can help understanding which battery type is a part of the regime and which batteries are growing in niches. This can give a picture of how the industry is formed today and which possible technologies that can enter the regime in the future. The framework on directionality can map the configuration of the battery industry. For example, within the social dimension of that framework, one can analyze which actors are most prominent at a certain time.

3. Methodology

This section describes the methodology used in this thesis. Firstly, a description is made on the link between the theoretical section and the methodology. Then, the methodology is divided into two main steps: data collection and data characterization.

3.1 Link to theory

The theoretical framework from Andersson et al. (2021) was used to interpret the results from different data sources. The relation between the different dimensions and corresponding data is illustrated in the Table 3. These research questions are also related to these dimensions. The questions regarding which the battery technologies that is being developed in Sweden lie within the technical dimension. The question concerning which parts of the value chain that is covered by research funding is also a part of the technical dimension. For the research questions regarding which actors that are involved in the Swedish battery development, the corresponding dimension is the social. Lastly, the spatial dimension is corresponding to the location of different actors.

Table 2. Relation between theory and data.

Dimension	Type of data
Technical	Type of battery chemistry e.g. Li-S
	Materials used in the technology value chain
	Data from interviews
Social	Characteristics of different organizations and public private relationships
	Number of organization/individuals owning patents
	Number of organizations producing batteries
	Data from interviews
Spatial	Where is the system located (Sweden)
	Number of organizations for each region
	Data from interviews

3.2 Data collection

The first steps of the methodology is about data collection from different sources, as illustrated in Figure 5. The first data source is the project database by the Swedish Energy Agency (Energimyndigheten, 2022), where data is obtained about the projects funded by the agency, thanks to a created R scraping tool script. The data was chosen from a strategic search inside the database, using adapted research strings. Search strings can be found in the paragraph “Strategic search in Swedish Energy Agency database”.

Since the identifying and categorizing projects from the Swedish Energy Agency is one of the primary data sources of this thesis, it is important to understand the aim and goal of Swedish Energy Agency to draw conclusions based on the obtained results. The Swedish Energy Agency aims to lead the Swedish society’s transition to a sustainable energy system (Energimyndigheten, 2022). The Swedish Energy Agency does not only support research, but also business development that can commercialize innovations and new technology. Thus, the projects from the database are a combination of investments in research, development and innovation. These differences also affect the characteristics of the projects. Some projects are pure investment projects, whereas others are research projects that require competent personnel and many working hours. It is also important to know that the Swedish Energy Agency is closer to application compared to other financiers that invest more in long-term and basic research. The Swedish Energy Agency therefore prefers company involvement when deciding to invest in different projects, which often leads to projects that offer return within a short time frame. However, it should be noticed that while the Swedish Energy Agency is the main funder of battery research in Sweden, its database does not cover all battery funding received in Sweden. For example, the European Union also funds research projects focusing on battery research, which are not included in this study.

Each project in the database is categorized according to what type of battery chemistry it considers, how much funding is invested in the project, where in the value chain it is centered, which actors that are involved in the project and which area and sector the project relates to. The aim is to understand which types of rechargeable battery chemistries, which actors that are involved in the research and which parts of the rechargeable battery value chain that are covered by research funding in Sweden, as per the RQs in Section 1.3. That data provides a foundation for an initial characterization of the Swedish battery industry and an understanding of which emerging battery technologies that different actors are focusing on. The actors identified from the Swedish Energy Agency's database were further analyzed through web search to find their types and location. Similarly, the battery chemistries found through the Swedish Energy Agency were further analyzed through a web search to categorize them into value chain diagrams.

Furthermore, data gathering from patent databases was conducted in a similar way as for the Swedish Energy Agency data, using strategic searches. Search strings can be found in the paragraph "Strategic search in patent database". The patents were analyzed to identify trends in upcoming battery technologies and the distribution of battery chemistries patented. The aim of the research is to identify what types of rechargeable battery chemistries and which actors that are involved in patenting within Sweden.

In addition, interviews were conducted to complement the other methods and verify their results. Prior to the interviews, an interview guide was developed, shown in Appendix A, with themes and questions that could provide further information about what direction the battery industry is taking. Three experts were selected: a prominent battery professor from a leading Swedish university when it comes to battery research, an experienced administrator from the Swedish Energy Agency, and an experienced electromobility project coordinator. Each person was interviewed according to the interview guide, and they also had the opportunity to examine preliminary results from the study. After the interviews, interview data was qualitatively analyzed to identify market and research trends.

Figure 5 provides a graphical overview of the data gathering.

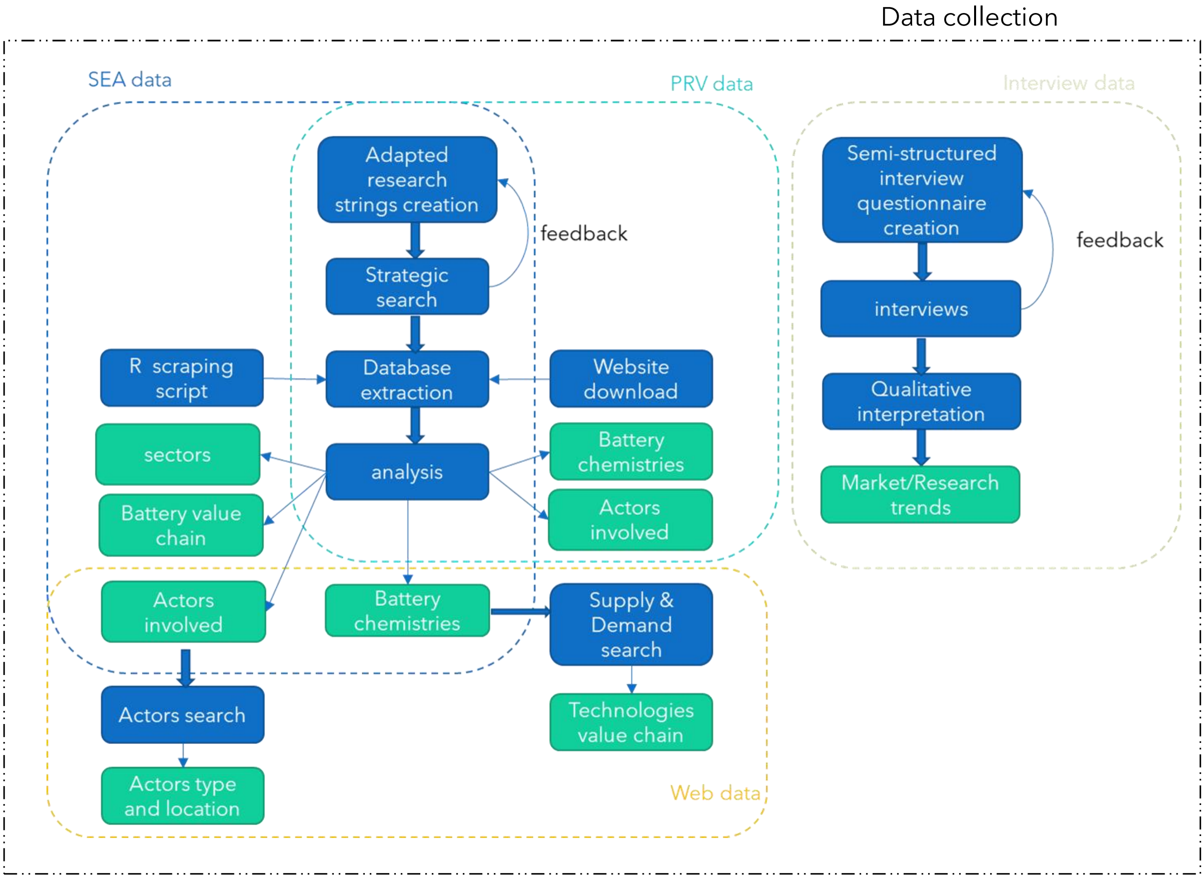

Figure 5. An overview of the methodology data collection. Green boxes represent results and blue boxes represent steps in the data collection and categorization. SEA=Swedish Energy Agency, PRV=Swedish Patent Database.

3.2.1 Strategic search in Swedish Energy Agency database

It was found that some projects related to batteries from "batteri" search were lacking in the "batterifondsprogramet" search. This happened similarly with “Litium svavel” and “Li-S” searches. Due to the unpredictable behavior of the database search and due to our previous knowledge on chemistries given by Ma et al. (2021) is the reason why at the end we opted for these research strings:

- *Batteri* (Eng. battery)
- *Litium* (Eng. lithium)
- *Natrium* (Eng. sodium)
- Organic
- *Litium svavel* (Eng. lithium sulfur)
- Li-S

Additionally, an advanced search on batterifondsprogrammet has been performed.

The data coming from these search strings was merged and qualitatively analyzed to find projects relevant to rechargeable batteries. Some projects were excluded since they did not regard rechargeable batteries, but rather alkaline batteries, compressed air, hydrogen (as main focus).

3.2.2 Strategic search in patent database

The approach with the strategic search in the Swedish patent database (*Swedish Patent Database*, 2015) was clearly influenced by the experience gained with the similar search in the Swedish Energy Agency database. Indeed, based on the discovery of relevance of lithium ion, lithium sulfur, redox flow, metal air, sodium ion, lithium metal, solid state, and organic technologies, these were the search strings considered:

- *Litium jon batteri* (Eng. lithium ion battery)
- *Litium svavelbatteri* (Eng. lithium sulfur battery)
- Redox flow battery
- *Metall luft batteri* (Eng. metal air battery)
- *Natriumjonbatteri* (Eng. sodium ion battery)
- *Litium metall batteri* (Eng. lithium metal battery)
- *Solid state batteri* (Eng. solid state battery)
- *Organiskt batteri* (Eng. organic battery)

As can be noticed, it was here opted for more structured and similar search strings. This was possible due to the predictable behavior of the database searches after some trials. However, the “redox flow battery” search was all in English since it was found that the English denomination was used also in applications in Swedish. Furthermore, the extraction of the data was performed through the Excel export feature provided by the website. Therefore, a limitation was that metal air and solid state battery results were restricted to the first 500 results (website export limitation).

3.3 Data categorization

3.3.1 Technologies

The technologies for each project were identified by a qualitative text analysis to identify the main technologies involved in the project. No grouping of technologies was made since it was not found necessary. The different technologies were identified based on the key material involved, for example, “Li-ion” was denominated “LIB”. The analysis of technologies considered the main technology as reference for the project, apart from the network system analysis, which considered all battery technologies of relevance.

3.3.2 Value chain

A value chain model is required to allow for a categorization of the Swedish Energy Agency project data along the value chain. Several iterations of the model based on information in the Swedish Energy Agency’s database resulted in a diagram that includes all relevant value chain stages for this study. These stages are shown in Figure 6. The method used for categorizing of individual projects into categories along the value chain model is described in Table 4.

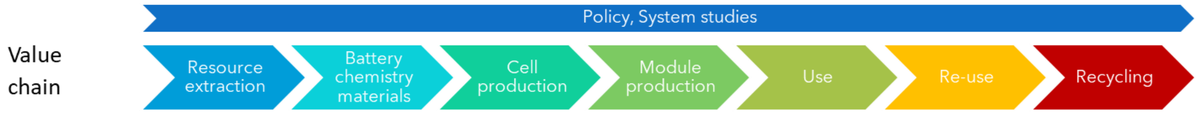

Figure 6. Value chain model used to categorise battery projects into stages along the value chain.

Table 4. Definitions of the various stages in the value chain.

Value chain stage	Description
Resource extraction	Project involves exploration, extraction, or sourcing of materials, where the purpose of the project is any kind of improvement in resource extraction methods not focusing on transportation or vehicles used.
Battery chemistry materials	Project involves studying the materials in battery interfaces, electrolyte, and electrodes for the purpose of improving materials, including manufacturing of electrodes, separators, binder, electrolyte, casing, and terminals.
Cell production	Project involves the production of cells from cell components, not restricted to specific chemistries.
Module production	Project involves the assembly of cells to modules up to packs, as well as electronic management of systems that manage power, charging and temperature.
Use	Project involves the integration of the battery pack into a product, including connectors, plugs, and mounts. It involves the use during the in-product specified battery lifetime.
Recycling	Project involves the collection and recycling of battery materials.
Re-use	Project involves the re-use or regeneration of batteries for second life applications.
Policy, System studies	Project involves overarching policy or system studies, including many parts of the value chain and/or the economy or markets, such as commercialization projects, life cycle assessments and theoretical feasibility studies.
unspecified	Description of the project does not give enough information to allow for a value-chain categorization.

In addition to value chain stages, sectors have been analysed according to the Swedish Energy Agency's classifications in the extracted database. The Swedish Energy Agency has two hierarchical categories to classify sectors. One is about the so-called area or field of science in which the project is taking place, and another is about the program under which it is funded, such as the battery fund program. We show both classifications.

4. Results

This section presents the findings of this study, beginning with an introduction of major investment projects. Then, the result within each dimension is presented, followed by the results from the network system analysis and technological value chain analysis.

159 projects have been analyzed from the Swedish Energy Agency. The total budget (public + external) was about 1.5 billion SEK budget, the public and the external funding were respectively, 0.8 billion SEK and 0.7 billion SEK. Figure 7 shows the development of rechargeable battery funding in Sweden originating from the Swedish Energy Agency between 2008 to 2022. There have been approximately four occasions where public and external investments have been particularly high (early 2018, late 2019, early 2021 and late 2021).

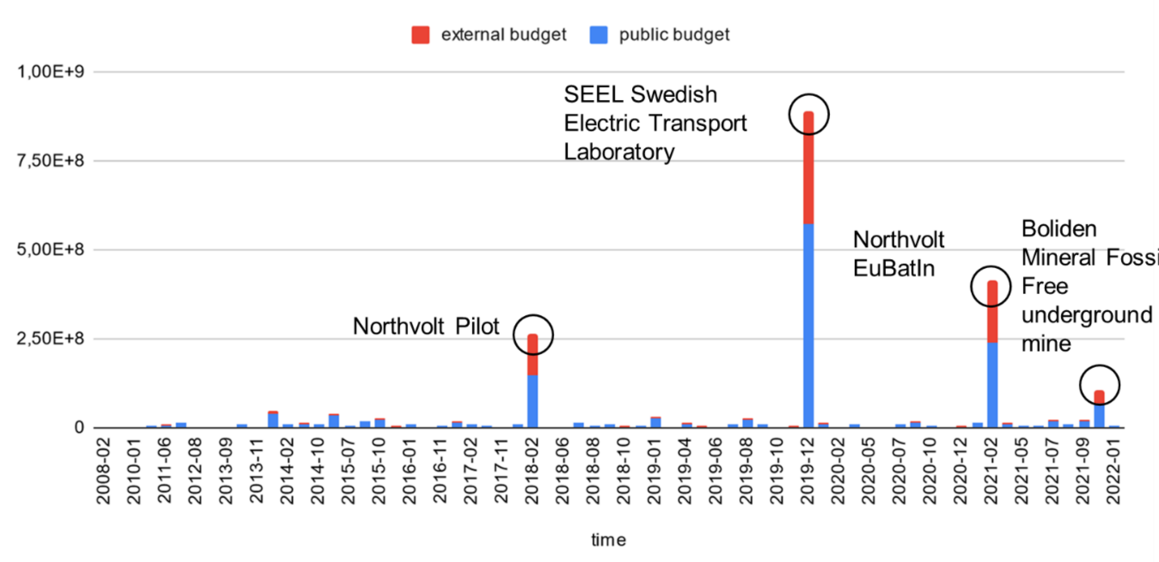

Figure 7. Swedish Energy agency public support complemented by external investments in rechargeable battery technologies.

The following section presents the four project (shown in Figure 7) in further detail. Northvolt pilot is one of the largest investment projects in LIB production. The Swedish Electric Transport Laboratory project is an important project of common European interest for the development of batteries. The EuBatIn project aims at developing LIB technology and the first generation of Li-metal batteries. Lastly, the Boliden Mineral project focuses on improving performances of batteries in a specific application.

4.1 Project description

<u>2018/02/01 Northvolt Pilot</u>

The project was 80% externally funded for an amount of 116 MSEK.

“The project concerns the design, commissioning, and testing of a pilot plant for the production of lithium-ion battery cells. The pilot plant intends to fulfill two purposes, partly to validate the vertically integrated production model that is characterized by process innovations and enables more sustainable battery production with lower carbon dioxide footprint, and partly to function as a center for research and development. The pilot plant is a crucial step towards an industry of strategic importance for Sweden and the EU. The project provides the conditions for Europe's first large-scale (> 32 GWh) battery cell factory to be established in Sweden." (Energimyndigheten, 2022).

2019/12/19 SEEL Swedish Electric Transport Laboratory
The project was 55% externally funded for an amount of 316 MSEK.

"On 21 December 2019, the Government commissioned the Swedish Energy Agency (N2019 / 03147 / EIN) to provide support for the period 2019 - 2022 with a maximum of SEK 575 million for the construction of a test and research center for electromobility (the Center). The structure of the Center is part of an IPCEI (Important Project of Common European Interest) for the development of batteries. The European Commission approved on 12 December 2019 (decision C (2019) 8823 final) that the Swedish state will contribute SEK 575 million to the construction of the Center. The center aims to create an arena for research and development of new technologies for electrified vehicles, ships, aircraft and work machines. The center will fulfill a function as a test facility for the entire development process, from research and innovation of components and systems to testing of complete electrified vehicle and propulsion concepts." (Energimyndigheten, 2022).

2021/02/01 Northvolt EuBatIn
The project was 73% externally funded for an amount of 174 MSEK.

"Within the project, Northvolt will: 1. Investigate and develop the next-generation advanced Li-ion battery and the first-generation advanced Li-metal battery, with important features such as energy density and a price / performance ratio that far exceeds today's state-of-the-art -species. 2. Develop innovative production process technologies that enable mass production of next-generation batteries, while reducing time to market. As an important supporting activity to (1) and (2) above, the project portfolio also includes the planning, construction and deployment of a battery cell development platform that will provide the physical resources in terms of R&D infrastructure and facilities required to deliver the project portfolio's objectives." (Energimyndigheten, 2022).

2021/10/13 Boliden Mineral Fossil Free underground mine
The project was 60% externally funded for an amount of 41 MSEK.

"The project aims to invest in a production system with a fleet of electrified machines and vehicles with both battery operation and electric trolley-assisted operation and thus in the long run be able to set a new standard for how small and medium-sized underground mines can be built. Development of systems and infrastructure of battery-powered vehicles together with a solution for electric trolley-assisted operation can overcome the limitations that currently exist in battery vehicles in applications with heavy and long transport cycles." (Energimyndigheten, 2022).

4.2 Project analysis

In Figure 8, it is possible to see the cumulative trend for public and external budget, together constituting the total budget of the Swedish Energy Agency directed towards projects. The highlighted larger projects are milestones for the increasing external budget into rechargeable battery funding. It took 10 years from the first investment before there was a major investment in Northvolt.

In Figure 8, the trend towards an increasing in the percentage of external budget into the total budget across the timeframe considered is clearly shown. It is easy to see how incremental the growth of external budget percentage was in the first ten years of accounting. The big steps represented by the highlighted four larger projects took Sweden to a situation where today about 30% of total budget invested by the Swedish Energy Agency is provided by other actors than the Swedish Energy Agency itself. Future direction is unpredictable and three different scenarios can be imagined. One in which external investment remain at about 30% of the budget. Another in which they may decrease back again, being overcome by public investment. A final in which they may increase further at the expense of public investment. The last would occur if the trend keeps going in the same direction as previously.

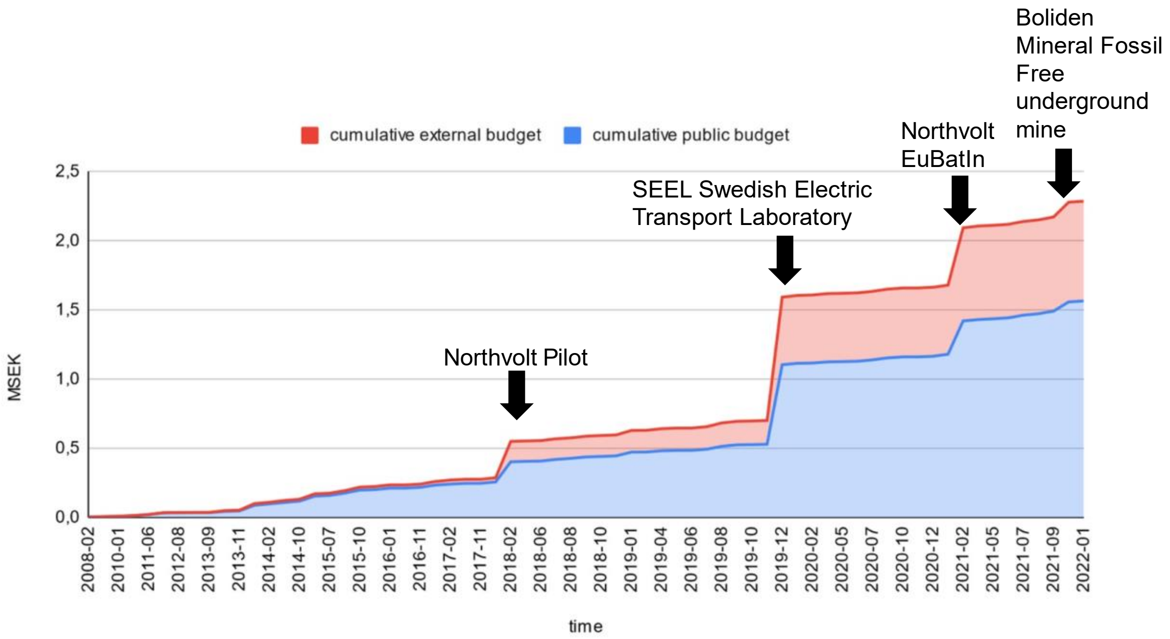

Figure 8. Cumulative Swedish Energy agency public support complemented by private investments in rechargeable battery technologies.

4.3 Actors

The characteristics of actors involved in the projects selected from the Swedish Energy Agency database is given in Figure 9 and Figure 10. The actor types are mainly companies (more than 50%), secondly universities (about 25%), third research institutes, finally there is a holding and a foundation.

There are three industrial poles corresponding to the three largely funded universities in Sweden. They are located in the three regions: Vastra götaland, Stockholm and Uppsala. Secondly, there are some actors almost equally distributed between Västerås, Östergötland and Norrbotten. Thirdly, there are some actors equally distributed in Västerbotten and Skåne.

Fourthly, there are some actors that are distributed all over other regions, each with less than 2% of the number of actors.

In Figure 11, the organizations with highest total budget are shown (>1%) and compared with the distribution of projects and external budget. The Swedish Electric Transport Laboratory (SEEL) and Northvolt dominate on total and external budget while universities dominate on number of projects. There are many small projects (36% of projects) apart from the big ones shown. Volvo and RISE stand out, since they have a lot of projects but not that much of funding. In Volvo's case, that might be because they mainly provide in-kind funding to research projects rather than receive funding. SEEL, Northvolt, Northvolt Labs, Boliden Mineral have only 1 project each even though they are on the top list for total budget.

In the same Figure 11, it is shown that patent applications are equally distributed across a multitude of actors like a "snake pit". However, it is possible to highlight some actors that stand out in terms of number of patents: Phinergy Ltd, Hydro-Quebec, and LG Chem Ltd. Additional data comprising the tables from which these illustrations were made can be found in Appendix B.

Similar to the findings from Figure 11, the interviews recognized the three universities Chalmers University of Technology, the Royal Institute of Technology and Uppsala University as main actors within the battery research field. The interviews also acknowledged Northvolt as an essential actor being responsible for the industry development of Sweden. One of the interviewees, the e-mobility project coordinator did point out some potential drawbacks related to this by explaining that Northvolt "uses up" a considerable share of the funds, making it more difficult for other companies to get funding from the Swedish Energy Agency. The e-mobility project manager rhetorically asked, how many facilities of that size can we have in Sweden in a short time? In addition, the person pointed out that other resources, such as the amount of expertise in the country or electricity network capacity, will also affect the possibilities for new actors to develop.

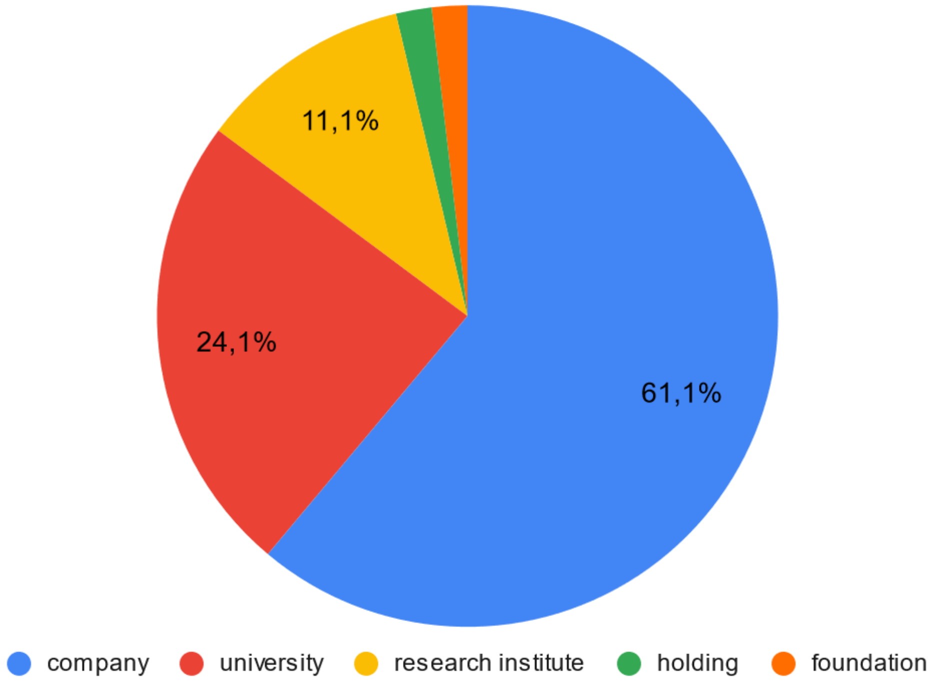

Figure 9. Actor types that receive battery funding via selected projects from Swedish Energy Agency between 2008 and 2022.

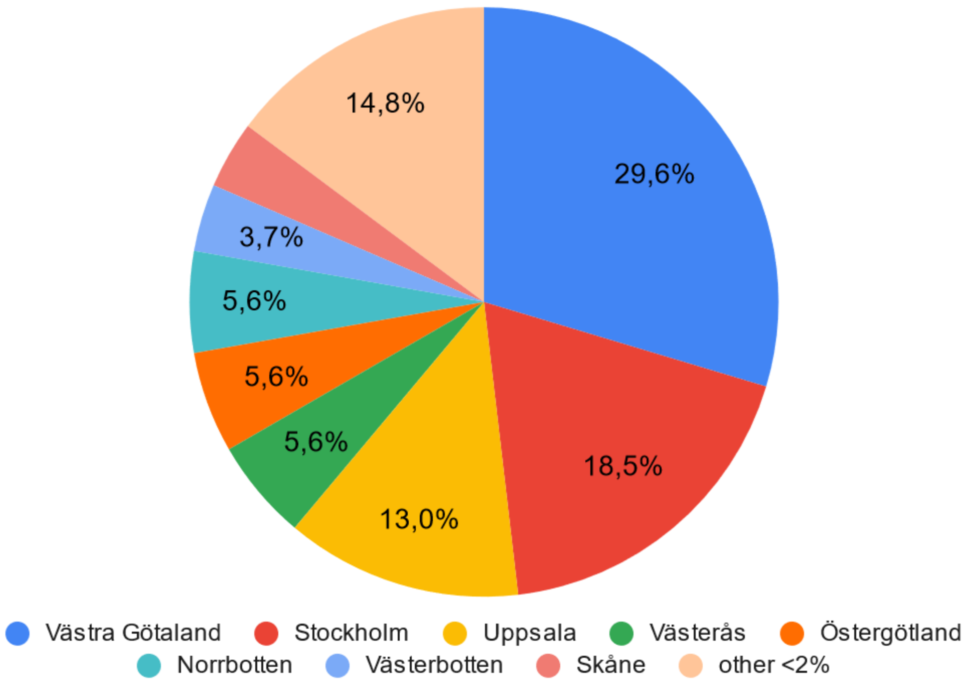

Figure 10. Locations of actors that receive battery funding via selected projects from Swedish Energy Agency between 2008 and 2022.

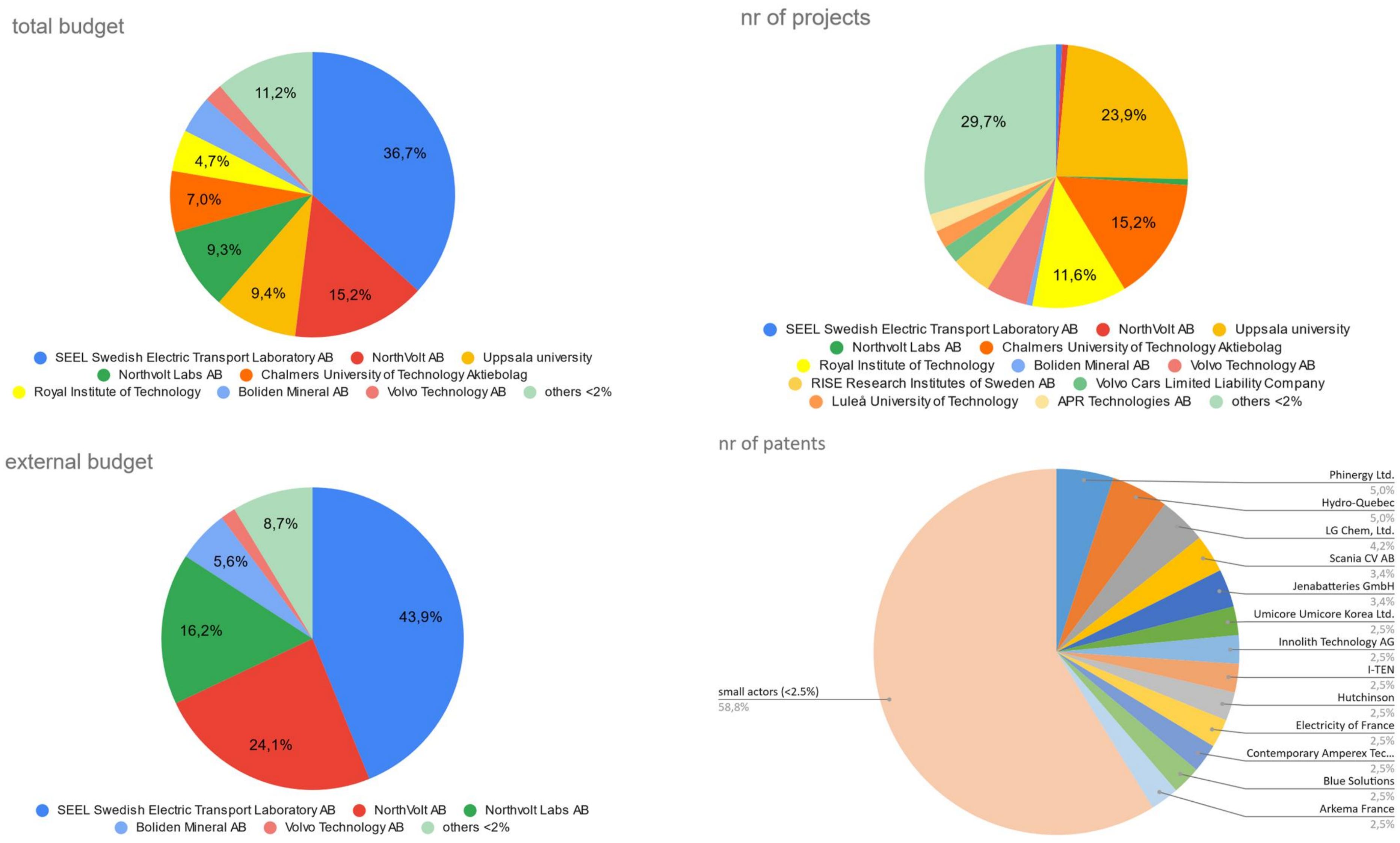

Figure 11. Organizations total budget distribution compared with number of projects and external budget distributions in 2008-2022 timeframe.

There are two specific individuals in Figure 12 that stand out as the project managers of the most funded projects: the CEO of SEEl and the CFO of Northvolt. They would be interesting candidates for more detailed interviews in future studies of battery industry formation in Sweden.

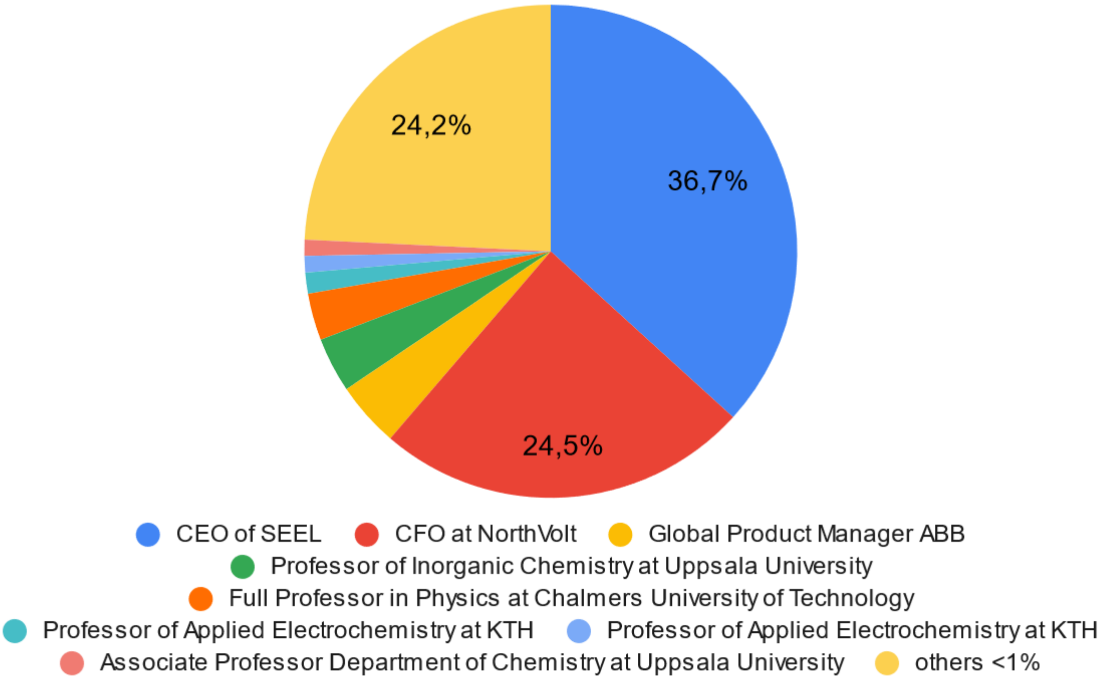

Figure 12. Distribution of budget given to specific project managers of Swedish Energy Agency projects.

4.4 Battery chemistries

Figure 13 shows the technologies involved in the Swedish Energy Agency projects. It is clear that the total budget goes mostly to unspecified technologies. Unspecified technology means that the project does not specify the technology used or related to the project, which may mean the focus is not a specific battery technology but it may still be relevant to the battery value chain. Regarding the projects where the main battery technology can be identified, LIB dominate Swedish Energy Agency's total budget, external budget and number of projects. However, it is possible to see how promising the options of Li-S, organic, SupCap and Na-ion are, since many projects are focusing on these technologies. The picture given by patents is one of a more equal distribution between the dominating LIBs and more emerging battery technologies. Additional data comprising the tables from which these illustrations were made of can be found in the Appendix C.

Even though the results from Figure 11 shows that Na-ion holds a share of 5.6% of the total projects, the interviewees all pointed toward Na-ion as the upcoming battery chemistry. In fact, the prominent battery researcher said that:

"Na-ion batteries could be a major player within 2-3 years, maybe even next year."

The researcher further explained that Na-ion is more developed than the other battery concepts and that it is possible to produce such batteries in an already existing production line that is currently used for LIB. The battery researcher further argues that Na-ion batteries has cost advantages, resource demand benefits and transportation benefits. However, the researcher pointed out that there will probably be another concept in addition to Na-ion that will enter the market in the future. Which type of chemistry is yet uncertain:

“Maybe magnesium, aluminum, organic or calcium. […] Everyone agrees that Li-ion and Na-ion batteries will be available. Too early to say which will be this additional technology.”

The Swedish Energy Agency administrator also pointed out Na-ion as an upcoming battery technology. The administrator explained that it is due to having the same manufacturing technology as LIB, which is an important factor for reaching a large market. Solid state lithium batteries was also mentioned as an upcoming battery concept. The administrator mentioned that premium vehicles are a strong driving force for the development of rechargeable batteries and these types of batteries provide high energy density, which premium vehicles require.

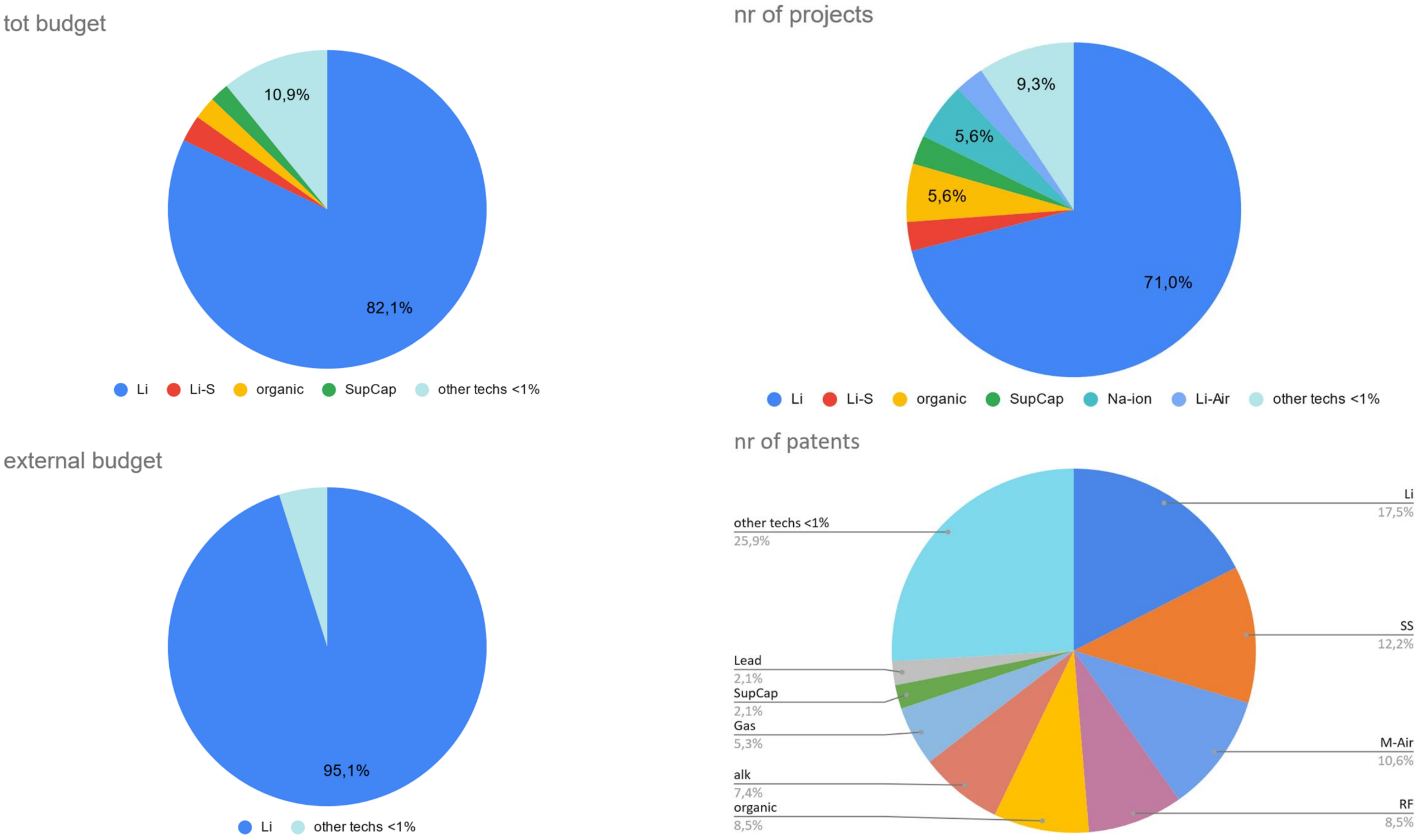

Figure 13. Technologies' total budget distribution compared with number of projects and external budget distributions in 2008-2022 timeframe .

4.5 Battery value chain

The results from the analysis of Swedish Energy Agency database regarding value chain coverage are shown in Figures 14 and 15. It is clear that the battery chemistry materials and use parts of the value chain contain most of the projects available, almost in equal shares. A different picture is given on the budget side. Here, use contains most of the budget and cell production arises as a considerable part in the budget distribution. Recycling, re-use and system are in focus in a relatively high number of projects, but they are not predominant on the budget side. The other parts of the value chain only contain a minor shares of projects and funding. Additional data comprising the tables from which these illustrations were made of can be found in Appendix D.

In line with the results obtained from the data analysis, all interviewees agreed on resource demand being one of the major challenges that the Swedish battery industry is facing right know. On the other hand, Sweden has developed within cell manufacturing and recycling.

The e-mobility project coordinator said that recycling of batteries will be a large source of metals in the long run. Currently, the lack of materials or access to certain metals is a problem. There are recycling processes that already exist, but they need to grow into large scale to manage the problem.

In contrast, the Swedish Energy Agency administrator mentioned that Sweden has half of the recycling capacity in the EU and that Sweden is moving upstream in the value chain. Instead, focus was mainly directed towards difficulties in upscaling:

"For each step in the value chain, much more money and competence is required. The bottleneck is not in ideas. For example, one person is enough to create an idea but many more people are needed along the way to be able to achieve commercialization."

The prominent battery researcher also pointed out that the value chain from producing a functioning concept to mass-producing battery cells takes long time, usually up to eight years.

"If we want to find out which battery concepts that will be on the market in 2030, we need to pay attention to the concepts that functions properly today."

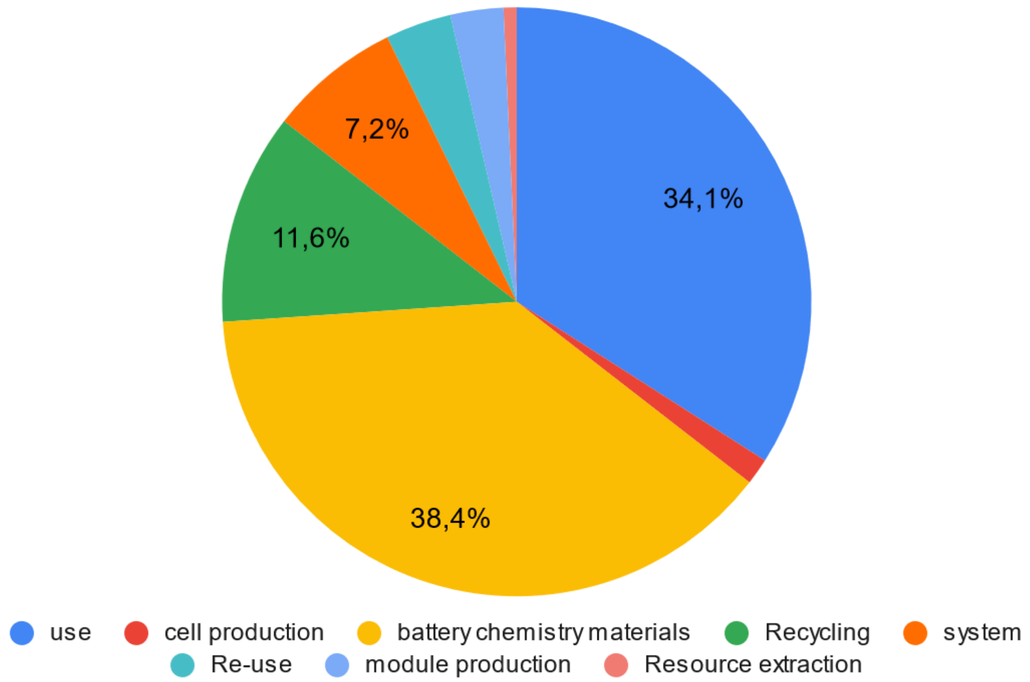

Figure 14. Share of projects per value chain category.

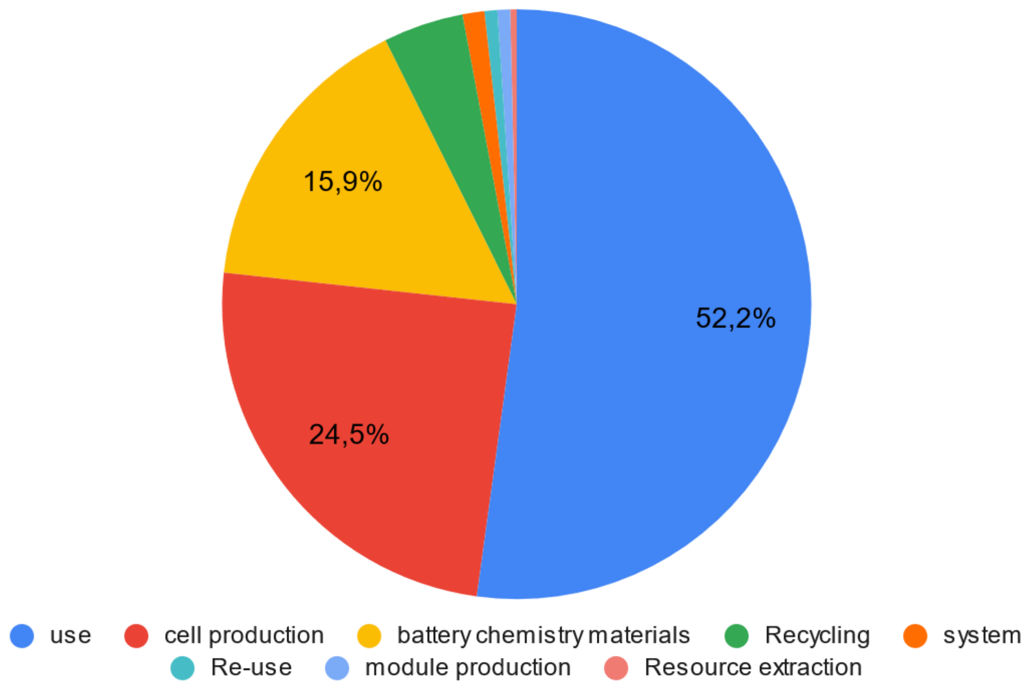

Figure 15. Share of budget budget per value chain category.

4.6 Comparison between technologies and value chain

In figure 16, the presence of funds across the value chain of all different chemistries can be seen. LIB funding is present in all parts of the value chain, it has no rivals in terms of value chain coverage compared with other technologies. However, organic, Na-ion and supercapacitor show some coverage too. It is interesting to notice that most technologies are funded in the "battery chemistry materials" step of the value chain. It may be because this is the bottleneck in the value chain. In contrast, redox flow batteries (RMF), lithium iron phosphate (LFP), nickel battery (Ni) and metal air (M-Air) focus only on "use", "recycling", "recycling" and "Policy, system studies", respectively. It is recommended to investigate these exceptions in further studies.

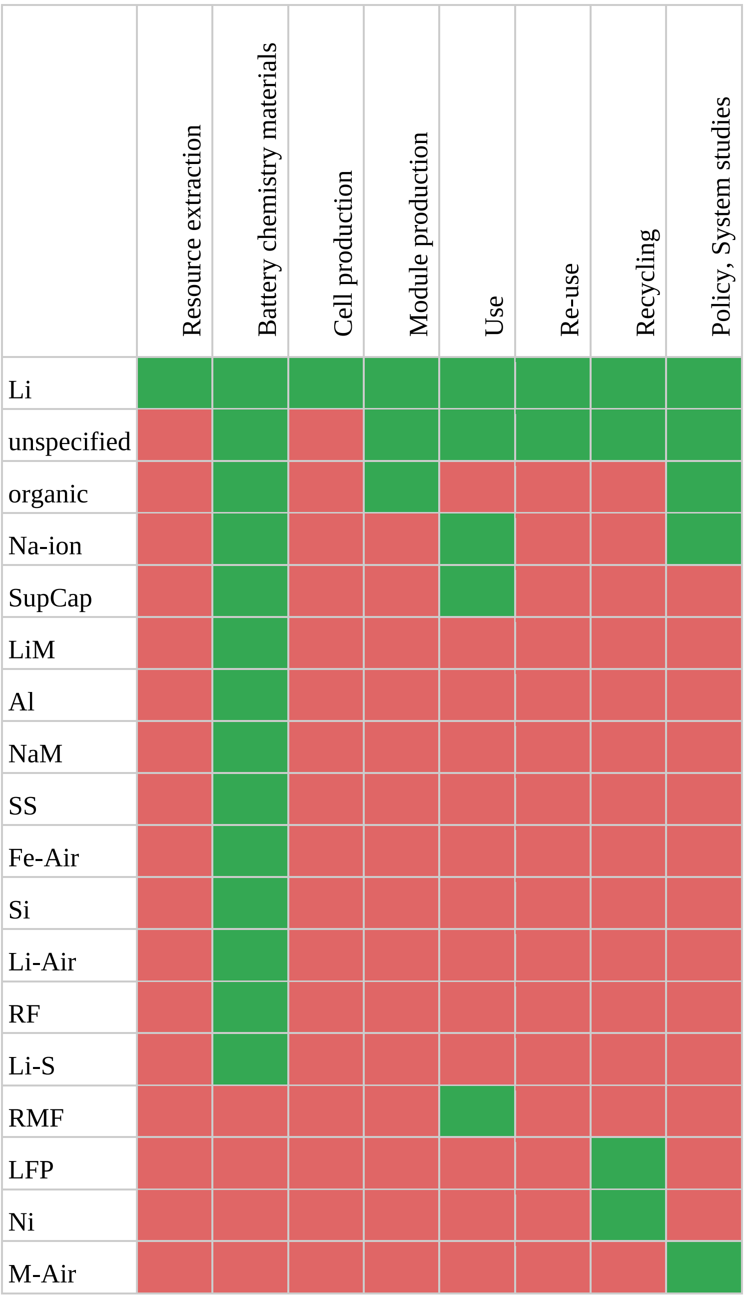

Figure 36. Heatmap showing the presence of funds across the value chain of all different chemistries identified.

4.7 Network system analysis

Figure 17 shows that there is a big focus on LIBs among the actors. All alternatives to LIBs, i.e. emerging, next-generation batteries, show modest and disparate interest, mainly by academic actors. They thus seem to constitute a “snake pit” of emerging technologies with no real leading technology (Grübler, 1998). This might be because largest funding initiatives have focused on LIBs, explicitly or implicitly.

Given this picture, we can identify the three most relevant actors according to network system analysis: Uppsala University (UU), Chalmers University (Chalmers), Royal Institute of Technology (KTH). These three actors and the technologies they received funding for will be further analyzed in terms of three different Gartner magic quadrant diagrams to show most promising technologies in the next section.

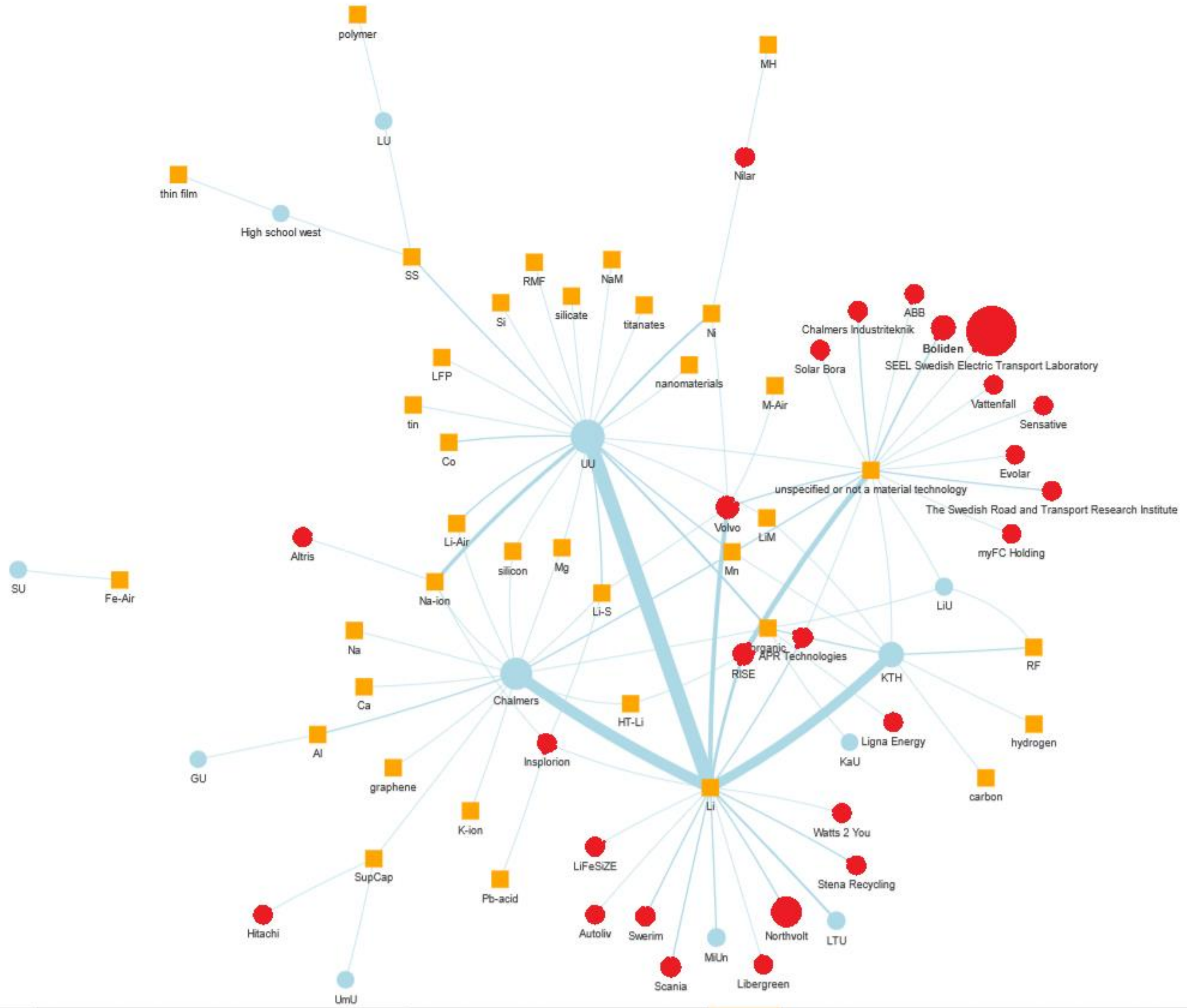

Figure 17. Network of technologies and actors in Swedish Energy Agency projects. Yellow squares show battery technologies[1], red dots are private companies, and blue dots are public actors. The size of the dots indicates total budget, while the size of flows indicates budget distribution.

4.7.1 Gartner Magic Quadrant diagrams

In this section, we present a comparison between the three main actors identified in the network system analysis through Gartner Magic Quadrant diagrams in Figures 18, 19 and 20. In Figure 18, it is possible to see that lithium sulfur and supercapacitor receive most of Chalmers' fundings while sodium ion, silica and lithium air batteries receive most of the Uppsala fundings. In Figure 19, it is possible to see that redox flow batteries receive most of the Royal Institute of Technology funding. Looking at Figure 18, 19 and 20 it is not possible to see any technology heavily funded by all of the three universities. However, lithium sulfur is heavily reseached by Chalmers and somewhat by Uppsala, while the lithium air technology

[1] It may be useful to see again the definition of "unspecified" technology back in section 4.3.

is heavily reseached by Uppsala and somewhat by Chalmers. Also, the redox flow battery is heavily reseached by Royal Institute of Technology and redox mediated flow battery is somewhat reseached by Uppsala. figure 21 represents the combination of the three actors' funds. It shows that lithium sulfur and redox flow technologies (if both RF and RMF are aggregated, since both are redox flow batteries) are the most funded, leaving the second positions with 20% less funds. It also shows that Uppsala university is greatly differentiating its research to several different technologies, comprising those technologies that are mostly funded in the two other universities. Next to Uppsala, which researches nine different technologies, Chalmers takes second position in terms of differentiation by researching three different technologies. The Royal Institute of Technology takes the last position since it only researches the redox flow battery.

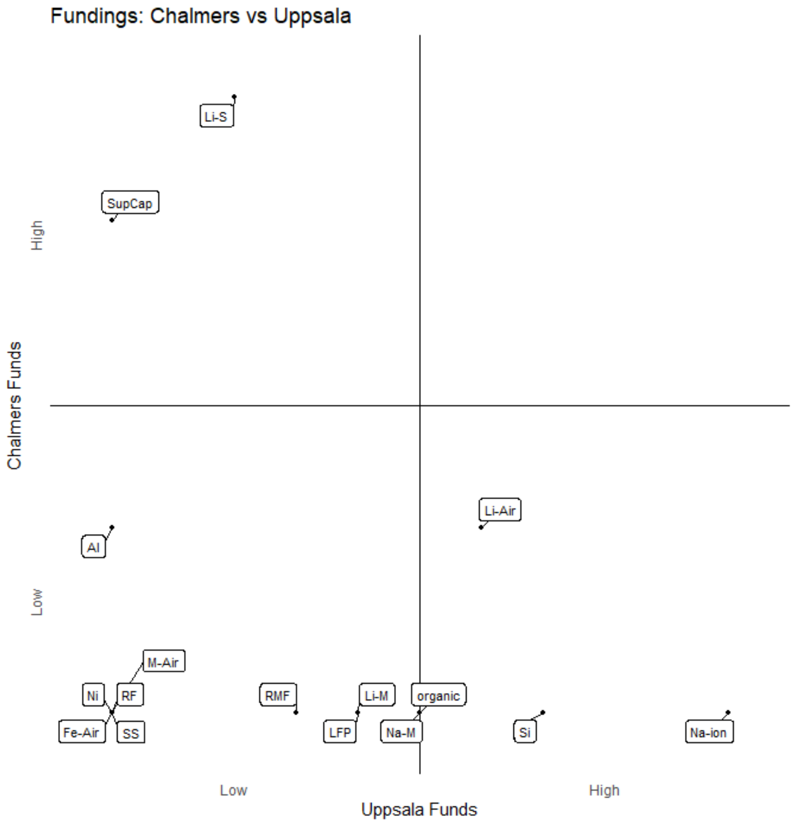

Figure 18. Gartner Magic quadrant of Chalmers vs Uppsala funds for battery technologies.

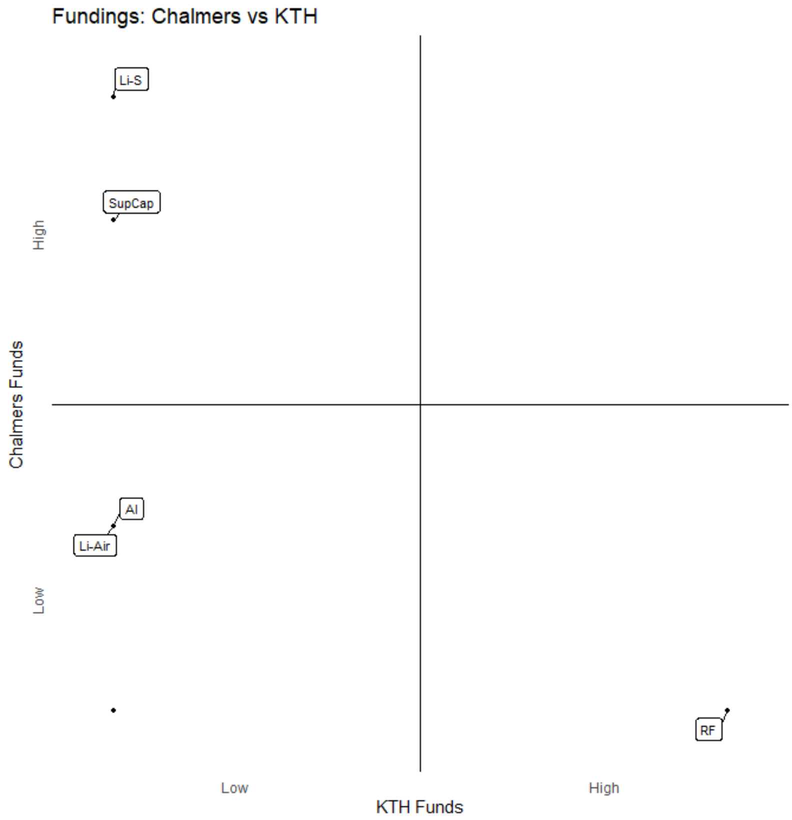

Figure 19. Gartner Magic quadrant of Chalmers vs KTH funds for battery technologies.

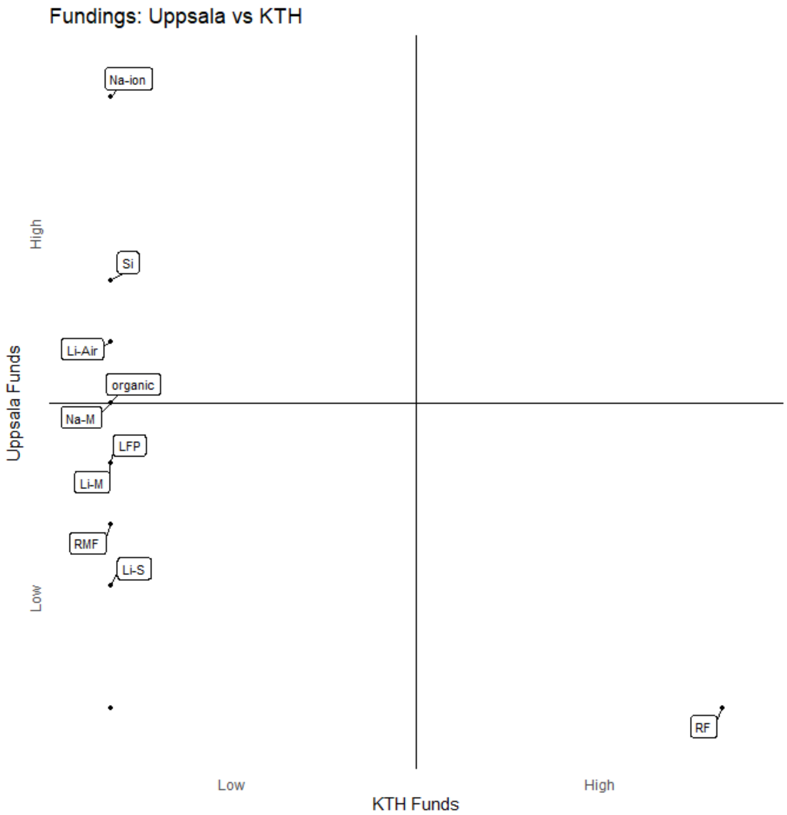

Figure 20. Gartner Magic quadrant of Uppsala vs KTH funds for battery technologies.

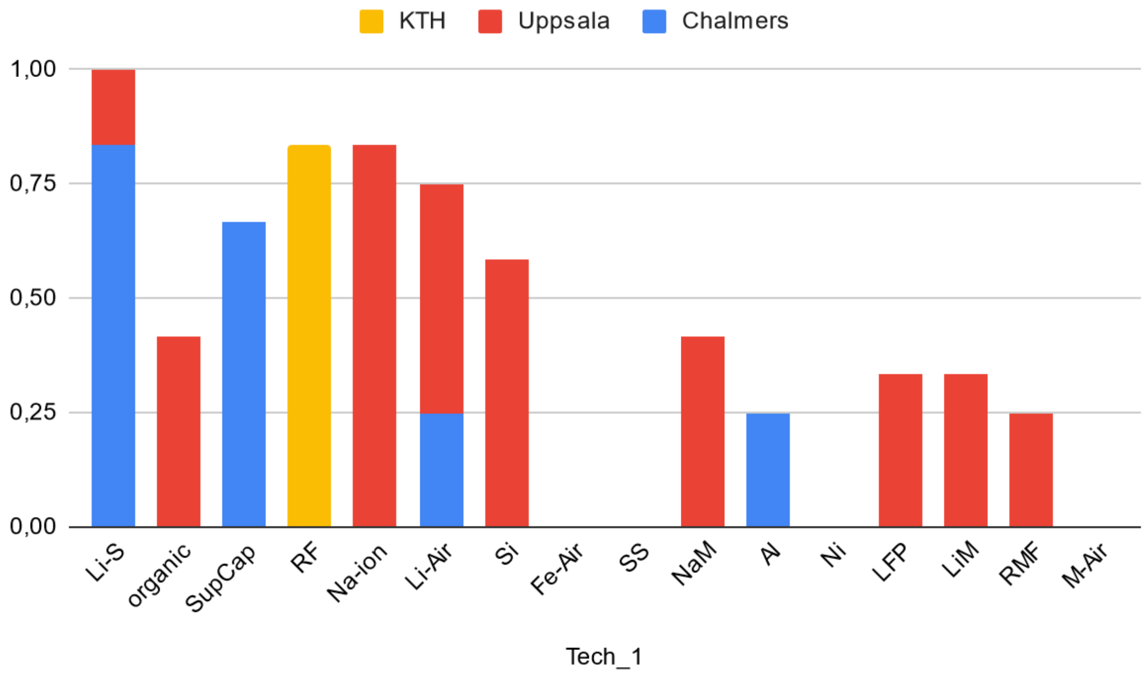

Figure 21. Combination of the three main university funds normalized.

5. Discussion

The purpose of the thesis was to analyze the directionality of battery industry developments and this chapter will further discuss the results from the study. Firstly, the results from this study indicates that LIBs constitute a regime, considering that they hold a majority of the total number of projects as well as the share of total funding. This result is expected, since this battery type is increasingly used in different applications today (Yoshino, 2014). For the emerging battery chemistries, the results from the Swedish Energy Agency's database showed that Na-ion, Li-S and organic batteries are supported by more projects and investments compared to other emerging battery chemistries.

In addition, the results from the interviews provided another aspect to consider when studying the potential of emerging batteries, namely the potential for large-scale production and creating a complete value chain. As explained by the interviewees, it requires a lot of capital, time and competence for an emerging battery to reach commercialization. Since Na-ion batteries can be produced in the same production line as LIB, they suggest it has an advantage compared to the other chemistries. Further research on these specific battery chemistries is recommended to understand different aspects that can affect their potential to enter the regime, possibly along one of the pathways outlined in table 2. In the case of Na-ion batteries, the similarities to the regime-holding LIBs in terms of production might mean that a transition can occur through e.g. substitution or reconfiguration.

The results of the actor analysis reveal that three universities – Uppsala University, Royal Institute of Technology and Chalmers University of Technology – are leading the battery research in Sweden. These universities hold the largest number of projects. Other actors that stood out in the result are SEEL and Northvolt, which hold a larger share of the total amount of investments. Since these projects are only based on investment rather than research it is reasonable that they stand out when looking at the amount of investments. These results can answer the question of which actors that are involved in research regarding rechargeable batteries in Sweden. However, there are also a number of smaller actors in the data, included among the "others" category in figure 7, which may have the potential to grow considerably. It is therefore advised to conduct further research on smaller companies and entrepreneurs in niches to discover potential upcoming actors.

There are also some important discussion points regarding the value chain analysis. For instance, the results indicate that the majority of the projects regards battery chemistry materials production and the use phase. This was also confirmed from the interviews; research projects tend to analyze the actual product, (i.e., materials and usage) compared to production methods and value chain analysis that are less likely to be researched. Currently, the part of the value chain that is most strikingly missing in Sweden is the resource extraction. In order to create a sustainable value chain, raw materials must be extracted sustainably. One option would be to shift the extraction to Sweden in order to gain a higher control of the raw material supply, e.g. in terms of sustainability performance of the mining. Currently, the European Union is trying to reduce its dependence on critical raw material in different ways (European Commission, 2022). One such way might include more mining within the EU. Another way is to decrease the dependency is through companies that are increasing the recycling rate. Since the geopolitical aspects of resource extraction are not explicitly covered in this study, it is recommended to conduct further research about this step of the value chain.

Finally, general recommendations from this study are to expand the spatial scope of the study to include the whole Europe, as well as to include additional data sources and projects in future studies.

6. Conclusion

From the results obtained in this study, it can be concluded that the rechargeable battery technologies covered by research funding in Sweden is mainly LIBs, followed by more minor financing of Na-ion, Li-S and organic batteries. Regarding patenting, again LIBs, followed by solid-state batteries, are the chemistries that have received most attention.

The parts of the value chain that are covered by research funding are primarily battery chemistry materials and usage. There are also notable shares of funding given to cell production and many projects involving recycling.

The main actors involved in research about rechargeable batteries in Sweden in terms of funding received are the research center SEEL and the company Northvolt. In addition, the academic actors Uppsala University, Chalmers University of Technology and the Royal Institute of Technology have received considerable amounts of funding.

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Appendices

Appendix A – Interview guide

Area	Example questions
Background	• What do you work with? • Why are you working on this? How did you get into this field? • How come you do not work with anything else? How would you compare the technology you work with in relation to other technologies/chemistries that you don't work with?
Directionality	• What would you say is the overall goal of battery research? • What do you want to achieve with battery research in Sweden? • What is reasonable to achieve by when?
Strengths	• What part of a value chain can Sweden take relative to other nations? • What are our relative strengths compared to other industrial nations?
Weaknesses	• What are the main obstacles/barriers to achieving the goals of the battery industry?
Results	• Our results shows X. Do you share the same opinion? • Is this desirable? If not, what do you think is?

Appendix B – Results for actors

Table 3. Organizations based on total budget involved in rechargeable battery funded programs.

Organisation	budget (MSEK)	Swedish Energy Agency budget (MSEK)	external budget (MSEK)	% tot budget	% tot Swedish Energy Agency budget	% tot external budget	Count of projects
SEEL Swedish Electric Transport Laboratory AB	575,0	258,8	316,3	36,75%	30,66%	43,87%	1
Northvolt AB	238,0	64,3	173,7	15,21%	7,61%	24,10%	1

Uppsala university	147,7	141,4	6,3	9,44%	16,76%	0,87%	33
Northvolt Labs AB	146,0	29,2	116,8	9,33%	3,46%	16,20%	1
Chalmers University of Technology Aktiebolag	108,8	99,0	9,8	6,95%	11,73%	1,36%	21
Royal Institute of Technology	73,6	71,4	2,1	4,70%	8,46%	0,30%	16
Boliden Mineral AB	66,8	26,7	40,1	4,27%	3,16%	5,56%	1
Volvo Technology AB	33,0	21,4	11,6	2,11%	2,53%	1,62%	7
RISE Research Institutes of Sweden AB	22,8	17,8	5,0	1,46%	2,11%	0,69%	7
Volvo Cars Limited Liability Company	18,7	12,4	6,3	1,20%	1,47%	0,88%	3
Luleå University of Technology	13,4	12,8	0,7	0,86%	1,51%	0,09%	3
Scania CV Aktiebolag	13,3	9,6	3,7	0,85%	1,14%	0,51%	2
Mid Sweden University	12,6	9,8	2,7	0,80%	1,17%	0,38%	2
Swerim AB	11,2	6,6	4,6	0,71%	0,78%	0,63%	2
APR Technologies AB	8,8	5,1	3,8	0,56%	0,60%	0,52%	3
University of Stockholm	8,2	6,9	1,3	0,52%	0,81%	0,18%	1
Linköping University	8,0	6,7	1,3	0,51%	0,79%	0,18%	2
Nilar AB	5,5	3,5	2,0	0,35%	0,42%	0,27%	1
Lunds university	5,3	5,3	0,0	0,34%	0,63%	0,00%	1
Karlstad University	4,9	4,9	0,0	0,31%	0,58%	0,00%	1
Umeå University	4,8	4,8	0,0	0,31%	0,57%	0,00%	1
The Chalmers Industriteknik Foundation	3,5	2,4	1,0	0,22%	0,28%	0,15%	2
The Swedish Road and Transport Research Institute	3,4	2,8	0,6	0,22%	0,33%	0,08%	2
RISE SICOMP AB	3,2	1,7	1,5	0,20%	0,20%	0,21%	1
ABB AB	3,0	2,3	0,8	0,19%	0,27%	0,10%	1
LiFeSiZE AB	2,9	1,5	1,5	0,19%	0,17%	0,20%	1
RISE Viktoria AB	2,9	2,4	0,5	0,18%	0,28%	0,07%	2
High school west	2,8	2,3	0,5	0,18%	0,27%	0,07%	1

Insplorion Sensor Systems AB	2,1	1,5	0,6	0,14%	0,18%	0,09%	2
University of Gothenburg	2,1	2,1	0,0	0,13%	0,25%	0,00%	1
Ligna Energy AB	2,0	0,9	1,1	0,13%	0,11%	0,15%	1
Vattenfall AB	1,8	0,5	1,4	0,12%	0,05%	0,19%	1
Stena Recycling International Aktiebolag	1,8	1,0	0,8	0,12%	0,12%	0,12%	1
Hitachi Energy Sweden AB	1,8	1,3	0,5	0,11%	0,15%	0,07%	1
Sensative AB	1,6	0,7	0,9	0,10%	0,08%	0,12%	1
AUTOLIV DEVELOPMENT AKTIEBOLAG	0,8	0,7	0,1	0,05%	0,08%	0,02%	1
AB Libergreen	0,8	0,6	0,2	0,05%	0,07%	0,03%	1
RISE IVF AB	0,5	0,3	0,2	0,03%	0,03%	0,03%	1
Stena Recycling AB	0,4	0,2	0,2	0,03%	0,03%	0,03%	1
Evolar AB	0,4	0,2	0,2	0,03%	0,03%	0,03%	1
UPPSALA UNIVERSITY PROJECT STOCK COMPANY	0,3	0,3	0,0	0,02%	0,04%	0,00%	1
Solar Bora AB	0,2	0,1	0,1	0,01%	0,01%	0,02%	1
Altris AB	0,1	0,0	0,1	0,01%	0,00%	0,01%	1
Watts 2 You AB	0,1	0,0	0,0	0,00%	0,00%	0,00%	1
myFC Holding AB (publ)	0,1	0,0	0,0	0,00%	0,00%	0,00%	1

Table 4. Organizations involved in rechargeable battery patents in Sweden in timeframe 2008-2022.

Organization	Count of patent applications
Phinergy Ltd.	6
Hydro-Quebec	6
LG Chem, Ltd.	5
Scania CV AB	4
Jenabatteries GmbH	4
Umicore Umicore Korea Ltd.	3
Innolith Technology AG	3
I-TEN	3

Hutchinson	3
Electricity of France	3
Contemporary Amperex Technology Co., Limited	3
Blue Solutions	3
Arkema France	3
Siemens Aktiengesellschaft	2
ROBERT BOSCH GMBH GS Yuasa International Ltd.	2
Renault SAS	2
Innolith Assets AG	2
Haldor Topsøe A / S	2
Fraunhofer Society for the Promotion of Applied Research eV	2
Central Glass Co., Ltd.	2
Center for Solar Energy and Hydrogen Research Baden-Württemberg Non-profit Foundation	2
Yung-Shen Lin	1
Volterion Besitz GmbH & Co. KG	1
thyssenkrupp Industrial Solutions AG	1
Sumitomo Seika Chemicals Co., Ltd. Osaka Research Institute of Industrial Science and Technology	1
Standard Energy Co., Ltd.	1
Solvay SA Commissariat for Atomic Energy and Alternative Energy	1
Solvay SA	1

SK Nexilis Co., Ltd.	1
SiteTel Sweden AB	1
SGL Carbon SE	1
Riegel, Jürgen	1
PPG Industries Ohio, Inc.	1
Pellenc (Societe par Actions simplifiee)	1
PELLENC (Société Anonyme)	1
Oxis Energy Limited	1
Northvolt AB	1
Nippon Power Graphite Company, Limited	1
Nilar International AB	1
National Center for Scientific Research Institute Polytechnic Institute of Grenoble	1
National Center for Scientific Research	1
Molecular Rebar Design, LLC	1
Molecular Rebar Design LLC	1
Mitsubishi Chemical Corporation MU Ionic Solutions Corporation	1
Microvast Power Systems Co., Ltd.	1
Martin SJÖDIN Christian STRIETZEL Rikard EMANUELSSON	1
Marc Busson Scytales AB Konstantin Papaxanthis	1
MAN Truck & Bus AG	1
Loui NAHRA Daniel LAURITSEN	1
Life Time Engineering AB	1

Kemiwatt	1
JUICE	1
IPS Integrated Power Solutions AG	1
Innventia AB Acreo Swedish ICT AB	1
Hydro-Québec Transfert Plus, SEC	1
Hydro-Québec SHOWA DENKO KABUSHIKI KAISHA	1
HUSQVARNA AB	1
HM Power AB	1
High Tech Battery Inc.	1
Grenoble Polytechnic Institute National Center for Scientific Research (CNRS)	1
Forschungszentrum Jülich GmbH (FJZ)	1
Enfucell Oy	1
Enerpoly AB Enerpoly AB	1
Energy Diagnostics Limited	1
Duesenfeld GmbH	1
DeLaval Holding AB	1
CTEK Sweden AB	1
Covestro Deutschland AG Thyssenkrupp Uhde Chlorine Engineers (Italia) Srl	1
Center for Solar Energy and Hydrogen Research Baden-Württemberg	1
Cabot Corporation	1
Bollore	1

Belenos Clean Power Holding AG	1
Bayerische Motoren Werke Aktiengesellschaft Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung eV	1
Alelion Batteries AB	1
Albemarle Germany GmbH	1

Appendix C – Results for technologies

Table 5. Techargeable battery technologies and relative budget.

Tech_1	**Nr of projects**	**budget (MSEK)**	**Swedish Energy Agency budget (MSEK)**	**external budget (MSEK)**	**% tot budget**	**% EM budget**	**% external budget**
unspecified	27	709,2	334,4	374,8	45,32%	39,62%	51,99%
Li	76	695,1	366,1	329,0	44,42%	43,38%	45,64%
Li-S	3	22,8	16,7	6,1	1,46%	1,98%	0,84%
organic	6	19,6	16,2	3,3	1,25%	1,93%	0,46%
SupCap	3	16,5	16,0	0,5	1,05%	1,90%	0,07%
RF	2	14,8	14,8	0,0	0,95%	1,75%	0,00%
Na-ion	6	14,6	11,6	3,0	0,94%	1,38%	0,42%
Li-Air	3	12,3	12,3	0,0	0,79%	1,46%	0,00%
Si	1	9,9	9,9	0,0	0,63%	1,18%	0,00%
Fe-Air	1	8,2	6,9	1,3	0,52%	0,81%	0,18%
SS	2	8,1	7,6	0,5	0,52%	0,90%	0,07%
NaM	1	6,7	6,7	0,0	0,43%	0,79%	0,00%
Al	2	6,0	6,0	0,0	0,38%	0,71%	0,00%
Ni	1	5,5	3,5	2,0	0,35%	0,42%	0,27%
LFP	1	5,4	5,4	0,0	0,35%	0,64%	0,00%
LiM	1	5,0	5,0	0,0	0,32%	0,59%	0,00%
RMF	1	4,3	4,3	0,0	0,28%	0,51%	0,00%
M-Air	1	0,9	0,4	0,4	0,05%	0,05%	0,06%

Table 6. Rechargeable battery technologies and relative number of patents in timeframe 2008-2022.

Tech	Number of patents
Li	33
SS	23
M-Air	20
RF	16
organic	16
alk	14
Gas	10
x	9
SupCap	4
Lead	4
Zn-Air	3
NiMH	3
Na-ion	3
MO	3
M-Gas	3
Li-S	3
HT	3
Galv	3
comp	3
Zn	2
NaS	2
Na-S	2
M-Cl	2
M-Alo	2
LiM	2
sea	1
S	1
NiCd	1
MO-H	1
MnO2	1
M-S	1
Li-I	1
Li-Air	1
Hg	1
Antymony	1

Appendix D – Results for value chain

Value chain category	**Nr of projects**	**Budget (MSEK)**	**% No of projects**	**% budget**
Use	47	816	34,06%	52,17%
cell production	2	384	1,45%	24,54%
battery chemistry materials	53	249	38,41%	15,93%
Recycling	16	68	11,59%	4,40%
System	10	18	7,25%	1,20%
Re-use	5	11	3,62%	0,71%
module production	4	10	2,90%	0,69%
Resource extraction	1	5	0,72%	0,36%
Total	**138**	**1564**	**100,00%**	**100,00%**

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