ON BEHALF OF THE SWEDISH ENERGY AGENCY

Competence needs and supply for a sustainable battery value chain in Sweden

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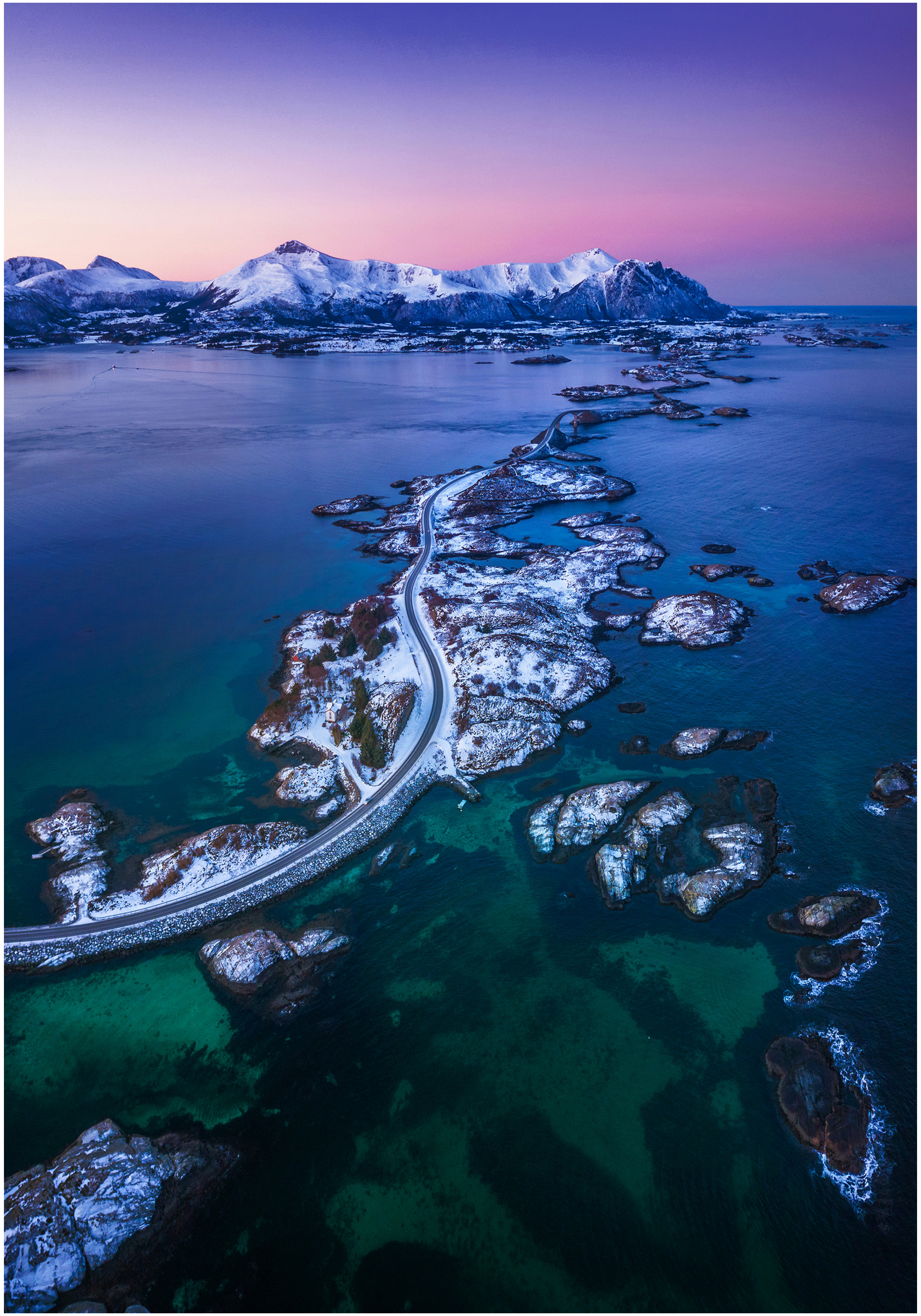


Executive summary

Batteries are considered a core technology for the decarbonization of the transport sector and the shift towards a renewable energy era. Developing a sustainable battery value chain is key to achieving Sweden's goal of a fossil-free welfare society, net zero emissions, and in ensuring the future (sustainable) competitiveness of the Swedish industry. With the emerging European battery economy, production capacities are being built up at a rapid pace. As the battery market is still dominated by Asia, skilled workers and competence for the battery value chain are in short supply in Europe. According to the European Battery Alliance (EBA), Europe will need to upskill and reskill 800,000 workers by 2025 to achieve its aim of the green shift and meet the demands of the growing battery value chain.

The sheer volume of competence needed in such a short time is a first for Europe's (and Sweden's) education and training ecosystem. Closing this skill gap and establishing more regional competence development in Europe is of utmost importance to supply the European battery value chain with a skilled workforce. To scale Sweden's role in the European battery value chain, substantial efforts need to be made on multiple fronts. From understanding what competences are needed to how these can be supplied by reinforcing and fast-tracking existing competence supply structures, designing new flexible education programmes, and strengthening Nordic collaboration.

This is the second of two reports that examine and unveil competence needs and supply for the sustainable battery value chain in Sweden. The first report employed an extensive literature review and survey of 66 industry experts to consolidate existing knowledge and to analyse Sweden's current competence demand. The second report completes the gap analysis by including the competence supply and proposes actions to bridge the competence gap for a sustainable battery value chain. This was done through 17 semi-structured interviews and a digital workshop with 21 participants. The result includes a knowledge synthesis, competence framework, challenges, preconditions, and suggested actions to close the gap.

Whilst a lot of initiatives and actions are currently in place to address the competence gap, the data from this study makes it clear that this is insufficient in its current form and scale. For the actual skills needed by the industry, there is a consensus by the industry on both transversal and specific skills (synthesized in a competence framework). Apart from this, the industry highlighted the need for a skilled workforce with:

- **Holistic understanding of the battery value chain, even for specialists**
- **Knowledge of battery chemistry, battery components, and battery systems integration**
- **A good understanding of circular economy and sustainability**
- **Operational knowledge of specific circular strategies, such as recycling**

To develop these skills and bridge the competence gap in the battery value chain, this study points to three main areas that need strengthening, these are:

1. **Need for coordinated efforts for the battery value chain**
2. **Challenges within the education systems**
3. **Keeping quality while increasing availability and capacity of education**

Finally, developing already strong environments and organizing the development of skills as well as access to education, both physical and virtual, is pivotal to meet the great demand that exists in the business community and thereby ensure Swedish competitiveness and welfare. Also, creating the conditions for a modular and dynamic range of courses, which can be adapted as needed, will be crucial for the ability to offer students and workers the right education with a high degree of accessibility, regardless of geographical residence. As such, increasing the share of research and innovation infrastructure as well as increasing accessibility to these environments, also for students, working professionals and between education levels, greatly affects Sweden's ability to meet the need for research and innovation, but also the supply of skills. This infrastructure should be available regardless of the residence and level of education of students. ●

Content

1. Introduction

1.1. Motivation – the emerging European battery value chain

Batteries are a core enabling technology in the transition towards a fossil-free society, from supporting renewable power generation and industry systems to the transport sector. In fact, a Swedish electric vehicle (EV) emits 83% less CO_2 emissions than a petrol driven car [1]. Whether or not this is an overly optimistic estimate, the demand for batteries is predicted to grow substantially over the coming decade, resulting in rapid growth in the global battery industry. The European battery market is expected to grow from 30-50 GWh in 2020 to 400-1000 GWh in 2030 [2]. So far, the transport sector has been the main driving force behind this growth with the most common battery chemistry being lithium-ion. As most lithium-ion batteries used in Europe today are produced in Asia, there is a strong incentive to create a European battery value chain, from an economic, environmental, and social standpoint. The European Union (EU) is forecasted to become the second-biggest global market for batteries and battery production [3].

Additionally, a significant amount of the world's EV batteries is produced in China, using scarce raw materials sourced in ethically conflicting parts of the world. Furthermore, the EU has provided an initial proposal to ensure a sustainable battery value chain [4] – which is expected to drive the market and demand for related competences and labour.

Today's global battery value chain is neither sustainable nor circular. As most battery chemistries (such as lithium-ion batteries) are made up of several scarce materials, contributing to high environmental impact, it is critical to ensure that the new European battery value chain is established in accordance with principles of the circular economy and net zero emissions. A move towards a circular economy could not only relieve the pressure on the environment but also provide substantial social and economic benefits such as improved security of material supply, increased competitiveness, stimulate innovation, and job creation [5]. A circular transition would also have positive ripple effects for the battery value chain. Fraunhofer estimates that for each GWh produced there will at least be 100 direct jobs and 300 indirect jobs connected to the battery value chain [2]. According to the European Battery Alliance (EBA), Europe will need to upskill and reskill 800,000 workers by 2025 to achieve its aim of the green shift and meet demands of the growing battery value chain. The sheer volume and competence need in such a short time, is a first for Europe's education and training ecosystem. The industry is estimated to create 4 million jobs for an annual value creation of €250bn, by 2025. With the forecasted increase in demand for batteries and workforce in the coming decades, this is an ideal opportunity for the Nordic countries to leverage their collective strengths and secure a strong foothold in the emerging European battery value chain.

Sustainable battery value chain is key for sustainable development. Developing a sustainable battery value chain is key to achieving Sweden's goal of a fossil-free welfare society, net zero emissions, and in ensuring the future (sustainable) competitiveness of the Swedish industry. Sweden is in a strong position to take advantage of this emerging market. With good access to renewable resources, technical cutting-edge skills and industrial infrastructure, the conditions are excellent to develop a circular battery value chain. Sweden is also one of the world leaders in the sustainable extraction of raw materials with developments of fossil-free mining and a highly automated and productive mining process [6]. Furthermore, as an IT nation Sweden has strong digital capabilities from traceability, lifetime optimization and other related IT services. These and other factors, such as access to clean and cheap electricity and a well-developed automotive industry, give Sweden good prerequisites to be a key actor in a sustainable European battery value chain.

While the demand for batteries will continue to grow over the next decades, several European players are making substantial strides to secure positions along the value chain. To successfully scale up Sweden's part of the emerging European battery value chain, efforts must be made quickly. As the battery market is still dominated by Asia, skilled workers and battery competence are in short supply in Europe. While other barriers exist, closing this skill gap and establishing more regional competence development in Europe is of utmost importance to supply the entire battery value chain with a skilled workforce. The European Commission's task force on education and skills puts it as follows:

«It is urgent to understand the demand for workforce and required qualifications arising across Europe [...]. The development and expansion of different educational segments must be rapidly invested in and implemented, including Academic, Professional, Vocational and Public/User segments along with measures that stimulate gender balance in all areas.» [7]

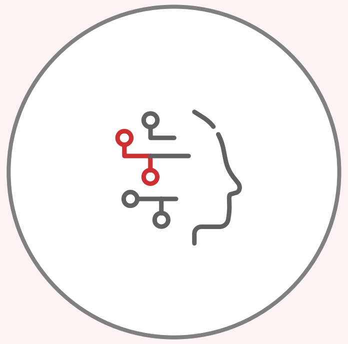
A study by Fossilfritt Sverige also highlighted that to overcome the knowledge gap in the battery sector, there is a need for long-term investments in research and education [6]. The lack of competence may be a crucial factor and a bottleneck for the Swedish parts of the battery value chain.

1.2. Scope

The aim of this study is to gain a better understanding of i) the current gap in terms of challenges and actions for addressing competence needs/supply, incentives, and workforce availability across the sustainable battery value chain, and ii) how this connects to the overall competence and structural changes needed to support Sweden's transition towards a sustainable society. This report is the second of two reports that examine and unveil competence needs and supply for the sustainable battery value chain in Sweden. The first report consolidated existing knowledge and analysed Sweden's competence and labour demands as a key actor in a sustainable and competitive European battery value chain and the associated transition towards a circular value chain. The second report completes the gap analysis by including the competence supply and proposing actions to bridge the competence gap for a sustainable battery value chain.

1.3. Limitations

The report focuses on competence needs and supply and will therefore not study human-related factors such as culture, access to housing, infrastructure, etcetera, which may influence Sweden's ability to attract, keep and develop the right competences and labour to ensure a sustainable and competitive battery value chain.



2. Method

This study is based on an analysis of available literature and a survey of experts from the Swedish battery value chain. To ensure consistency and comparability with other European and Nordic countries, this study leveraged methodology, insights, and questionnaire designs from both the BattKOMP [8] project in Norway and the ALBATTS [9] project in Europe. The work was carried out by Sopra Steria on behalf of the Swedish Energy Agency.

For the literature review, a comprehensive list of relevant literature was compiled and analysed. This included industry reports, government reports and research papers with direct and indirect relevance for the competence needs, competence supply, and competitiveness for a Swedish sustainable battery value chain. A complete list of the sources can be seen in References.

For the survey, a questionnaire was disseminated to 166 experts and companies across the battery value chain (or the 'competence demand' segment). A total of 66 respondents replied with a response rate of 40%. The sample showed good coverage across all stages in the battery value chain as can be seen in Figure 1.

To support the quantitative data collected in the questionnaire, 17 people were interviewed and a digital workshop with 21 participants was conducted. To complement the more 'competence demand' oriented nature of the questionnaire, the interviews mostly targeted experts from the Swedish education system (or 'competence supply'), including universities, vocational schools, and regions/municipalities. To complete the picture and gap between competence supply and demand, the workshop included a mix of experts from industry, government, and the education sector. At large, the goal of the questionnaire and interviews were to identify relevant competences, challenges, and measures to close the competence gap. Building on this, the workshop aimed at completing the identified gap by proposing and prioritizing targeted actions and assigning responsibilities to the three main stakeholders (government, academia, and industry).

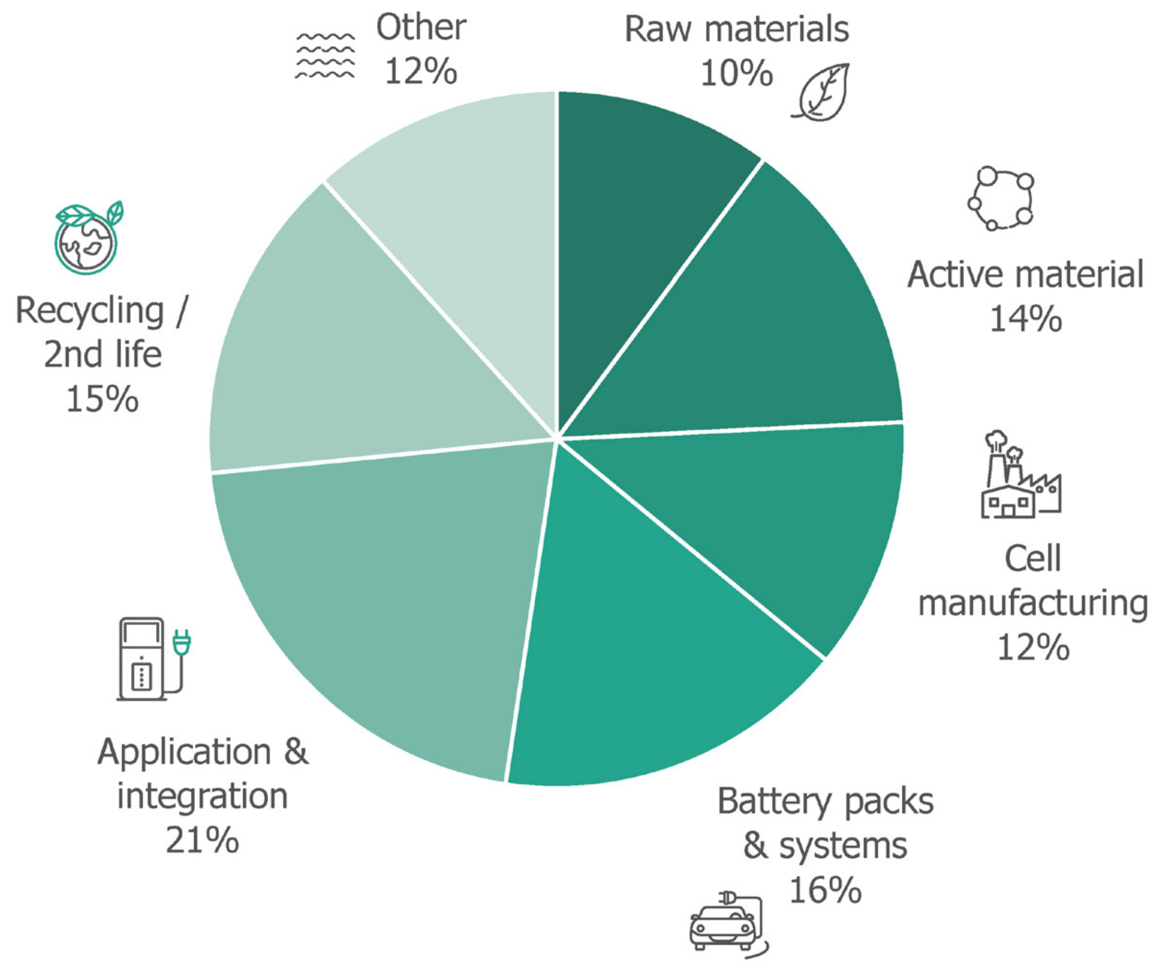


Figure 1.
An overview of respondents' position in the battery value chain. Each respondent can be active and operate in more than one step. The battery value chain has been divided into the same six steps: raw materials, active materials, cell manufacturing, battery packs & systems, application & integration, and recycling / 2nd life as the European Battery Alliance [10].

3. The sustainable battery value chain

3.1. The Nordic battery value chain

Towards the most sustainable and integrated region in the world. The Nordic Council of Ministers have a clear vision for the Nordic region: to become the most sustainable and integrated region in the world by 2030 – by jointly promoting a green transition, a carbon-neutral society and a sustainable circular economy [11]. Developing a sustainable battery value chain is a critical piece of this puzzle and the Nordic countries are in a good position to take a leading role and attract investment and competence along the entire value chain. The Nordic region's strong position is based on access to sustainable energy at competitive prices, reliable infrastructure, stable markets, access to minerals, leading industries for materials technology, competitive automotive industry and battery integrators, leading research hubs, along with experience, knowledge and commitment to the circular economy [12]. In other words, the Nordic countries have an important role to play in developing an innovative, competitive and sustainable battery value chain in Europe.

However, the battery value chain is complex and involves a large number of stakeholders, each with their own set of detailed processes, technical know-how and competence needs. From mining, sourcing and processing of raw materials and production of active materials for the anode, cathode and electrolytes, to production, application, integration and reuse/recycling of battery cells, packs and systems. For consistency, we use the same model of the battery value chain as Fossil Free Sweden and the European Battery Alliance. See Figure 2 of the steps involved and an example of relevant actors in the Nordic battery value chain.

Developing a sustainable battery value chain is a complex and multifaceted challenge. It requires insight and interdisciplinarity extending far beyond the core business of any individual actor in the value chain. Consequently, to be a competitive

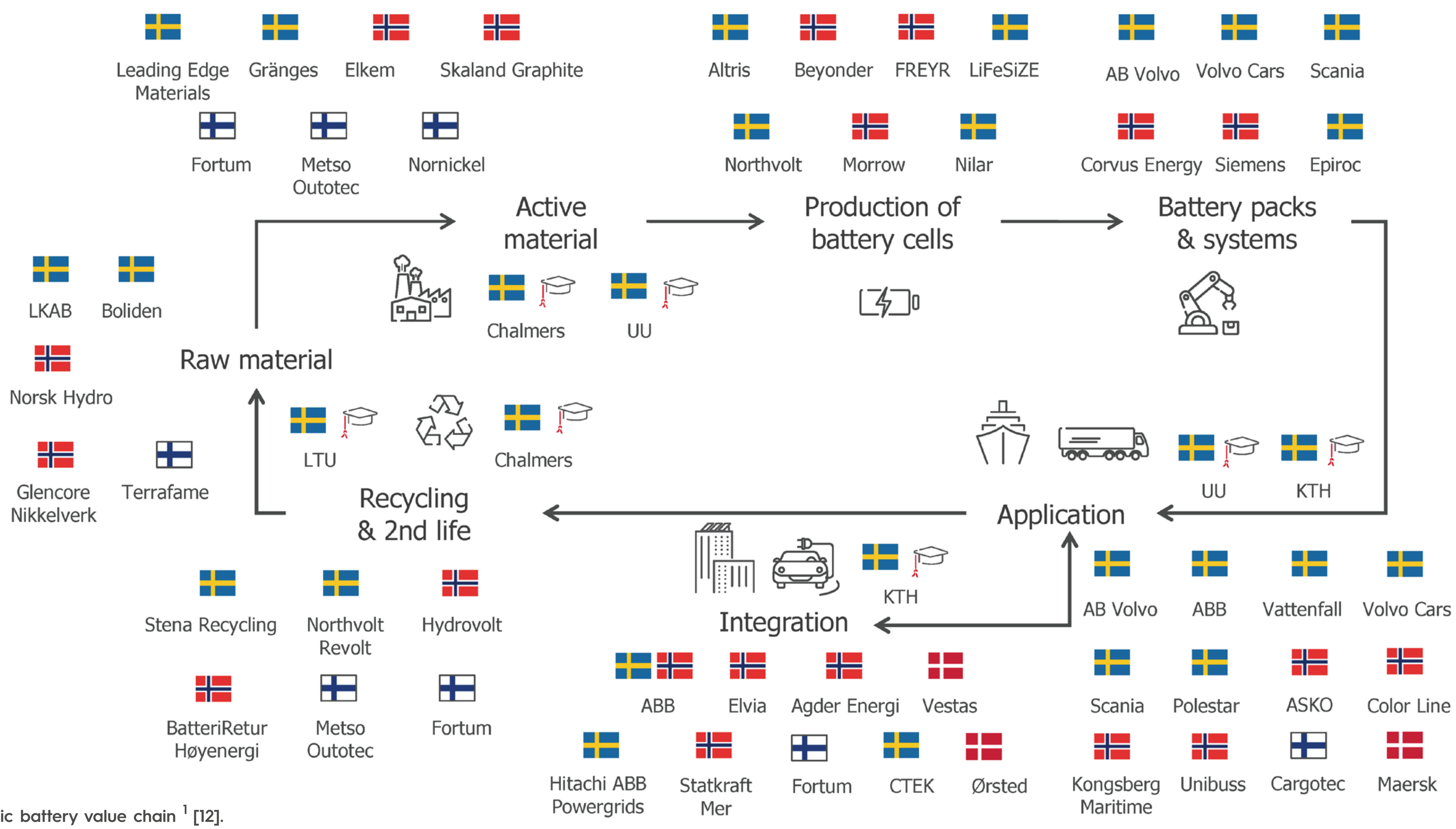


Figure 2.
The Nordic battery value chain [1] [12].

[1] Note: The flags inside the circle represent universities. Namely, Uppsala University (UU), Chalmers University of Technology (Chalmers), KTH Royal Institute of Technology (KTH) and Luleå University of Technology (LTU).

actor one must understand the entire battery value chain to succeed in developing new advanced materials, processes and to meet sustainability requirements and customers' needs for special adaptation or niche products [8]. Interestingly, this complexity is a potential competitive advantage for the Nordic battery value chain as the region is well suited to leverage the countries' comparative strengths, close interaction across the value chain and established cross border industrial networks (e.g., as seen with the recent webinar series "Nordic Battery Thursdays" hosted by Business Finland, Business Sweden, Innovation Norway and EBA250 – EIT InnoEnergy [13]). The Nordic region is also recognized for its high degree of trust, mature technology management and willingness to share expertise and knowledge - all essential elements in achieving a competitive and sustainable battery value chain.

Nonetheless, important parts of the battery value chain still exist outside of Europe. This makes Swedish actors dependent on imports, both in terms of the supply of materials to produce batteries and the skills needed for the production and use of batteries [6]. Therefore, developing a circular economy is critical for the battery value chain as a whole.

3.2. Circular Economy

Our current, linear economy of 'take-make-use-waste' is frequently characterized by the presence of waste: instances where components, products, or materials reach their end-of-use/life prematurely or where their capacity for value creation is underutilized. To address this, the concept of circular economy emerged in the 2010s as an approach to contribute to sustainable development [14]. It encompasses a range of activities for narrowing, slowing, and closing material and energy flows as a means of addressing waste. See Figure 3 for an illustration of linear vs circular economy. Circular economy remains in an early stage of development, with international standards still under development [15]. With over 100 definitions present in academic literature alone, the following meta-definition is provided:

"A circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, and recycling [. . .] materials in production/distribution and consumption processes, [. . .], with the aim of accomplishing sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations" [16]

CIRCULARITY ≠ SUSTAINABILITY. While no equal sign should be put between 'circular' and ´sustainable´, the concept has gained increasing prominence among academic scholars, organizations, and policymakers for its ability to promote sustainable development while increasing economic development [17]. This is due to its underlying mechanism of decoupling value creation from the consumption of finite resources, possible through a range of restorative, efficient, and productivity-oriented strategies that keep materials, components, and products in use for longer [18]. This enables increased competitive performance for companies by securing access to raw materials, increasing resource efficiency, minimising risk, reducing climate impact, increasing innovation capacity, digitalization, and increasing revenue.

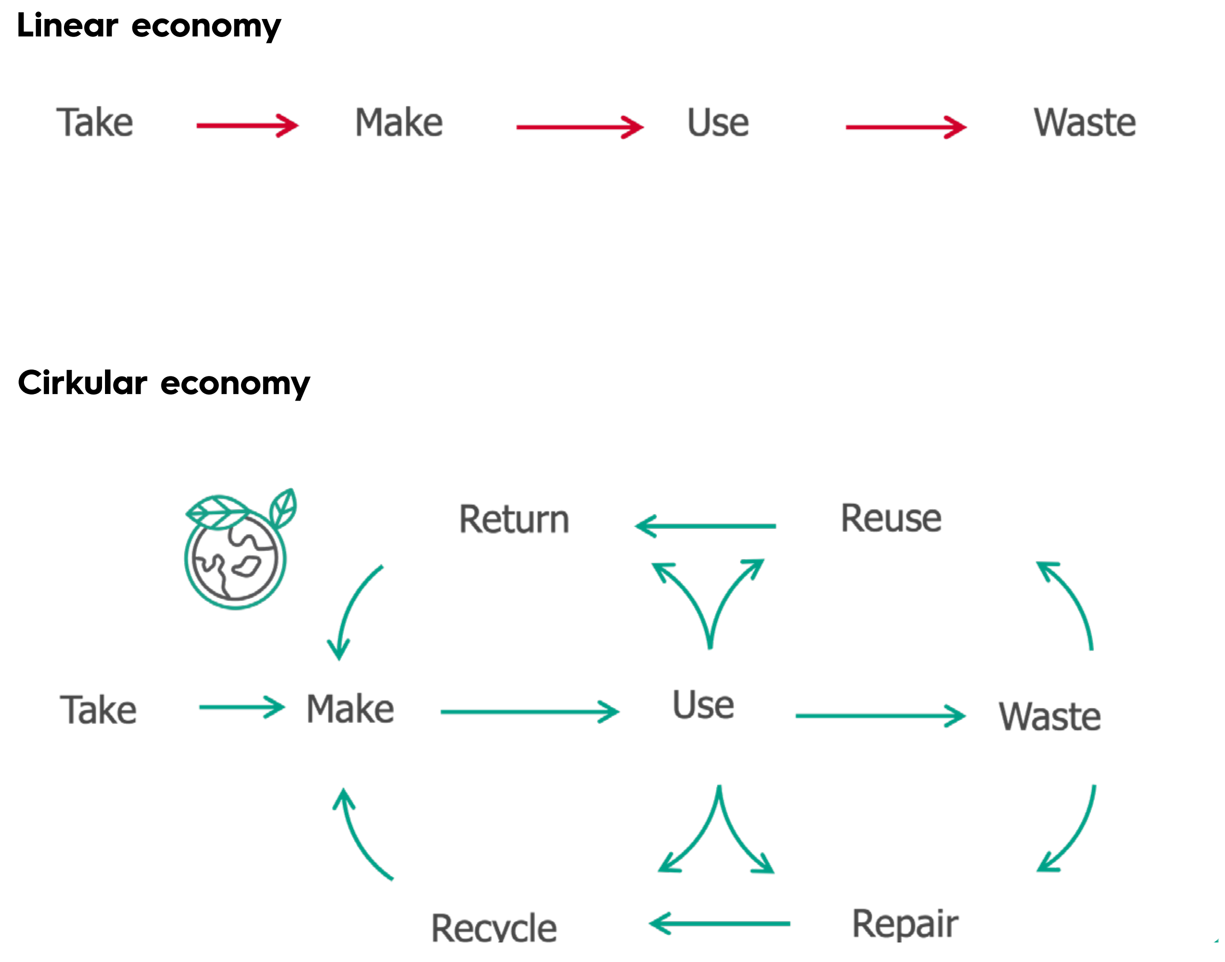


Figure 3.
Linear vs circular economy.

The advantages of such an approach are substantial and, for Europe alone, estimated to create a net benefit of €1.8 trillion by 2030 while addressing mounting resource-related challenges, creating jobs, spurring innovation, generating substantial environmental benefits and increased resilience through reduced import dependencies [19, 20]. However, the circular transition would also involve considerable costs for such an economy-wide project, particularly in areas of research and development and the redesigning of global value chains. Therefore, it is imperative that the shift to a circular model is well-managed and aligned with Europe's growth and governance structures. Circular economy is one of the key elements in the European Green Deal, known as the Circular Economy Action Plan [5]. All Nordic countries (except for Iceland) have also developed national strategies for how to transition towards the circular economy whilst increasing competitiveness. Specifically, Sweden has set out to create a more sustainable production of goods and services with the vision to create "A society in which resources are used efficiently in non-toxic circular flows, replacing virgin materials" [21]. The strategy highlights four focus areas:

- Sustainable production and product design
- Sustainable ways of consuming and using materials, products and services
- Non-toxic and circular material cycles
- Driving force for the business sector and other actors through measures to promote innovation and circular business models.

The areas are closely linked, indicating that many different solutions need to be developed and several barriers need to be overcome (e.g., market barriers for recycling metals [22]) to make Sweden's transition to a circular economy a reality [23]. Nonetheless, the circular economy can strengthen Swedish competitiveness through economizing with resources and new technologies, services and business models [24]. Economizing with resources is nothing new, but now digital technologies offer entirely new possibilities to create a resource-effective future.

DIGITAL TECHNOLOGIES ARE KEY ENABLERS.

Digital technologies, such as the Internet of things, big data, blockchain, and artificial intelligence, are considered essential enablers of the circular economy [25]. By positioning information flows that enable resource flows to become more circular, digital technologies may accelerate Sweden's transition towards a circular economy. Also known as the digital circular economy [26], digital and data-driven innovation creates new technologies and services that can accelerate the transition by the replacement of products with services or by making it easier to reuse or share products and services. Digital solutions can also enable tracing, mapping and sharing of resources, provide more information about individual needs and lead to optimal design of products, processes and production.

3.3. Creating a sustainable battery value chain by increasing circularity

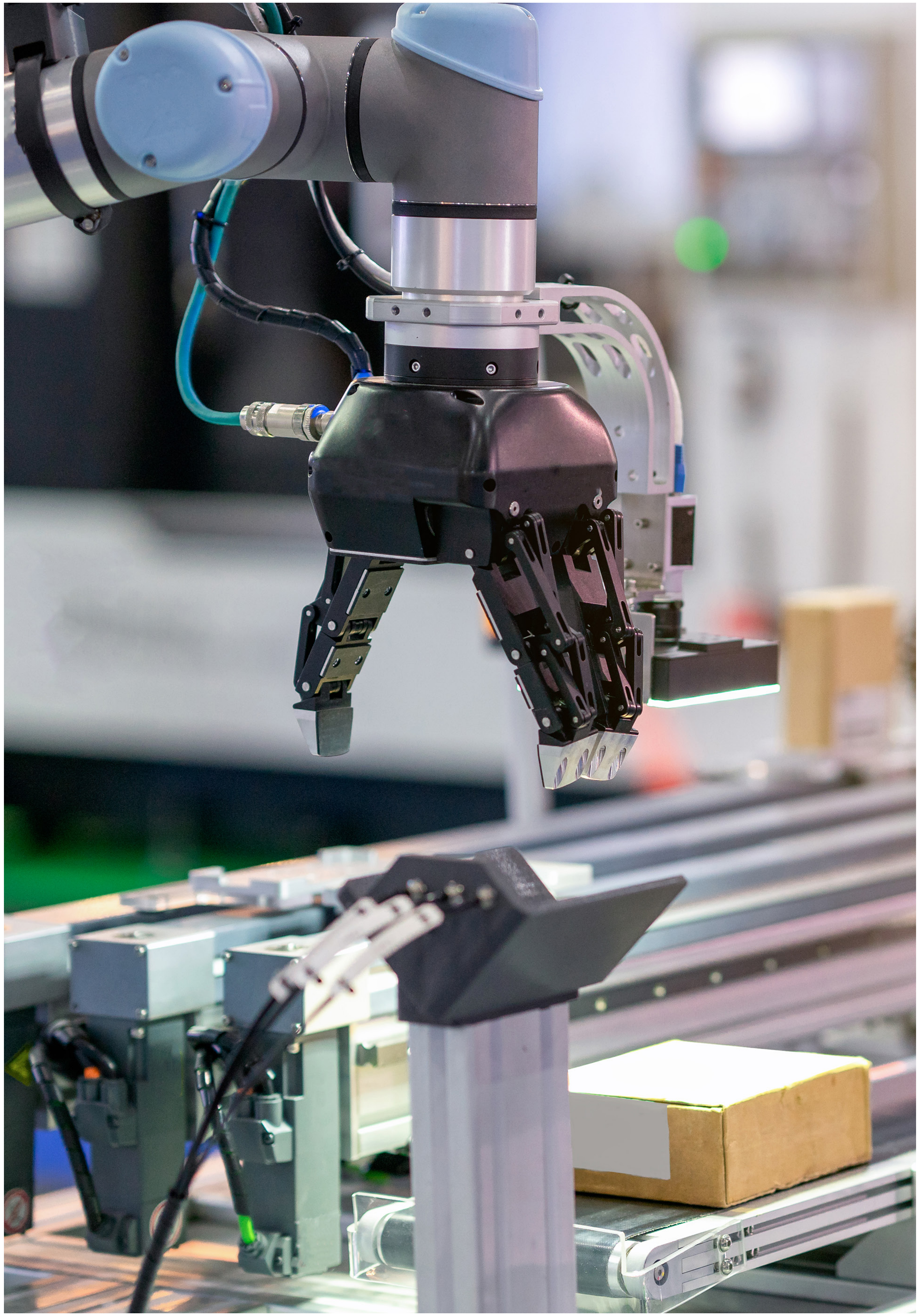
Despite the importance of batteries to underpin the fossil-free transition of Sweden's economy, how these batteries are designed, made, and integrated into the economy will define their environmental impact for generations to come. Therefore, creating a circular economy for batteries is crucial to prevent one of the solutions to the current environmental crisis from becoming the cause of another.

Thus, it is not accidental that new rules to the battery sector were listed as one of the main activities in the EU Circular Economy Action Plan [5]. Currently, a new battery regulation (2020/0353 (COD)) and modernization of the Batteries Directive (2006/66/EC) is under development intending to solve most of the regulatory and standardization obstacles for a truly sustainable European battery value chain. This includes mandatory requirements on sustainability (such as carbon footprint rules, minimum recycled content, performance, and durability criteria), safety, labelling, and requirements for end-of-life management, to name a few. The regulation also includes proposals for due diligence obligations for sourcing of raw materials, battery passports and responsibilities for actors across the value chain in terms of information and emission requirements [27].

In the future, all batteries must be recycled. This is not only due to a regulation or competitive perspective, but also due to limitations in the availability of primary metals (and the eco- »

nomic viability extracting these scarce minerals) combined with the need for raw materials for new batteries. Despite the importance of establishing a circular flow of materials, there are simply not enough secondary materials available to supply the rapidly growing demand for batteries. While EU has set its goal to create an unbroken European battery value chain by 2025, we are currently highly dependent on import of primary materials. Therefore, we need to develop the mining industry whilst also increasing the use of secondary materials. It may seem counterintuitive – but handling this ambidexterity will be critical for the success and scale of the sustainable battery value chain.

If not handled correctly, we may fail to supply the industry with batteries to enable the fossil-free transition towards a net zero society. For instance, the cumulative lithium demand is estimated to exceed current known reserves by 2050 [28]. Batteries are subject to degradation due to time and age, and the life of a battery depends on its chemistry and usage patterns. When a battery is considered obsolete for its primary application, it often has capacity left that could be used for other purposes. At this point, it must be considered whether the batteries should be replaced and then either recycled or reused in another application. Although the range of a car will be significantly reduced by the end-of-life, the batteries may have sufficient capacity for less demanding applications where the capacity/weight ratio is less important, such as stationary storage [29].



3.4. Towards a competitive advantage

To understand how Sweden can develop a competitive battery value chain it is important to understand the nature of competitiveness. The measurement of competitiveness and strategy development is an important issue for policymakers. Despite many attempts to provide objectivity in the development of measures of national competitiveness, there are inherently subjective judgments that involve, for example, how data are aggregated, defined, and their importance weighted. How and under what conditions is a competitive advantage developed and maintained? What is the role of public institutions, and which measures ultimately foster or hinder the international competitiveness of companies?

Competitive companies. For companies, academic scholars mostly agree on the underlying theories of company performance and competitiveness. With its roots in strategic management literature, the competitiveness of companies is seen as a combination of resources[2] they possess and their capability[3] to leverage these resources in an efficient and dynamic manner. The resources of the company should be valuable, rare, inimitable, and nonsubstitutable. The capabilities should be dynamic and support the company's ability to craft, refine, implement, and transform its business model. This includes underpinning organizational routines and managerial skills to support the company in building, integrating and reconfiguring internal competences to address, or in some cases to bring about, changes in the business environment. However, most of the resources that a company needs to utilize to gain a competitive advantage must be acquired, at some point in history, from its external business environment. Therefore, the capability of a company to survive and have a sustained competitive advantage in global markets also depend on the efficiency of public institutions, the excellence of educational, health and communications infrastructures, as well as on the political and economic stability of their home country [30].

Competitive countries. At the country level, there are two schools of thought on the competitiveness of nations: trade (economic perspective) and international competition (management perspective) [31]. The international competitiveness of countries is an ever-growing concern of governments and has spurred great debate amongst academic scholars. The reason for the debate stems from the implicit base assumption in management theories that company competitiveness can be extended to country competitiveness – a thought popularized by the work of Porter [32] but not supported by the trade theories. While the economic perspective of trade is useful within its bounds, the managerial perspective of Porter's work is seen as the most useful framework for this study. The reason being that this provides a tool to identify a country's sources of competitive advantage that companies can leverage to enhance their internationally competitive positions. As such, it can help stakeholders make informed decisions on how to shape the battery value chain, and importantly which aspects to focus on. However, it should not be used to devise trade policy with the aim to enhance international competitiveness.

According to Porter, competitive advantage is based on the productivity of a nation or the value of the output produced per capital. Porter argues that any company's ability to compete in global markets is based on an interrelated set of (national) advantages that certain industries in different countries possess, namely:

- **Factor conditions**
- **Demand conditions**
- **Related and supporting industries**
- **Company strategy, structure, and rivalry**

Factor conditions. Factor conditions is typically referred to as a country's natural, capital, and human resources. Importantly, human resources is referring to the created conditions such as skilled labour force, good infrastructure and a scientific knowledge base. In contrast to the natural conditions that are already present, it is imperative that these created conditions are continuously upgraded through the development of skills, competences, and knowledge. As a result, the competitive advantage results from the presence of both world-class research institutions and knowledge-intensive industries that first create specialized factors and then continually work to upgrade them.
To enable this, sustained and heavy investment is needed.

Demand conditions. The home demand largely affects how favorable and lucrative an industry is within a country. A large market means more challenges and competition, but also creates incentives for companies to grow. However, the main deciding factor of demand conditions is the type of demand – not the size of the demand. The presence of sophisticated and demanding local customers pushes companies to innovate, improve quality, and continuously work on competence development. Striving to satisfy a demanding domestic market propels companies to scale new heights and possibly gain early insights into the future needs of emerging customers across borders – gaining a competitive edge.

Related and supporting industries. All companies are part of a value chain and depend on alliances and partnerships with other companies. Close upstream suppliers often give more cost-effective inputs. They can often take advantage of short lines of com-

[2] Organizational resources are defined as stocks of tradable and nonspecific assets in the company and can be both tangible and intangible. Tangible assets are physical things such as land, buildings, machinery, equipment, and capital. Intangible assets are everything else that has no physical presence such as brand reputation, trademarks, and intellectual property.

[3] Organizational capabilities are defined as a company's specific and nontradable ability to deploy such resources, through organizational processes, to affect a desired end.

munication, quick and constant information flow, and ongoing exchange of ideas and innovations. With well-connected companies (e.g., industry clusters), R&D practices and testing can help spur innovation.

Company Strategy, Structure, and Rivalry. The national environment under which companies operate largely determines how they are created, organized, and managed. A company's strategy and structure must be in line with the ways of working in the nation. Domestic rivalry pushes companies to innovate and build more sustainable strengths and capabilities. Therefore, having multiple companies work in the same industry is instrumental for international competitiveness as it forces companies to develop unique advantages [33].

As detailed above, the Swedish government should keep some basic principles in mind to best foster a competitive battery value chain. Importantly, the government itself cannot create competitive industries, only companies can do that. However, government can both be a catalyst and a challenger that encourages and pushes companies to raise their aspirations of international competitiveness. This can be done by focusing on targeted actions for each of the four aforementioned factors. For instance, stimulating early home demand and factor conditions for advanced products. Norway's EV policy is a good example of this where targeted incentives, tax exemptions, public procurements, and development of charging infrastructure has resulted in EVs accounting for over 80% of all new passenger cars sold in 2022. Investing in research centers and the education system is another important area for government interventions. The battery value chain is seen as a knowledge-intensive industry in great need of a highly skilled and experienced workforce. Sweden has world-leading research at, for example, Ångströms Advanced Battery Centre (ÅABC), which will help strengthen the position of the industry. Furthermore, working together by increasing national and Nordic collaboration enables related and supporting industries and education systems to share information and knowledge.

4. Competences and skills for a sustainable battery value chain

4.1. Generic competence needs for sustainability

Europe will only become a climate-neutral continent, a resource-efficient society and a circular economy with an informed population and workforce that understands and knows how to think and act sustainable [34]. While sustainability competence has been a topic of extensive debate for many years, it has yet to see an agreed-upon reference framework to date. The most frequently cited reference framework is that of Wiek et al. [35]. For this study, we use the updated version of this framework by Brundiers et al. [36] to illustrate the relationship between basic academic competence, sustainability competence, and topical competence (in this case for the battery value chain), as can be seen in Figure 4.

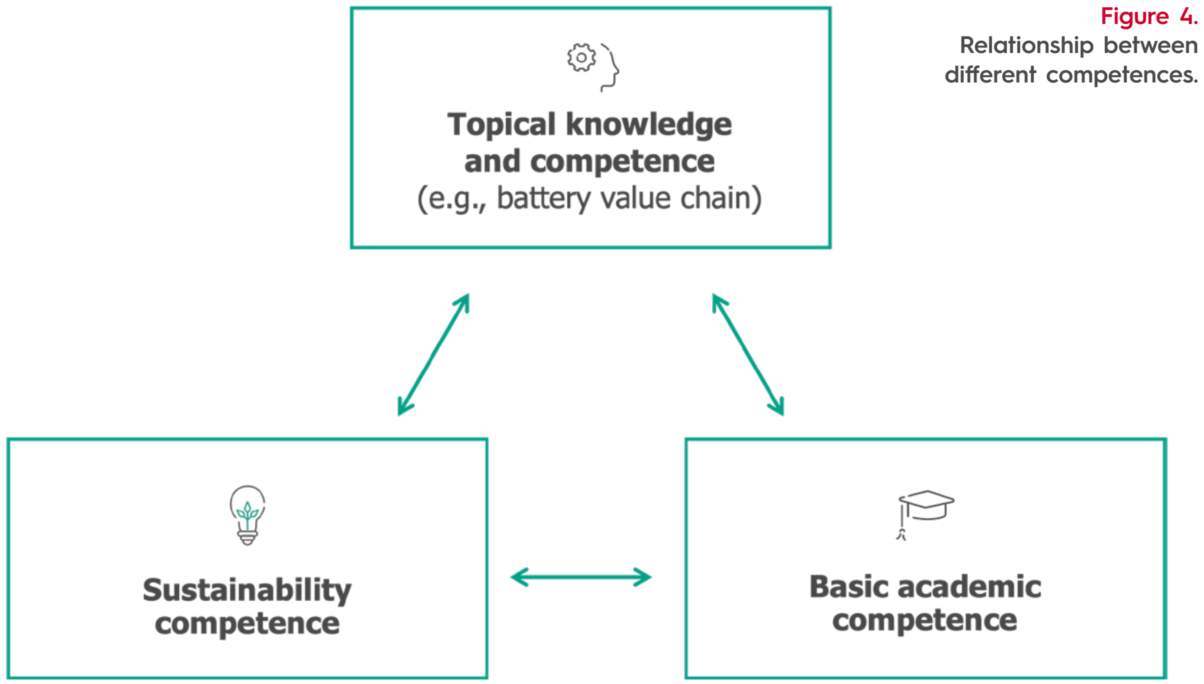


Figure 4. Relationship between different competences.

Additionally, The United Nations Educational, Scientific and Cultural Organization (UNESCO) have identified eight key sustainability competences. As transversal, multifunctional and cross-cutting competences they can be understood as the foundation, or building blocks, for more industry and discipline-specific competences [37]. See Figure 5 for an overview of the competences and the Appendix B for definitions of the competences.

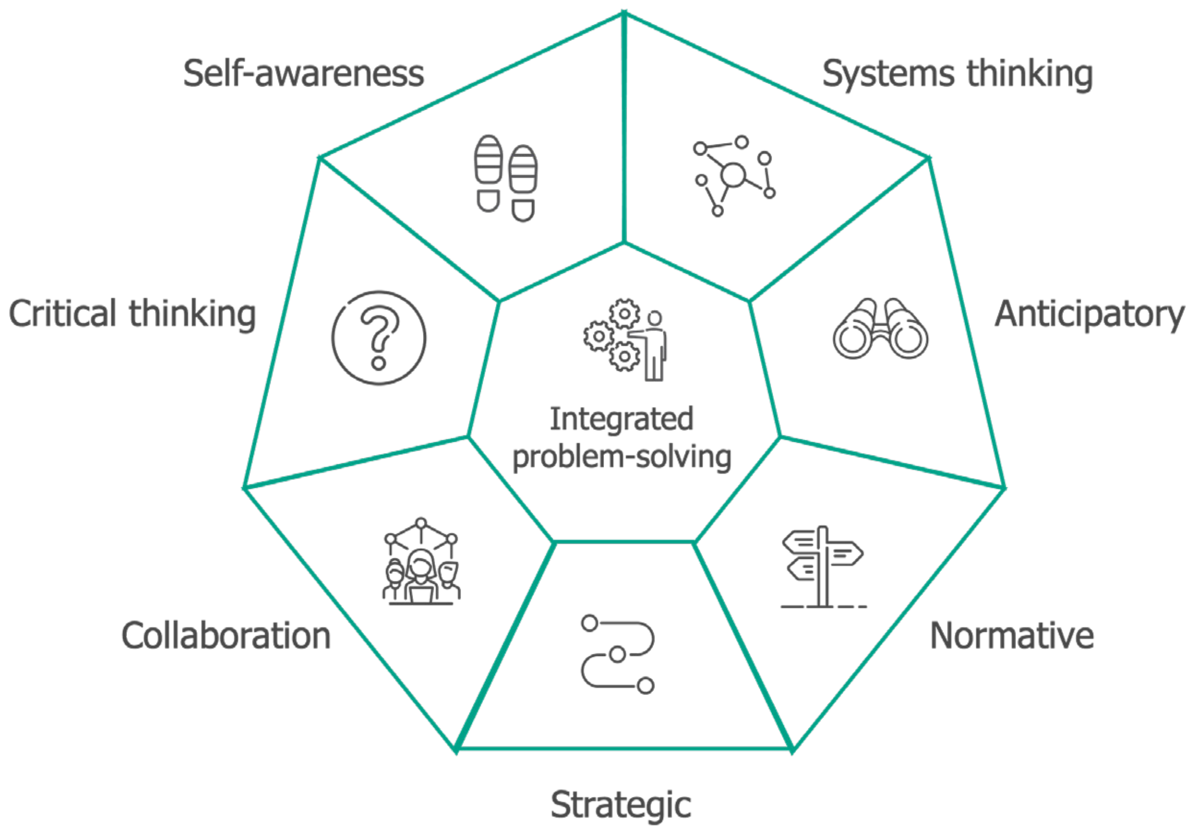


Figure 5. UNESCO's key competences for sustainability (picture by [38]).

4.2. General and specific skills for a sustainable battery value chain

For this study, we have used the aforementioned frameworks and competences as the theoretical foundation to identify and map skills and competences relevant for the sustainable battery value chain. We have focused specifically on the "Topical knowledge and competence" and "Sustainability competence" sections with selected competences from UNESCO:s key competences.

Building on this, we propose a universal competence framework for the sustainable battery value chain, see Figure 6. This framework is a synthesis of findings from both the literature review and our questionnaire. The framework aims to improve the understanding of how specialist and generalist skills can be combined in an increasingly interdisciplinary labour market [39]. The framework places value on having a combination of both specialist and generalist skills and knowledge. The horizontal bar represents broad and general competence, and the vertical bar represents deep and specific competence. That is deep specialist expertise within an individual's primary field combined with general knowledge and the ability to work and collaborate across disciplines. This approach stems from the increasing demand for cross-disciplinary collaboration to solve complex societal issues [40].

The framework introduces a set of transversal and specific skills that are important in the creation of a sustainable battery value chain and aims to be in line with the proposed requirements in the new EU battery regulation. It covers both the need for employees to have in-depth expertise in specific steps of the battery value chain and the holistic understanding of the entire value chain to be able to work with other actors and across disciplines. While the transversal skills (referred to as general skills/competences hereafter) capture most of the general knowledge areas, they need to be combined with more deep knowledge and specific skills from relevant disciplines to be operationalized.

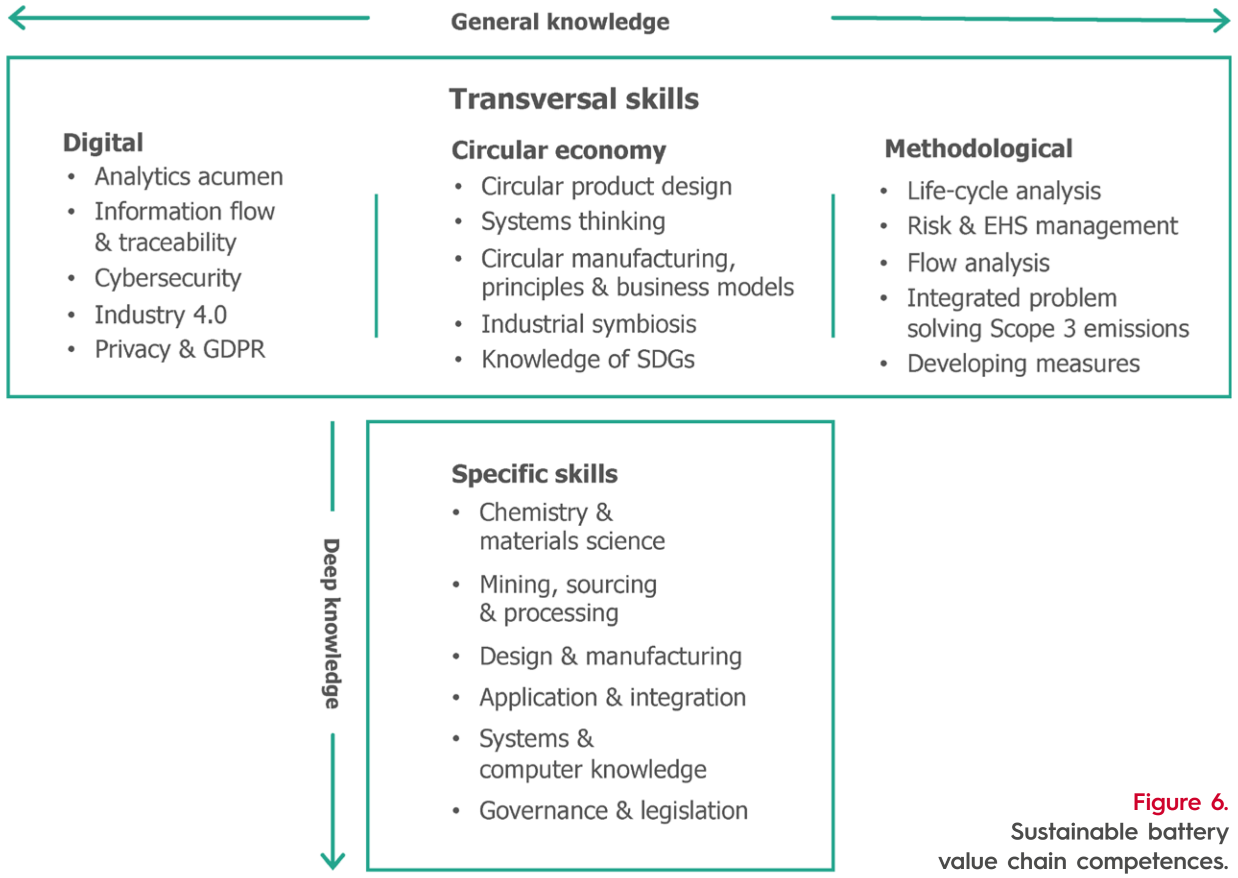


Figure 6. Sustainable battery value chain competences.

5. Competence demand in the sustainable battery value chain

This chapter presents the results from the questionnaire sent out to experts in the Swedish battery value chain. For an overview of the respondents, see Method. The questionnaire was scoped to capture the competence needs and demand from the industry, but does not investigate the capacity demand. The results are structured in accordance with the competence framework presented in the previous chapter, see Figure 6. First, an overview of all general skills and competences is provided, followed by details for each respective category. Second, an overview of all specific skills and competences requiring deep knowledge is presented, followed by each specific category.

The respondents were asked to rank the level of importance of different competences for the sustainable battery value chain. To analyse the results, weighted point method was used with the following weights:

1 = Not important
2 = Slightly important
3 = Moderately important
4 = Important
5 = Very important

Before the respondents were shown the respective competences and categories, they were asked the question *"Which strategic and critical competences do you believe are lacking in order to enable a sustainable battery value chain in Sweden?"* This was done for two reasons. Firstly, to control for response bias in the sample. Secondly, to not limit answers to the predetermined competences identified from the literature review. The respondents were also given the option to add competences and comments throughout the questionnaire in open text boxes. To analyse the open-ended questions, the open coding scheme by Yin [41] was used, where themes and concepts were coded in accordance with the competences in the specific and general categories. The coded answers covered 73% of all statements included in the questionnaire, meaning we had sufficient coverage of the competence categories presented in the aforementioned framework, see Figure 6.

The competences that respondents saw as strategic/critical and that could not be directly connected to a specific code/statement included in the questionnaire was knowledge of; the whole battery value chain (12), industrial processes (9), cell manufacturing (8), practical experience (6), energy storage (5), active materials (5), future batteries (3), basic STEM/battery education (2), electric charging infrastructure (2), electric driveline (2), sustainable chemistry (2) and control of complex systems (1). The need for employees to have knowledge of the whole battery value chain was mentioned by several respondents. This underscores the importance of general skills and the need for employees to build a holistic understanding of the entire value chain in conjunction with their respective disciplines and specific skills.

[4] Number of times a competence was mentioned is shown inside the parentheses.

5.1. General competences for batteries

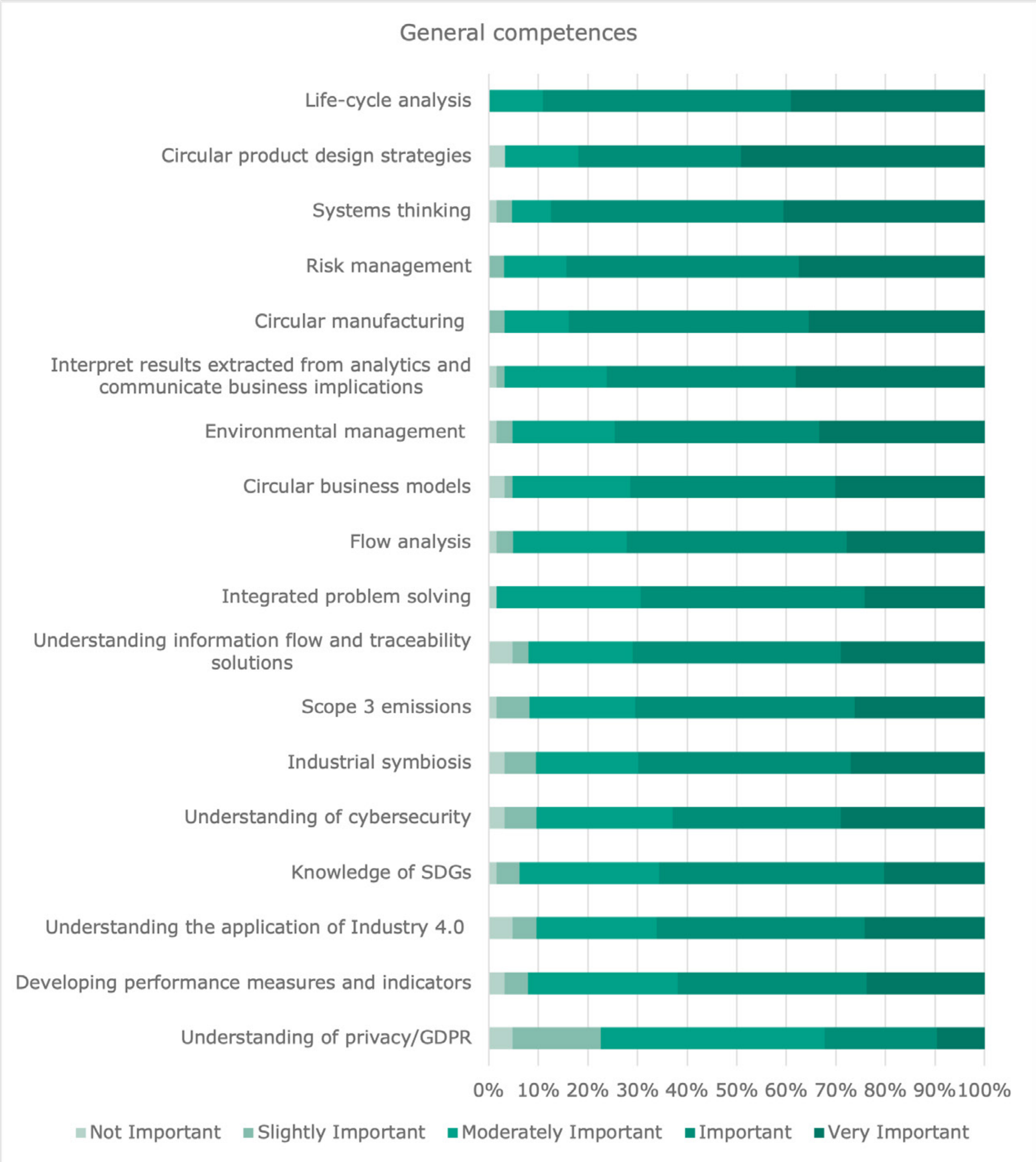


Figure 7.
The importance of different general competences based on the answers from the questionnaire.

Overall, the general competences *life-cycle analysis, circular product design strategies*, and *systems thinking* are the most important competences to develop. The general competence *life-cycle analysis* with the highest average ranking, had a score of 4,28, closely followed by *circular product design strategies* with a score of 4,25 and *systems thinking* with 4,22. On the other end of the spectrum, the least important competence to develop is understanding of *privacy/GDPR* with a score of 3,15 and the second least important being *developing performance measures and indicators* with a score of 3,75. Even though *understanding of privacy/GDPR* is an outlier with a lower average, it is still considered moderately important.

Looking at the different general competence categories, the average score for *methodological skills and circular economy* were both 4,00 and for *digital competence* the average score was 3,73. The result for each category will be presented in detail in the following sub-chapters.

IMPLICATIONS AND CONCRETE STATEMENTS:

- The most important general competences to develop are ***life-cycle analysis, circular product design strategies*** and ***systems thinking.***
- The least important general competence to develop is the ***understanding of privacy/GDPR.***

5.1.1. Digital competence

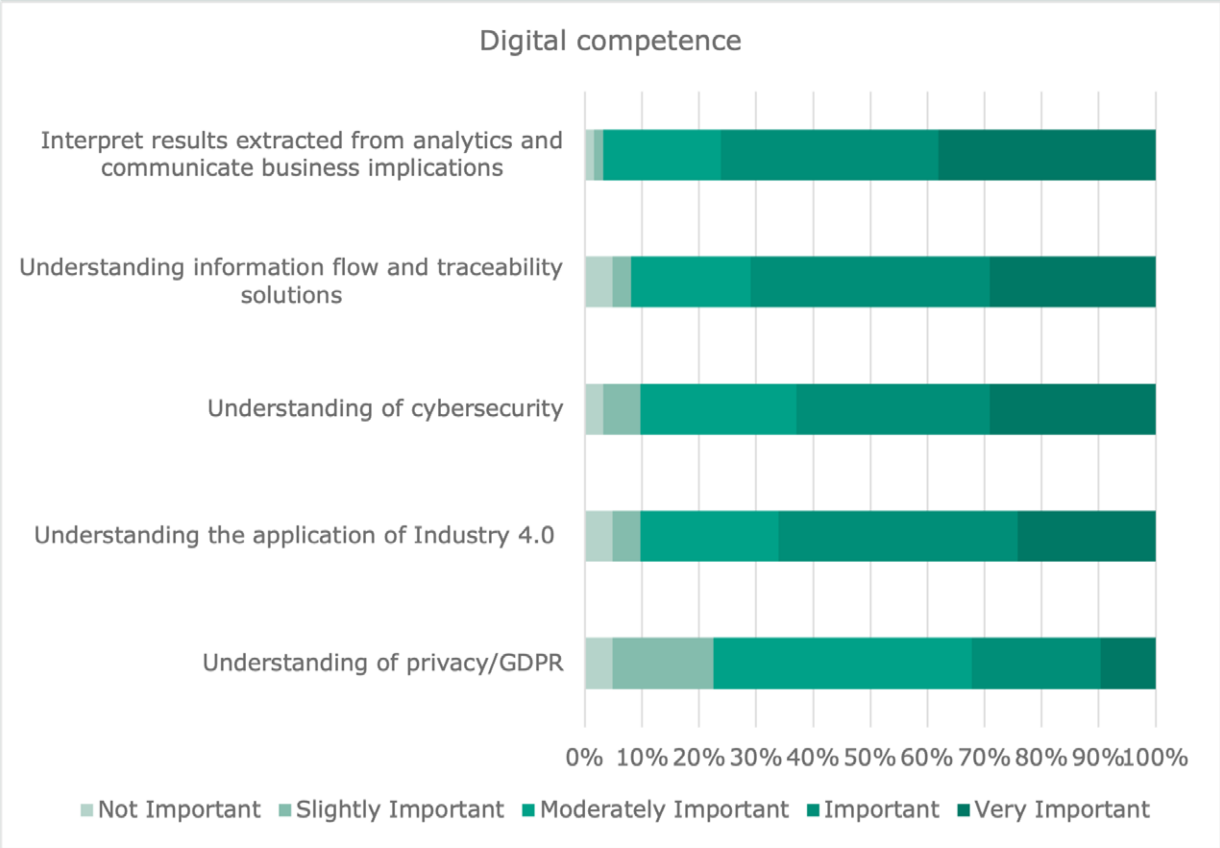


Figure 8.
The importance of different digital competences for a sustainable battery value chain based on the answers from the questionnaire.

IMPLICATIONS AND CONCRETE STATEMENTS:

- To be able to ***interpret results extracted from analytics and communicate business implications*** (also known as analytics acumen) is seen as the most important digital competence.
- ***Understanding of privacy/GDPR*** is seen as the least important digital competence

OTHER ASPECTS THAT RESPONDENTS ADDED CONNECTED TO DIGITAL COMPETENCE WAS:

- Understanding of connectivity through systems of systems
- Knowledge of human-computer integration
- Understanding of data warehousing and data mining
- Digital competence must be combined with other competence

5.1.2. Circular economy

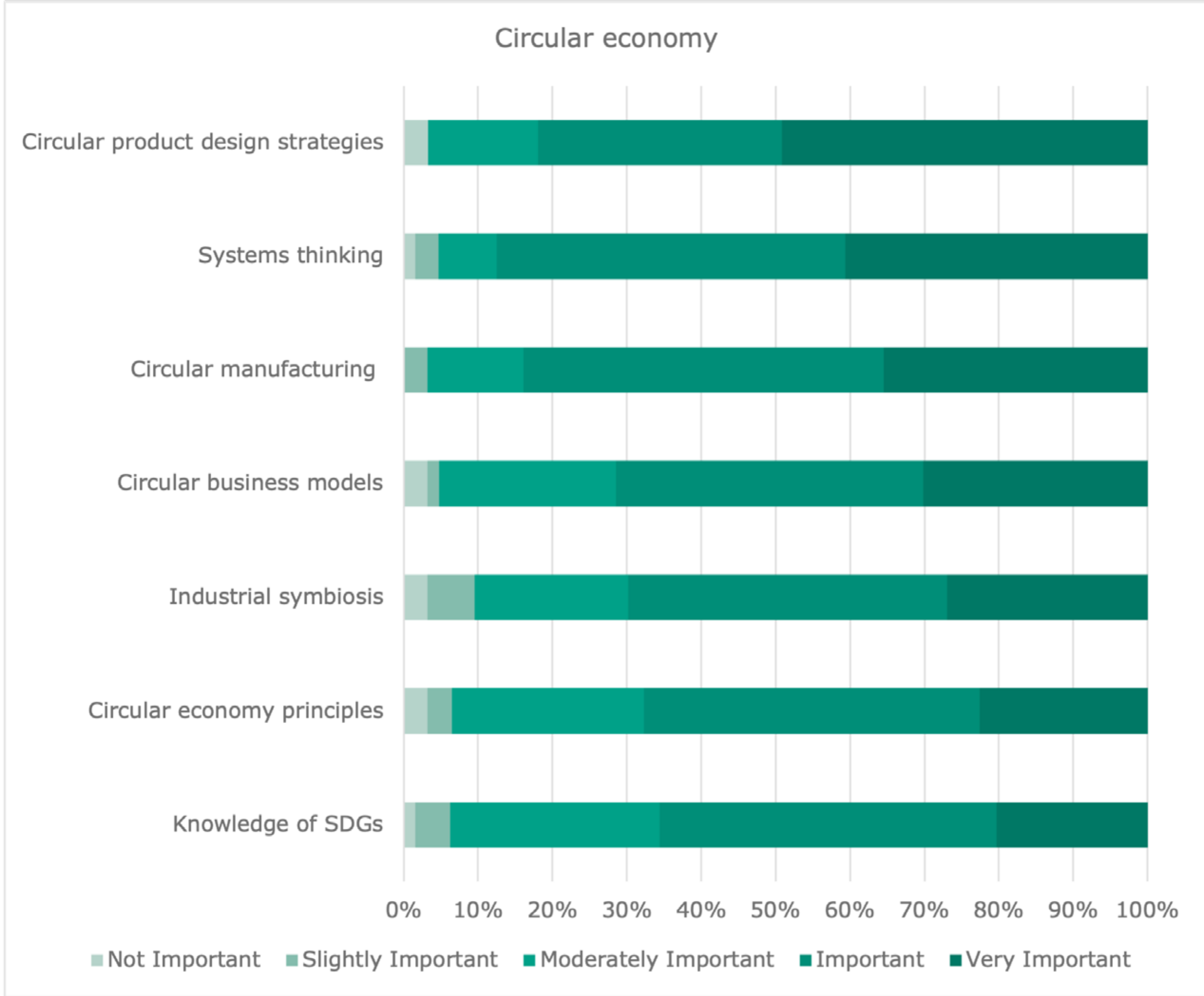


Figure 9.
The importance of different circular economy competences for a sustainable battery value chain based on the answers from the questionnaire.

IMPLICATIONS AND CONCRETE STATEMENTS:

- ***Circular product design strategies*** are seen as the most important competence
- ***Knowledge of SDGs*** is seen as the least important competence

OTHER ASPECTS THAT RESPONDENTS ADDED CONNECTED TO CIRCULAR ECONOMY WAS:

- Understanding of circular dismantling
- Understanding that business models will change, and the importance of optimization across the whole battery value chain
- Understanding of how economic systems and models will change and how to do cost calculation based on circular business models
- Evaluation of companies using circular business models

5.1.3. Methodological skills

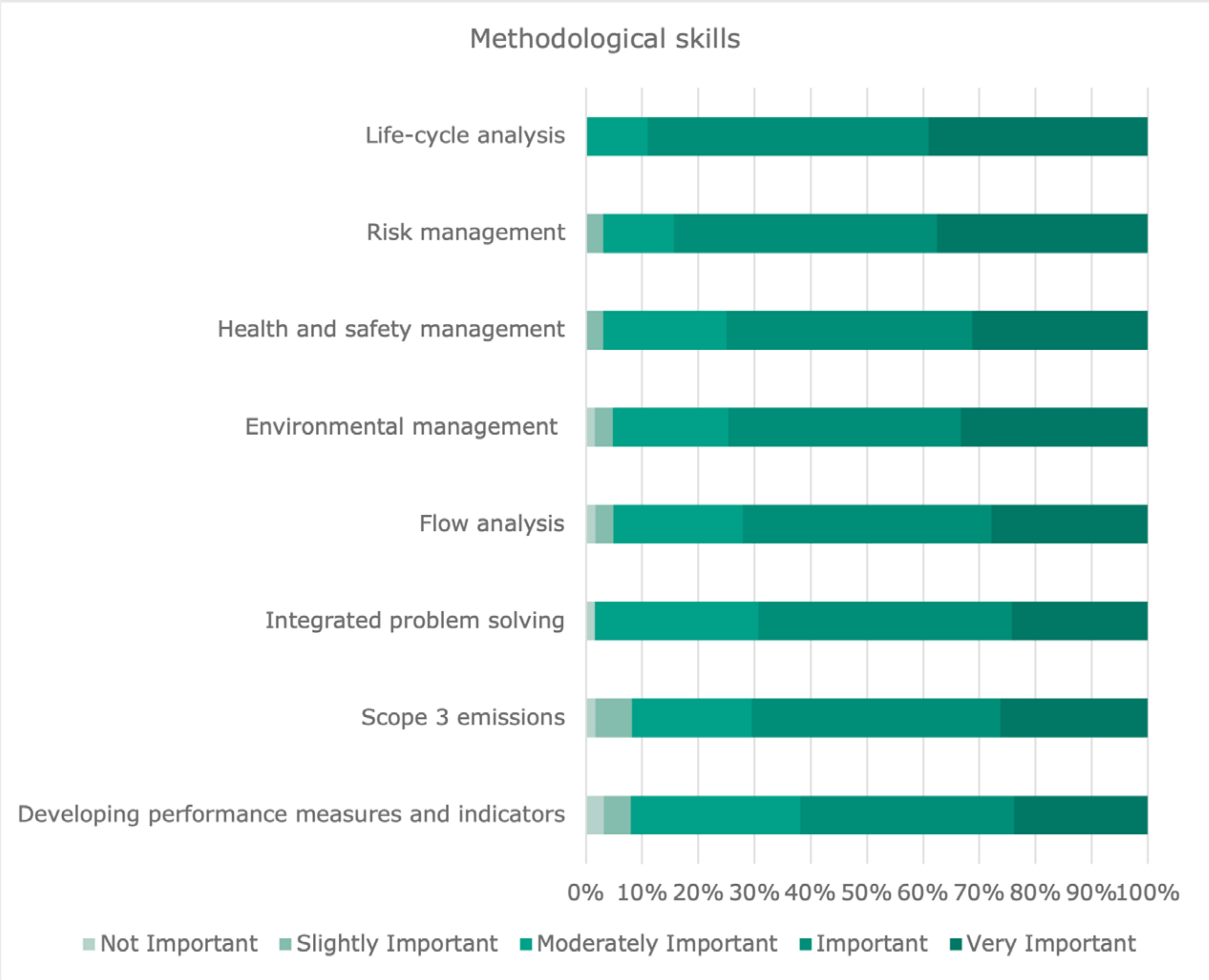


Figure 10.
The importance of different methodological skills for a sustainable battery value chain based on the answers from the questionnaire.

IMPLICATIONS AND CONCRETE STATEMENTS:

- ***Life-cycle analysis*** is seen as the most important methodological skill.
- ***Developing performance measures and indicators*** is seen as the least important measure

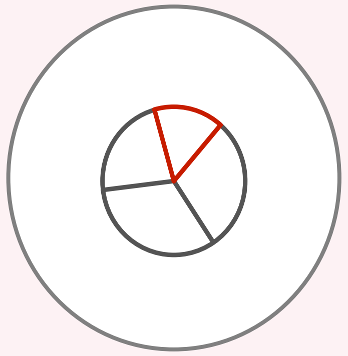
OTHER ASPECTS THAT RESPONDENTS ADDED CONNECTED TO METHODOLOGICAL SKILLS WERE:

- Understanding the method of design thinking
- Importance of understanding life-cycle analysis methodology as calculations and models often are simplified, showing large variation

5.2. Specific competences for batteries

5.2.1. Overview of all specific competences for batteries

While the specific competences are indeed needed for operation throughout the battery value chain, it should be highlighted that the below skills are more relevant in the short-term and will likely change over time. Overall, the specific competences *integration of batteries in systems, recycling and remanufacturing* and *battery chemistry* are the most important competences to develop. The specific competence *integration of batteries in systems* with the highest average ranking had a score of 4,58, which means it is the most important competence (both general and specific) needed for a sustainable battery value chain of the ones included in the questionnaire. The competences *recycling and remanufacturing, battery chemistry* and *understanding of battery components* were all close behind with average scores ranging between 4,53 and 4,57. On the other end of the spectrum, the least important competences to develop are *blockchain* (3,23), *use of CAD software* (3,34) and *urban mining* (3,35).



For the specific competence categories, the average scores were the following: application & integration (4,47); chemistry & materials science (4,34); designing & manufacturing (4,32); governance & legislation (3,92); systems & computer knowledge (3,78); mining, sourcing & processing (3,75). The result for each category will be presented in detail in the following sub-chapters.

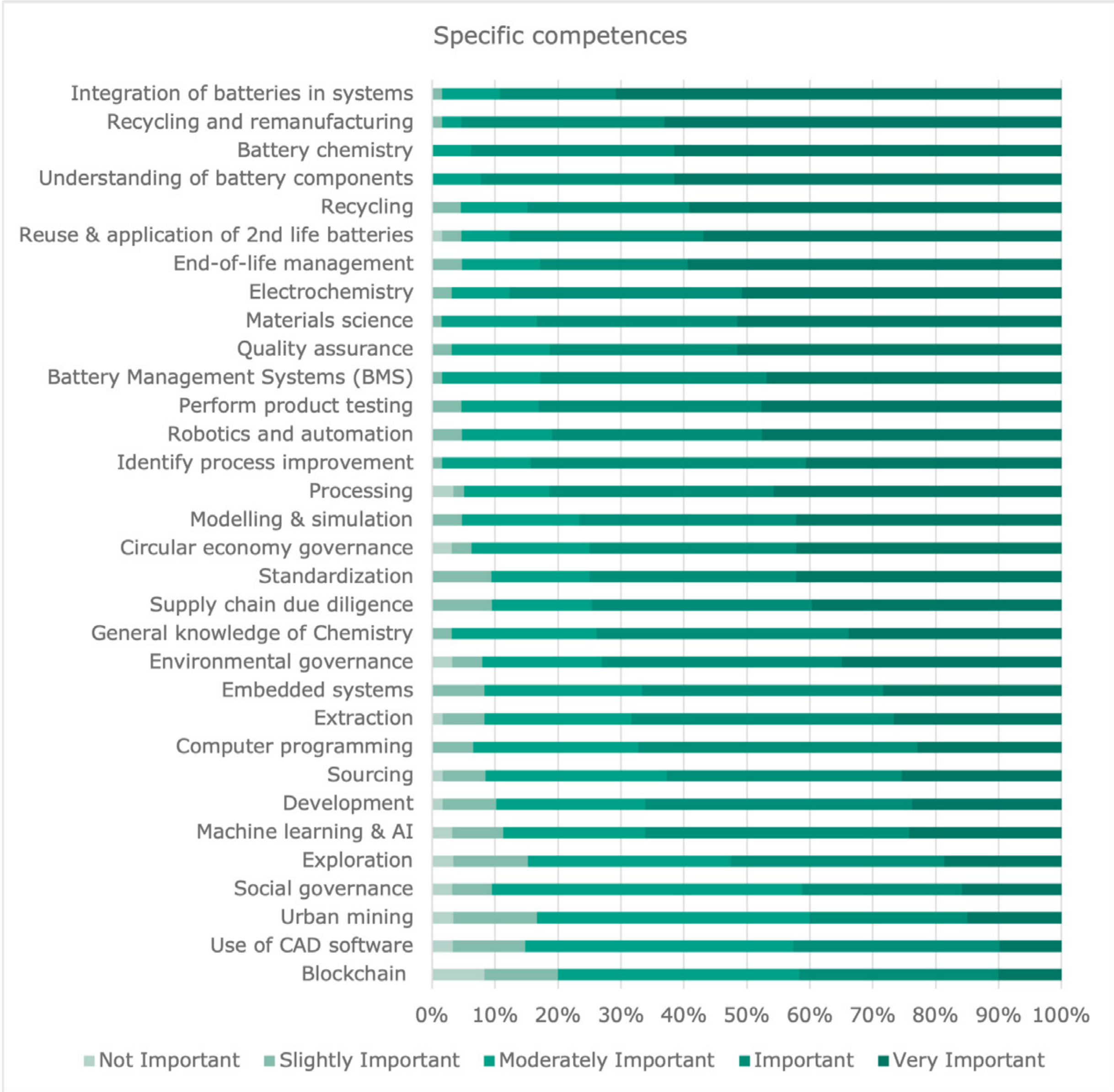


Figure 11.
The importance of different specific competences based on the answers from the questionnaire.

IMPLICATIONS AND CONCRETE STATEMENTS:

- The four competences of ***integration of batteries in systems, recycling and remanufacturing, battery chemistry,*** and ***understanding of battery components*** are the most important specific competences to develop.
- ***Blockchain, use of CAD software*** and ***urban mining*** are seen as the least important specific competences to develop

5.2.2. Chemistry & Materials Science

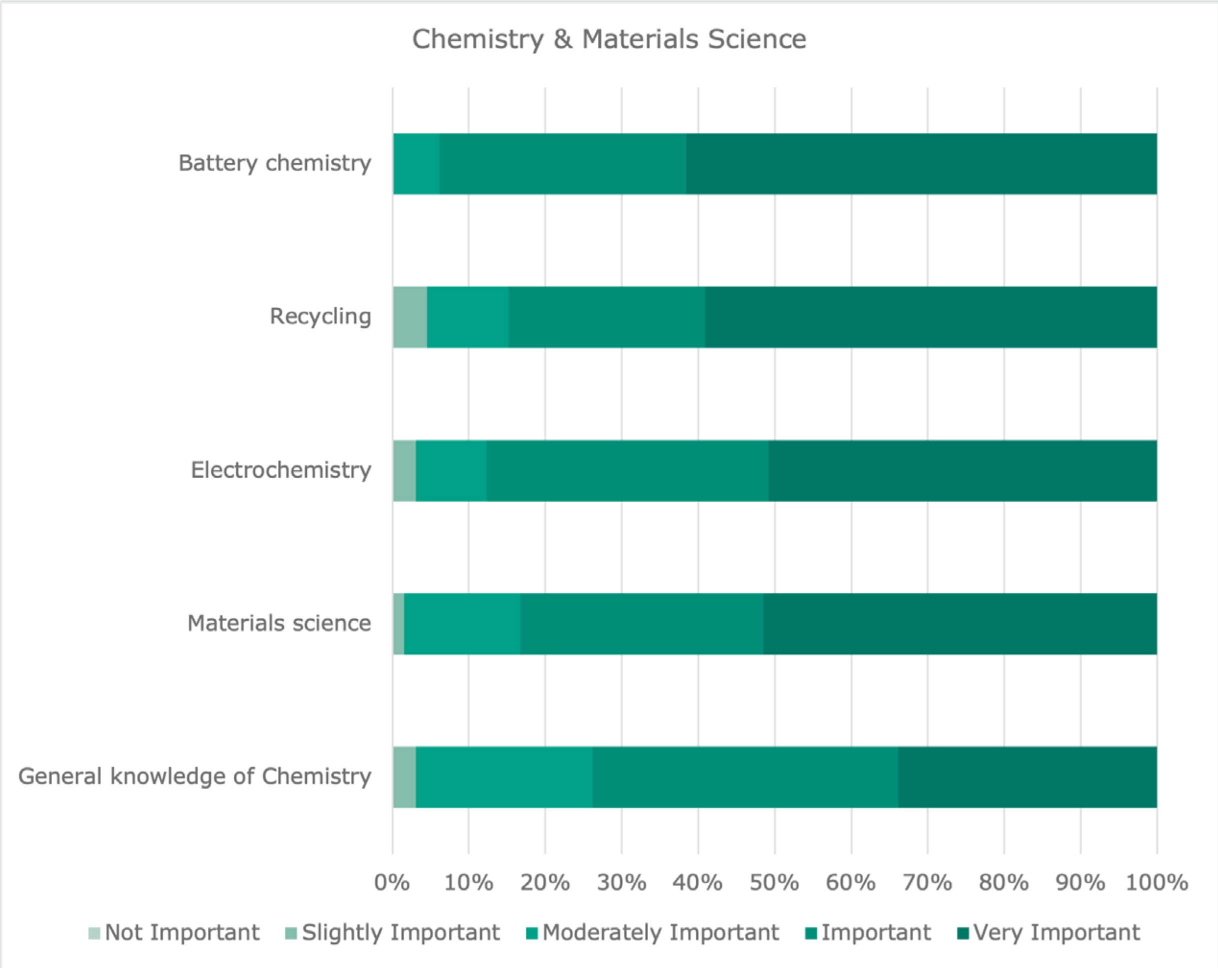


Figure 12.
The importance of different chemistry & materials science competences for a sustainable battery value chain based on the questionnaire.

IMPLICATIONS AND CONCRETE STATEMENTS:

- ***Battery chemistry*** is seen as the most important competence to develop
- ***General knowledge of chemistry*** is the least important competence to develop

OTHER ASPECTS THAT RESPONDENTS ADDED CONNECTED TO CHEMISTRY & MATERIALS SCIENCE WAS:

- Understanding of physical chemistry (thermodynamics, metallurgy, rheology, surface chemistry etc.)
- Understanding of electromagnetic compatibility and power electronics.
- Usage of computational chemistry and molecular modelling
- Knowledge of sustainable chemistry and ecotoxicology

5.2.3. Mining, sourcing & processing

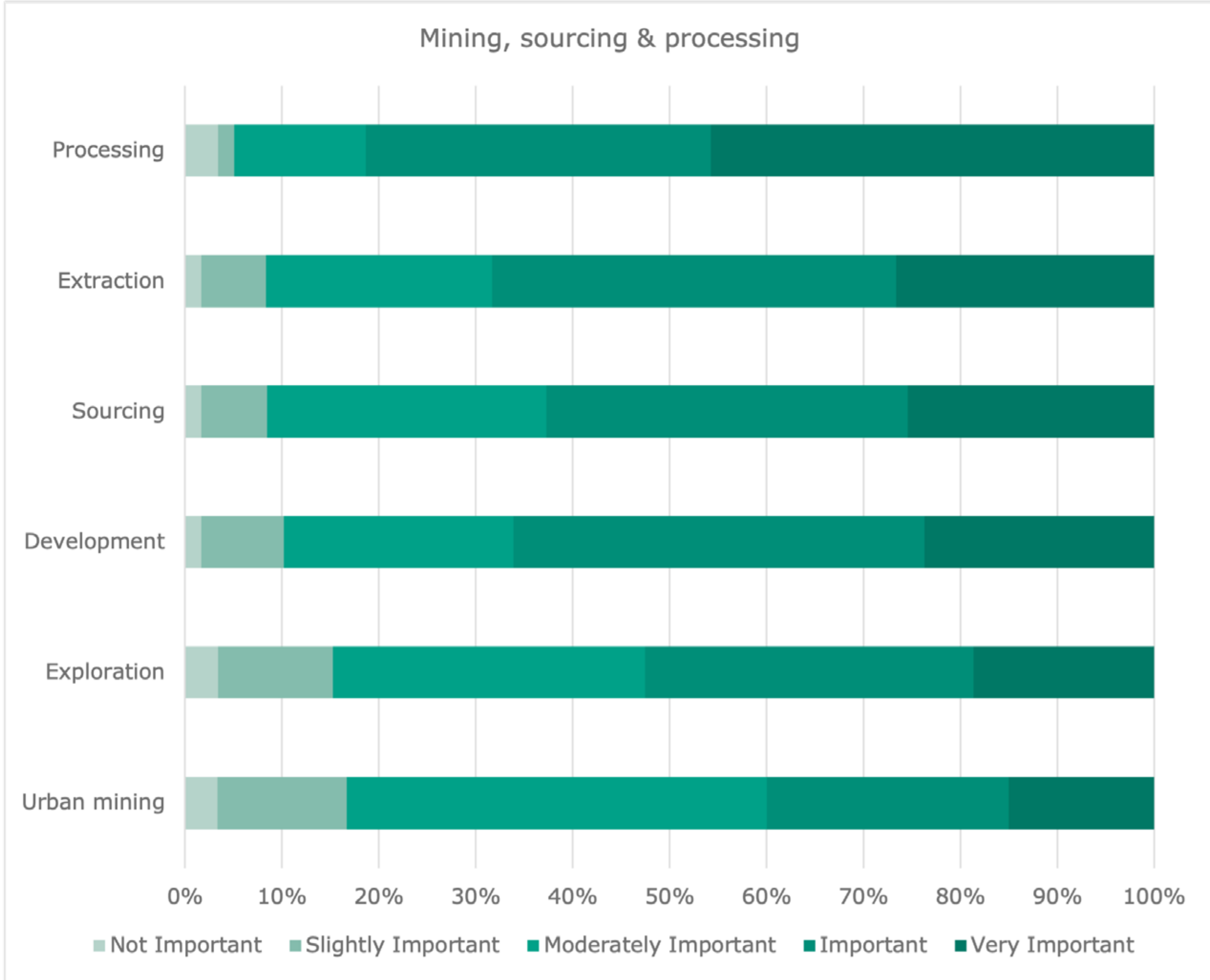


Figure 13.
The importance of different mining, sourcing & processing competences for a sustainable battery value chain based on the answers from the questionnaire.

IMPLICATIONS AND CONCRETE STATEMENTS:

- ***Processing*** is seen as the most important competence to develop
- ***Urban mining*** is seen as the least important competence to develop
- The category of ***mining, sourcing & processing*** has the lowest average score (3,75).

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OTHER ASPECTS THAT RESPONDENTS ADDED CONNECTED TO MINING, SOURCING & PROCESSING WAS:

- Knowledge of sustainability and environmental awareness, to be able to early incorporate it in the battery value chain
- Better sourcing of secondary materials and working closely with recycling facilities
- Understanding of environmental permits, conducting environmental impact analysis and restoration of mining areas
- Understanding and comparing consequences of mining-related processes in Sweden compared to other countries
- Understanding of logistics and procurement.
- The public needs to be informed on which materials are needed for a fossil-free transition

5.2.4. Design & manufacturing

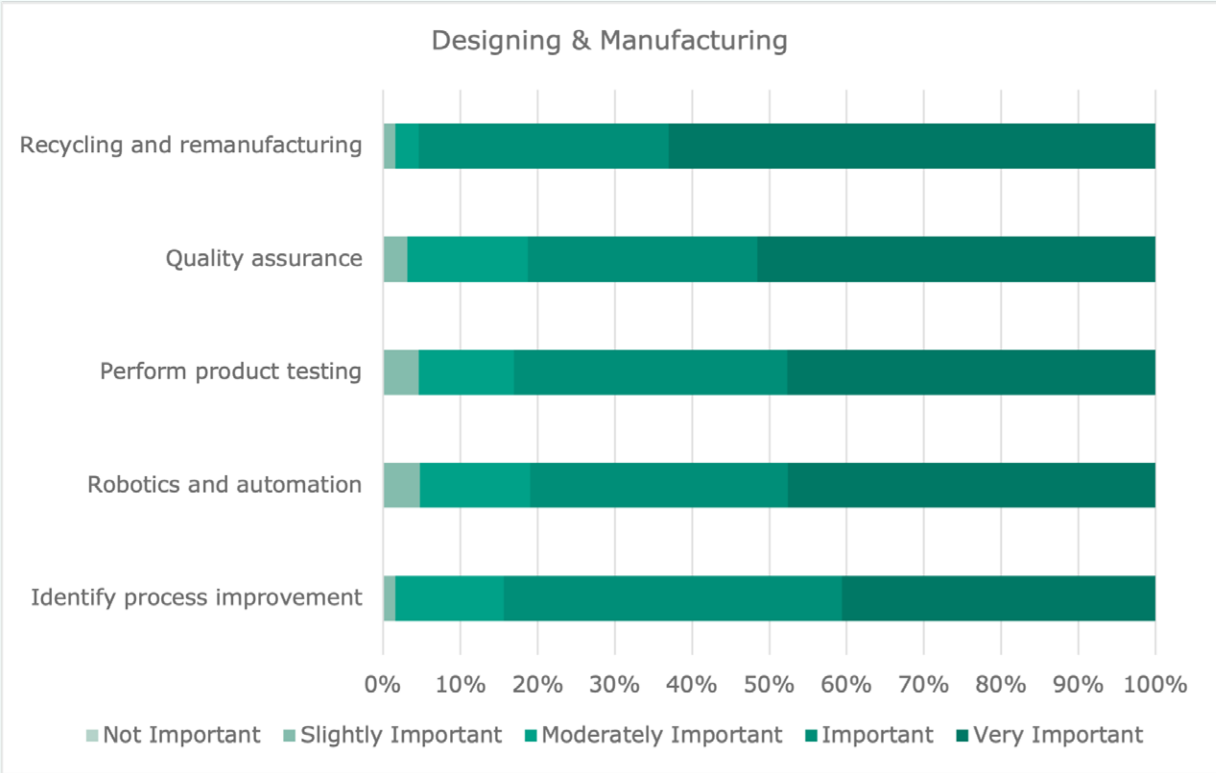


Figure 14.
The importance of different designing & manufacturing competences for a sustainable battery value chain based on the answers from the questionnaire.

IMPLICATIONS AND CONCRETE STATEMENTS:

- ***Recycling and remanufacturing*** are seen as the most important competence to develop
- ***Identify process improvement*** is seen as the least important competence to develop

OTHER ASPECTS THAT RESPONDENTS ADDED CONNECTED DESIGN & MANUFACTURING WAS:

- Focus on designing for disassembly and recycling
- Understanding how to design from a customer perspective (user perspective)
- Competence connected to designing and producing the battery manufacturing machinery needs to be developed
- Transdisciplinary competence is lacking and could be leveraged throughout the value chain, but also specifically useful for the design and manufacturing steps of the value chain
- Methods of laser welding, nanowire etc. for joining cells into battery modules and packs

5.2.5. Application & integration

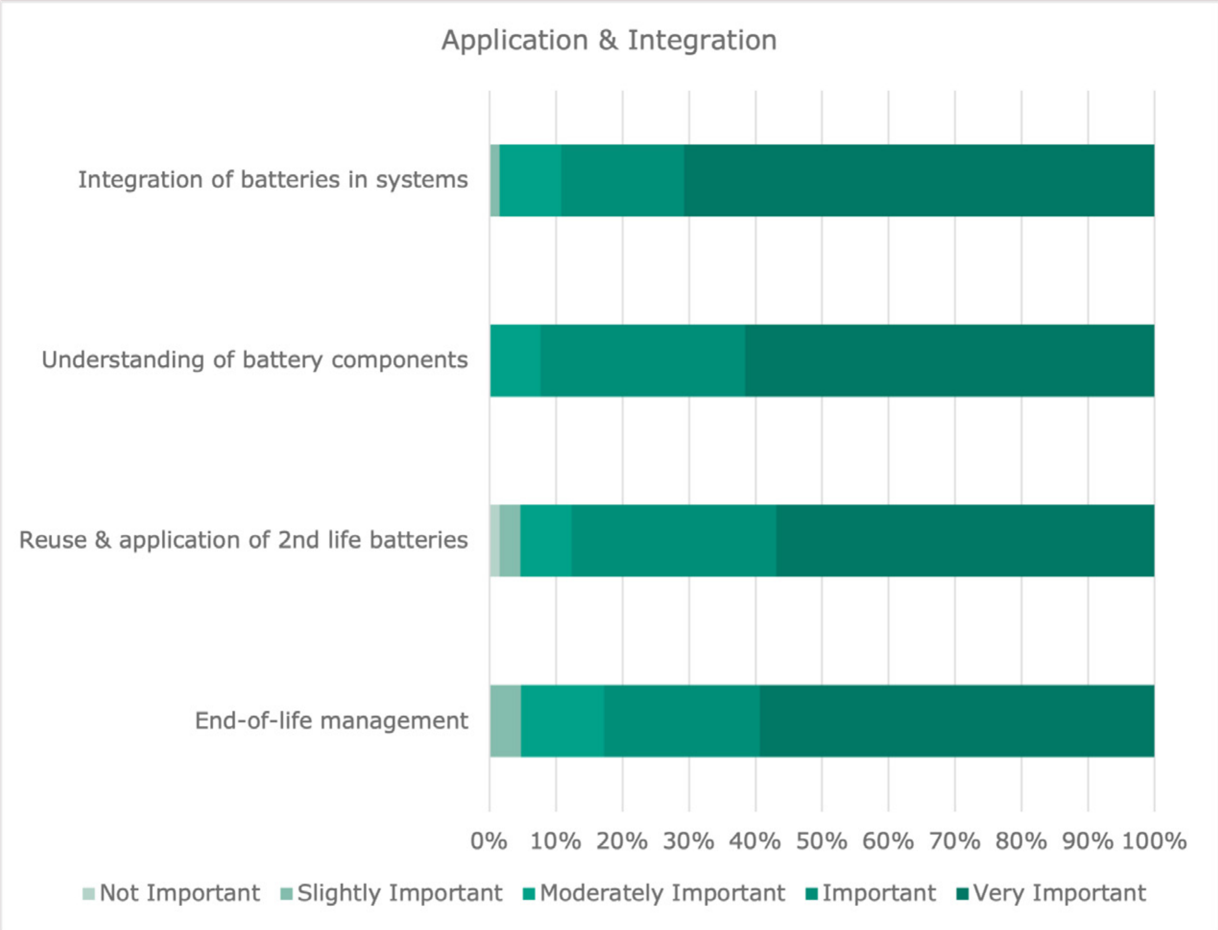


Figure 15.
The importance of different application & integration competences for a sustainable battery value chain based on the answers from the questionnaire.

IMPLICATIONS AND CONCRETE STATEMENTS:

- ***Integration of batteries in systems*** is seen as the most important competence to develop
- All competences in the ***application & integration*** category have high importance, with an overall average of 4,47

OTHER ASPECTS THAT RESPONDENTS ADDED CONNECTED APPLICATION & INTEGRATION WAS:

- Coordination of recycling for lithium-ion batteries should be on EU-level, as it is not reasonable that Sweden would have all different recycling processes needed
- Understanding of the energy market
- Understanding logistics for end-of-life batteries
- Understanding logistics for new types of electrified traffic networks
- Understanding of physically embedded systems
- Deep knowledge in critical and non-critical emissions when recycling batteries to reduce costs
- Informing consumers of associated risks of mishandling batteries and connected safety measures.
- There is a need for developing competence connected to handling of batteries and electric vehicles in case of accidents

5.2.6. Systems & computer knowledge

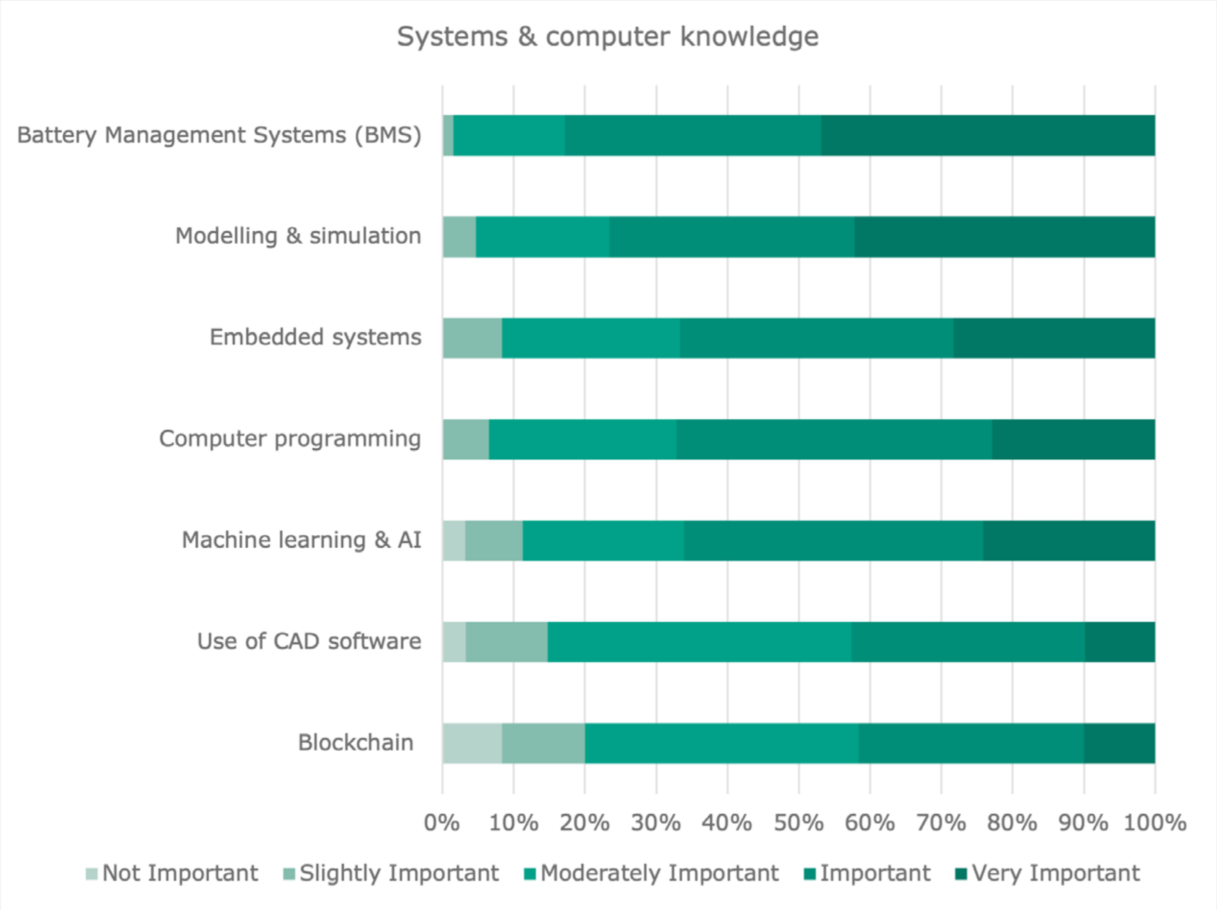


Figure 16.
The importance of different systems & computer knowledge needed for a sustainable battery value chain based on the answers from the questionnaire.

IMPLICATIONS AND CONCRETE STATEMENTS:

- ***Battery management systems (BMS)*** is seen as the most important competence to develop
- ***Blockchain (3,23)*** and ***use of CAD software*** (3,34) are of relatively low importance compared to other competences.

OTHER ASPECTS THAT RESPONDENTS ADDED CONNECTED SYSTEMS & COMPUTER KNOWLEDGE WAS:

- Understanding of how to perform cell diagnostics and the difficulties associated with cell diagnostics
- High-performance computing and parallelization using supercomputers.

5.2.7. Governance & legislation

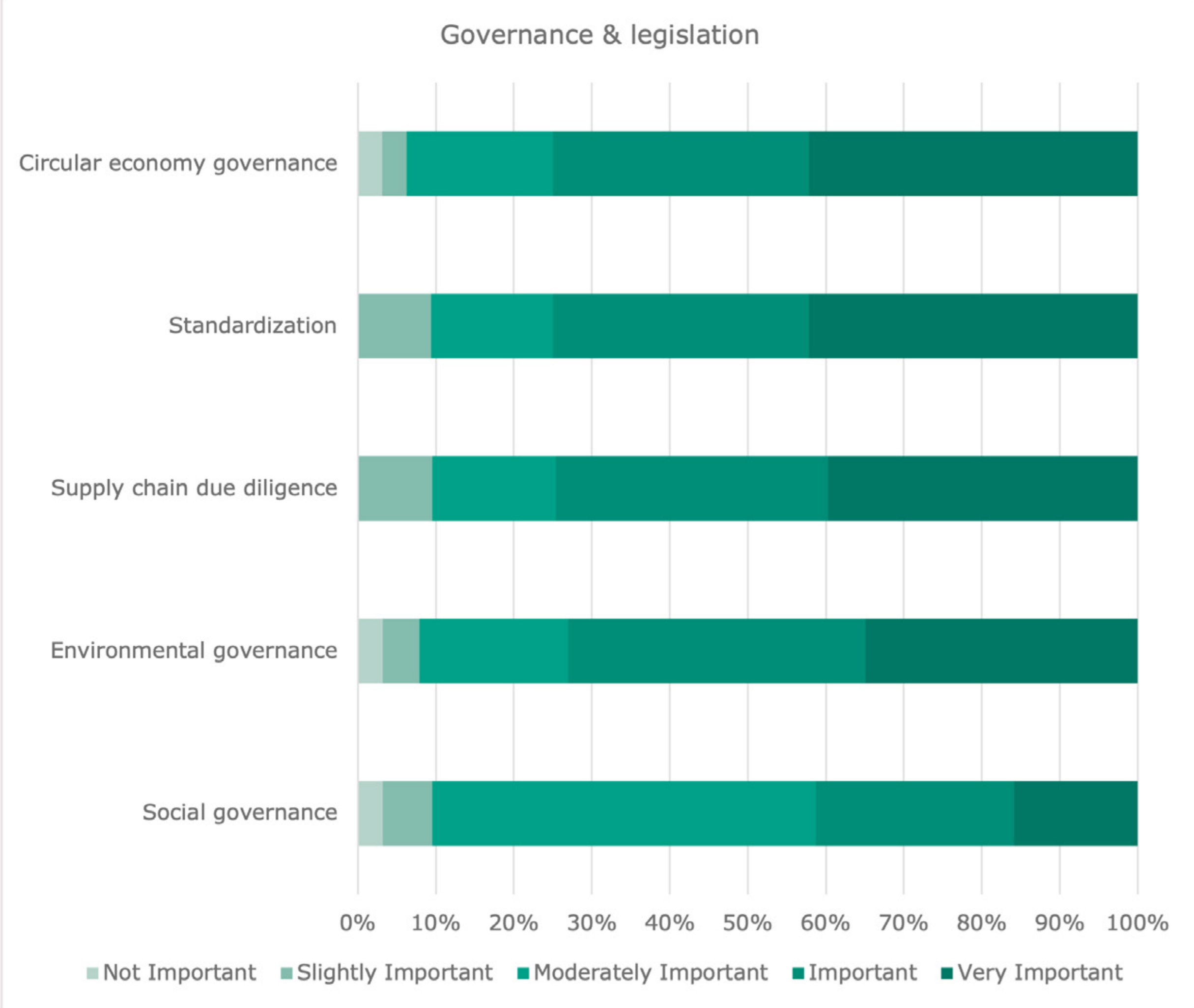


Figure 17.
The importance of different governance & legislation competences for a sustainable battery value chain based on the answers from the questionnaire.

IMPLICATIONS AND CONCRETE STATEMENTS:

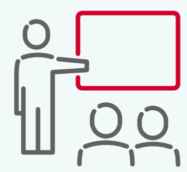
- All competences have an average score ranging between 3,97 and 4,08 except s***ocial governance*** with a score of 3,44
- ***Circular economy governance*** is seen as the most important competence.

»

»

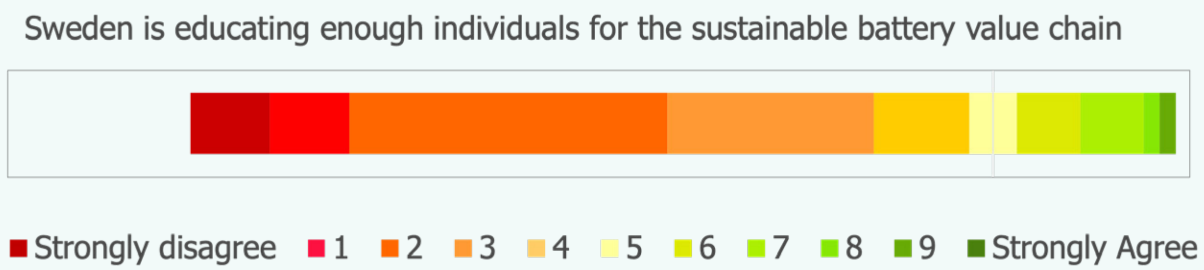
OTHER ASPECTS THAT RESPONDENTS ADDED CONNECTED GOVERNANCE & LEGISLATION WAS:

- Knowledge of governance related to rare earth metals and other materials
- Knowledge of infrastructure governance
- Importance of transparency and certain predictability of upcoming permits and legislation, to enable better investments by companies and the public.
- Cooperation between the private and public sectors to enable better implementation of rules and regulations.



6. Education relevant to the battery value chain

In general, several stakeholders have expressed the need for more education programmes and more educated individuals in Sweden. Most of the respondents of the questionnaire believe Sweden is not educating enough individuals for the sustainable battery value chain, see Figure 18. The average response was 3,18, indicating that most respondents disagreed with the statement "Sweden is educating enough individuals for the sustainable battery value chain". To better understand this deficiency, we conducted desktop research to identify Swedish education programmes/courses relevant for the battery value chain and compared this with a European outlook. In addition, input from the interviews, workshop, and questionnaire have been added.



Figur 18.
A bar chart showing the questionnaire respondent's answers to the statement «Sweden is educating enough individuals for the sustainable battery value chain».

6.1. European outlook

Creating a competitive European battery value chain is of strategic importance for both the European automotive sector and for transitioning towards clean energy. For this to be accomplished, Europe needs to have a highly skilled workforce that is qualified for the growing number of jobs along the battery value chain [7].

Education programmes available for vocational and professional training are more limited compared to higher academic education across Europe. Generally, these types of programmes depend on industry demand and should offer both practical and local relevance in terms of skills relevant for the battery industry. For regions that have started or are planning to establish battery manufacturing plants (including Sweden) the importance of specific programmes related to production is likely to increase [2].

Increasing need for professional education. Professional education on battery value chain related topics is generally provided to a limited extent often in the local language or English throughout the Member States in Europe [7]. Difficulties are seen in the reskilling and upskilling of personnel along the entire battery value chain. In general, the education and training for professionals in adjacent fields are increasing in Europe [2]. There are several specialized training programs, both offered online and physically at levels ranging from a basic introductory level to high expertise [7]. However, these programs are often not free and are mainly offered in areas such as energy storage, technology, and electro-mobility. Throughout Europe, there is a lack of professional education offered related to battery production, which is highlighted as crucial for upskilling and reskilling the European workforce needed for battery production facilities [7]. In other words, the entire battery value chain is not covered to a full extent by the general offering of professional education in Europe. The European Education Area acknowledges a growing need for people in the European Union to update their competence and knowledge to reduce the gap between their formal education and the everchanging needs from society and the labor market [42]. One of the suggested areas to further develop is therefore micro-credentials, which is a way of certifying short-term learning experiences. This type of knowledge validation is deemed especially useful for people that need to reskill or upskill their competence and skills. Setting a European standard for micro-credentials could then increase cross-border comparability between countries.

Most of the education offered in Europe is found at higher academic levels in the education systems (bachelor, master, doctoral and post-doc programmes). Master programmes such as electrical vehicle engineering and materials chemistry are exam-

ples of programmes that are relevant to the battery industry. Courses and programmes available in the field are becoming more available, but the teaching capacity is generally considered limited [2]. Specialized skills, such as large-scale manufacturing, are still lacking along the education provided. The Education and Skills Task Force Position Paper [7] expresses a need for increased education programmes within electrochemistry, material science and technology, process and chemical engineering and a circular battery economy. Research and innovation centres in connection to universities in Europe currently offer a diverse knowledge and expertise that is needed, but the number of students is less than the industry demand.

Competition for expert talent. On the PhD level, universities are providing researchers and professors with high skills. The background is generally in electrochemistry, materials science, and engineering. The EU is supporting various doctoral programmes, where the Future Expert Needs in the Battery Sector report is mentioning the European Training Networks Polystorage [43] and DESTINY [44] as examples. These programmes are offered with high mobility between both universities and knowledge institutions, as well as partners from the industry. On the other hand, the Future Expert Needs in the Battery Sector report highlights the limitation of the number of experts, leading to an increase in competition between academia and industry [2]. While both measures and academic programmes for battery technology exist, they have been insufficient so far in matching the upcoming need for skilled and specialized personnel. Considering the share size and pace of the ongoing scale-up of battery production capacity in Europe, the available educational and training programmes are undersized. Thus, more investment in education and training is seen as crucial to upscale the number of professionals to benefit from these programmes [7]. Creating a competitive European battery value chain is of strategic importance for both the European automotive sector and for transitioning towards clean energy.

6.2. Educational Programmes and Training in Sweden

The report 'Strategy for a Sustainable Battery Value Chain' presented by Fossilfritt Sverige [6] highlights access to a skilled workforce as a key area where central government and industry need to cooperate. The report calls for major national investments (500 million per year for the next 10 years) in skills development and for more than 1,000 people to be educated per year with skills related to the battery value chain. The transition towards a sustainable battery value chain will require new competence at all levels, ranging from upper secondary school to higher education to top-ranked research. With the increased adoption of batteries in transport, energy storage systems, and various industrial applications, new competences will be required. The increased demand for workforce related to this transition needs an expansion of education at both basic and higher level, as well as an increased possibility for conversion in working life (such as lifelong learning and career changes) [6].

Currently, the universities Uppsala University (UU), Chalmers University of Technology (Chalmers), KTH Royal Institute of Technology (KTH) and Luleå University of Technology (LTU), cover many of the competences needed for the battery value chain (BVC). Uppsala University is especially strong in active materials and their connection to the other steps of the value chain and in the application of batteries. Chalmers is strong in active materials (cell concepts and cell chemistries), battery steering systems and recycling. KTH is especially strong in the areas of application and integration. KTH is also strong in general understanding of materials science, but not specifically for the battery value chain. Finally, Luleå is strong in raw materials and sourcing.

Notwithstanding the need for higher education, the demand for blue collar workers, such as process technicians and automation operators, is very high. Vocational schools are offering several education programs within this field, but lack of knowledge and interest in the programs is seen both from companies and students. In addition, collaboration between the industry and adult (VUX) education is seen at local hotspots such as Skellefteå, where fast-track education programmes have been developed. Increased awareness of what the vocational schools and VUX can offer, and the job opportunities within the industry, is needed for accelerating the student applications.

In the below sub-sections, the various levels of education and training are presented, ranging from adult education to the PhD level, see Figure 19 for an overview of the different levels. Examples of education programmes offered at the various education levels will be incorporated in each section. Exploring the current education and training programmes offered in Sweden that are relevant for a sustainable battery value chain is a complex task. Several education programmes offered at a higher education level are often offering a broad competence base for students, making it difficult to distinguish whether a programme is relevant for the sustainable battery value chain or not. Further evaluation is needed to understand the extent that programmes and courses are feasible for educating individuals for working in a sustainable battery value chain. The following distinction between directly and indirectly related education for the battery value chain:

- **Directly related education programmes:** courses and other learning resources. These distinctly involve battery-specific learning outcomes in one or several parts of the battery value chain.

- **Indirectly related education programmes:** courses and other learning resources. These do not distinctly involve battery-specific learning outcomes, but as the competence needs are broad and involve more general competences, the aim is to present broader education programmes in the engineering field involving chemistry, energy, sustainability, circular economy, and process engineering.

NOTE:

the below mapping is not an exhaustive list of relevant education programmes/courses. Further, the relevancy of these have not been weighted nor verified with the institutions. As such, this should only be used as examples and not a complete mapping of battery education in Sweden.

					Bologna level	**1**	**2**	**3**
EQF level	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
SEQF level	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Qualifications					• High school engineering degree • Higher vocational education diploma	• Bachelor's degree • Higher education diploma • Advanced higher vocational education diploma	• Master's degree • 1-year master's degree	• PhD • Licentiate degree

Figure 19.
Reference frameworks for Swedish qualifications and degrees

6.2.1. High School and Adult (VUX) Education

The EQF 4-level equals education and training on an upper secondary level. Upper secondary education in Sweden covers programmes that are both university entrance qualifying and those that are vocational [46]. The latest start of the upper secondary school in Sweden is before the end of the spring term in the year of the student's 20th birthday. If the person is older, the education is offered through the adult education system. The adult education system in Sweden is called komvux, and mainly serves the purpose of offering adults the ability to complement their upper secondary education.

In a press release from the Swedish Department of Education, the government is proposing several suggestions for increasing the validation of komvux education in Sweden [47]. Increasing the number of validations aims to give the Swedish labour market faster access to competence needed and giving foreign-borns' better opportunities to validate their competence, thus decreasing segregation.

Examples of gymnasium level education found relevant for the sustainable battery value chain currently offered in Sweden:

SKELLEFTEÅ VUX

Automation Operator

The education includes both theoretical and practical modules [69]. The education is a mix between remote studies and studies at Campus Skellefteå for 24 weeks. Automation Operators work in clean and dry environments and the work tasks include automated manufacturing, quality control, prevention maintenance and tests. VUX has laboratory environments at Campus Skellefteå where automated production equipment is used. The program is conducted in collaboration with Northvolt.

MUNKEDAL KUNSKAPENS HUS

Process Technology

The adult education is aimed towards people interested in a career as production technician, process operator, or operations technician, and is a one-year programme [71]. The profession is relating to technology, environmental thinking, and safety, and the programme offers both theoretical and practical learning modules. Examples of courses provided are:

- Water and process chemistry
- Environment and energy
- Maintenance and operations security
- Industry Automation

6.2.2. Vocational Education

The EQF 5-level of education is translated to the adult vocational education (yrkeshögskoleutbildning) offered in Sweden. This level of education also involves the high school engineer education, where students at the technical gymnasium program can study an additional year to receive the diploma. The Swedish vocational education is offered as post-secondary education and combines theory with learning in a working environment (LIA). The vocational diploma covers at least one year of full-time studies, and a qualified educational diploma covers a minimum of two years of full-time studies, including at least 25% of the study time consisting of learning in a working environment [48].

Programmes are offered in sectors where a need for skilled labour is seen, with the aim of direct employment after taking the diploma. The Swedish National Agency for Higher Vocational Education decides which programmes should be offered as Higher Vocational Education (HVE) and is responsible for analysing the labour market. If the education currently offered does not match the competence needs seen of any employer, a possibility of participating in an application for a new programme is offered, as well as contributing to the analysis of future needs in the specific industry [49]. In the analysis of the energy sector made by the Swedish National Agency for Higher Vocational Education 2020, the increased battery production and recycling of earth metals is mentioned as an urgent issue having a high strategic effect on the competence need in the area [50]. Furthermore, the government is issuing an investigation of the future vocational education in Sweden [51]. Part of the assignment is to examine the vocational education's role in the transition towards a sustainable society, involving suggestions for how vocational education can contribute to competence for climate change and if this type of education should be prioritized.

Examples of vocational education found relevant for the sustainable battery value chain currently offered in Sweden:

HIGH SCHOOL ENGINEER

Production Technique Profile

The students study an additional year after their high school education from a technical program. Courses within production and automation are mandatory and the students can choose courses within for example CAD-specialisation, industrial IT, and industrial production methods [61].

SKELLEFTEÅ MUNICIPALITY HIGHER VOCATIONAL EDUCATION

Production Technician; Automated Manufacturing Processes

A 2-year higher vocational programme with both theoretical and practical elements. The programme has been developed in collaboration with companies such as ABB, Boliden and Northvolt. Courses included in the programme are for example 3D-CAD and drawing technology, LEAN and sustainable production, and production technology [67].

CREANDO HIGHER VOCATIONAL EDUCATION

Operations Technician and Process Operator

A 2-year higher vocational programme offering remote studies of which 10 weeks are at the assigned study location (Västerås, Sundsvall, or Piteå). During the second year, the student can specialize in battery production or the chemical industry. Several companies are involved in the education, including Northvolt. Examples of courses offered are process techniques, process governance, and maintenance techniques [75].

OLOFSTRÖM HIGHER VOCATIONAL EDUCATION

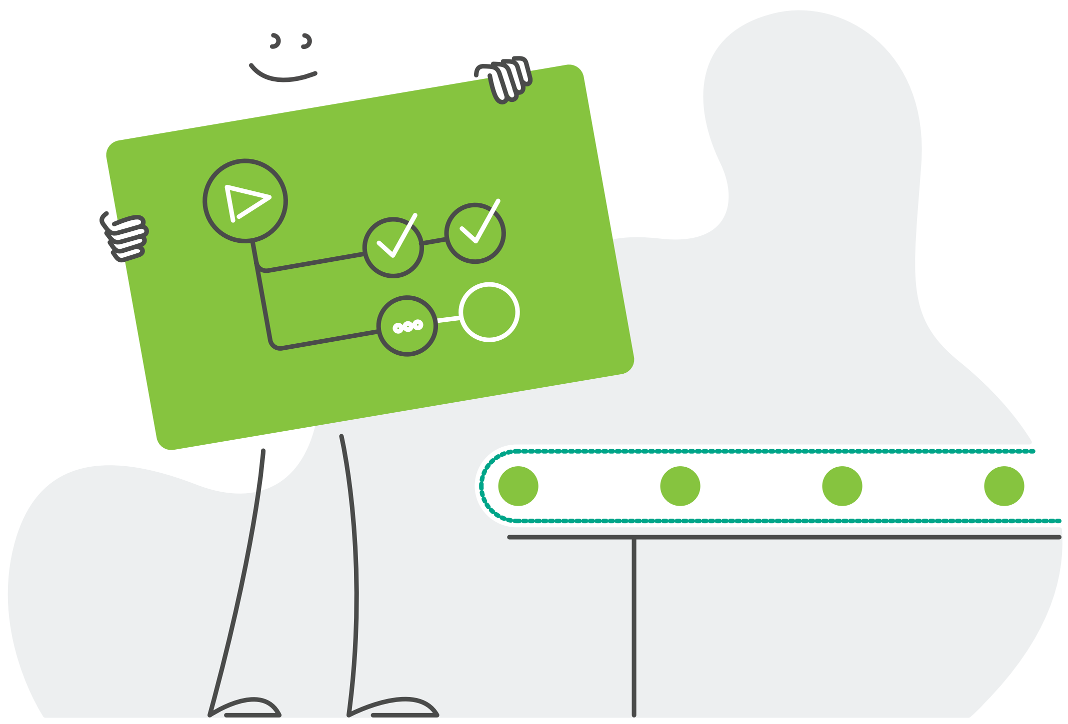
Automation and robotics engineer

A 2-year higher vocational programme offering education for working as an automation engineer, automation technician, maintenance electrician amongst others. The students are being prepared for conducting work tasks such as installing and maintaining automated facilities and controlling and surveilling production processes. Examples of courses included in the programme are industrial IT, automation systems, production economy and sustainable development, and project methodology. The programme involves three periods with learning in a work environment (LIA) [81].

LUND HIGHER VOCATIONAL EDUCATION (HERMODS AB LUND)

Automation- and Robot Engineer within Industry 4.0

A 2-year higher vocational programme offering education for working as an automation and robotics engineer, automation technician or maintenance technician. A third of the education is divided into two periods of learning in a working environment. The courses provided include for example industrial automation, smart industry and property automation. The students gain competence within electronics, control and steering technology, automation in the production process, and management of automation projects [74].



6.2.3. Bachelor and Master Education

The EQF 6-level education is translated to the bachelor level of post-upper secondary level, and the EQF 7-level is translated to the master level of post-upper secondary level. In Sweden, many engineering programmes are offered as a 5-year programme, with the opportunity to graduate with a bachelor's diploma after 3 years or finish with a master's degree after 5 years of education. 1-year master programmes (magister) are also offered in Sweden, translating to EQF 7-level of education.

Tillväxtverket's report on strategic competence supply points out systematic barriers for adapting the curricula in formal education for the industry needs. Academic education needs to have good scientific quality and corresponding requirements for relevance for the labour market. The higher education reform (Högskolereformen) in 1993 moved the governance of educational content from the labour demand towards the individual and the student's choice of education. If the application pressure is low, this imposes challenges to what extent the higher education institutions can change and adjust the educational content to meet the labour demands [52].

Examples of higher education relevant for the sustainable battery value chain currently offered in Sweden:

UPPSALA UNIVERSITY

Master's Programme in Battery Technology and Energy Storage

The programme aims to provide specialist competence in batteries and energy storage and is based on materials chemistry and materials analysis. Within the programme, two specialisations provide the possibility to build specialist competence in battery materials or battery cells and systems [63].

LULEÅ TECHNICAL UNIVERSITY

Civil Engineer Programme in Sustainable Process- and Chemical Technology

A five-year programme with the aim of building competence in using and developing processes for the future's sustainable material- and resource use. During the fourth year, the students are offered a practical course for up to one semester. The programme has two specializations [73]:

1. **Chemical and bioprocess technique:** building competence in developing new sustainable processes. The area of electrochemistry is noted as a demand from the industry, and battery manufacturing is highlighted as an area where increased demand is found.
2. **Mineral technology and metallurgy:** suggested working areas for engineers in this field is extraction and recycling of minerals and metals, and minimization of emissions and energy use.

INDIVIDUAL UNIVERSITY COURSES SWEDEN

Luleå University of Technology

- Batteries for a sustainable society: from raw materials to battery cells [58].

Uppsala University

- Batteries and Storage [80]
- Calculation modelling of energy-related materials [59]

Lund University

- Environmental system analysis, life cycle analysis [64]
- Hydrogen, Batteries and Fuel Cells [79]

6.2.4. PhD and Research centres

The EQF 8-level of education is the postgraduate/doctoral level in Sweden. The education offered at a doctoral level is 2 or 4 years and leads to licentiate and doctoral diplomas respectively. The higher education institutions in Sweden have a general permit at a doctoral level. Those who receive permits for a degree at a doctoral level in a certain area have the right to give a degree within that given field [53].

In the situation that postgraduate education is given at universities without a degree permit for that level of education, the doctoral students are admitted and examined at another university that has the degree permit. This education can also be offered at graduate schools (forskarskolor) [53]. There are several funding options for doctoral studies in Sweden. The forms of funding currently offered are [54]:

- Doctoral student employment
- Other employment at the university
- Education grants
- Scholarships
- Employment outside the university (company doctoral employment)

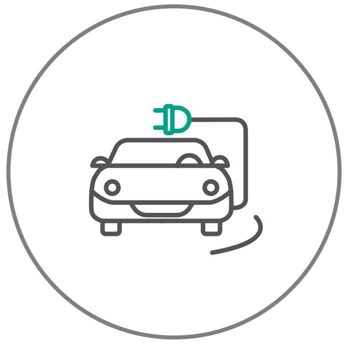
Examples of research clusters relevant for the sustainable battery value chain currently offered in Sweden:

ÅNGSTRÖM ADVANCED BATTERY CENTRE (ÅABC) AT UPPSALA UNIVERSITY

ÅABC is led by Professor Kristina Edström and is the largest assembly of battery researchers in the Nordics. The research is focused on lithium-ion batteries and the chemistry of fuel cells, including cathode, anode, and electrolyte materials. Within the lithium-ion battery research, research is conducted on the application of batteries for the EV industry and the challenges faced when upscaling the use of lithium-ion batteries. Security and the life span of automotive batteries are two issues explored [62].

COMPETENCE CENTER RECYCLING (CCR) AT CHALMERS UNIVERSITY OF TECHNOLOGY

The CCR aims at being a network for R&D collaboration in the field of circular use of materials. The research involves the reuse of products and recycling technologies as well as developing an efficient use of materials for increasing competitiveness and contributing to a sustainable society [76]. The research of Industrial Materials Recycling is part of the CCR and include projects in the recycling of batteries [77].



CIRCULAR AND GREENER PROCESSES FOR LI-ION BATTERIES RECYCLING AND PRODUCTION

A collaboration between Chalmers University of Technology, Uppsala University, Volvo Cars, Northvolt, and Meab Metallextraktion. A project aiming at finding a greener and circular process for li-ion batteries recycling and production is currently ongoing. The project is combining both industrial and academic partners and has the goal of creating a unique competence in sustainability and circular economy within the Nordic region [78].

THE SWEDISH ELECTROMOBILITY CENTRE

A national research centre serving as a platform for academia, industry, and society to gather competence for electromobility [82]. The Swedish Electromobility Centre promote both cross-discipline and cross-institution research, while conducting technological studies. A national network for PhD students have been developed, where the platform serves as an arena for collaboration and knowledge building through courses, seminars, and workshops.

BATTERIES SWEDEN (BASE)

A centre for Swedish batteries, providing a platform for developing scientific discoveries in battery materials and cell chemistries, where one of the goals is to build a Swedish Centre of Excellence for battery concepts that is internationally leading [83]. BASE serves as an open environment for sharing knowledge, where collaboration between young scientists and industry partners as well as collaboration with international competence centres is facilitated.

6.2.5. Partnerships with industry (professional education)

Collaborations between the educational sector and the industry are common. For example, commissioned education at universities is seen as important for meeting skill requirements from the industry and ensuring lifelong learning. Partnerships can also involve other actors, such as municipalities. This is seen in the project T-25, initiated by Luleå University of Technology, Boliden, LKAB, Mobilaris, Northvolt, Skellefteå Kraft and SSAB [55]. Within five years, the aim of the project is to increase the number of employees in the companies with 25 000 people. Since the start of the project, both regions and municipalities have joined [56].

Other examples of partnerships between the education sector and industry that is relating to a sustainable battery value chain:

THE PROMPT PROJECT

The PROMPT project is a national education initiative in collaboration between several academic institutions and Swedish industry companies and organisations [70]. The project aims at securing the supply of advanced software computational competence and innovation within the Swedish business context. Commissioned training is offered through Chalmers University of Technology, Blekinge Institute of Technology, and Mälardalen University, and the project is funded by the Knowledge Foundation. Examples of courses offered by the higher education institutions:

- Applied cybersecurity
- Safety-critical software
- Machine learning with Big Data

PROJECT PREMIUM (PROFESSIONAL EDUCATION FOR MANUFACTURING INNOVATION)

Jönköping University and Mälardalens University is offering competence development through education in production development [66]. The competence development is aimed at key persons in the manufacturing industry, and the project is funded by the Knowledge Foundation. Within the project, two courses are offered:

- Industrial project management
- Big Data and Cloud Computing for industrial applications

THE PRODKOMP PROJECT

The ProdKomp project aims at supporting the individuals and companies to develop skills in production technology. Courses are developed in a collaboration between academia and industry partners and is funded by the Knowledge Foundation. Example of courses offered are:

- Batteries in electric vehicles
- Manufacturing and recycling of lithium-ion batteries

6.2.6. Massive open online courses

Swedish Higher Education Authority (UKÄ) is defining Massive Open Online Courses (MOOCs) as open web-based courses that are scalable and created for a large number of attendees [57]. Swedish universities are offering MOOCs to a broad audience. Another benefit of MOOCs is that people can access courses given by universities around the world, often without cost. It should therefore be noted that both battery value chain specific and related courses could be found outside of Sweden.

Examples of MOOCs found relevant for the sustainable battery chain offered in Sweden:

CAMPUS SKELLEFTEÅ

Batteries, Fuel Cells, and their Role in Modern Society

The course aims at building a basic understanding of the subject of batteries and fuel cells, as well as the main drivers of sustainable development [68]. The focus is on the transportation and energy markets and the processes involved. Basic knowledge of key technologies, electromobility, and renewable energy will be provided. The course is estimated to take 12-24 hours over 6 weeks.

CHALMERS UNIVERSITY OF TECHNOLOGY

MicroMasters Programme

In collaboration with Volvo Cars, Volvo Group, and Zenuity, Chalmers University of Technology has developed a course package with a certificate on EdX in Emerging automotive technologies [65]. The courses can be studied one by one, with a study load of 10-20 hours per week:

- Electric and conventional vehicles
- Road Traffic Safety in Automotive Engineering
- Hybrid Vehicles
- Model-Based Automotive Systems Engineering
- Sensor Fusion and Non-linear Filtering for Automotive Systems
- Multi-Object Tracking for Automotive Systems
- Decision-Making for Automotive Systems

LUND UNIVERSITY

Circular Economy: Sustainable Materials Management

The course looks at how materials can be used more efficiently in closed loops [72]. Expert researchers and practitioners from Europe are explaining the foundation of circular economy through five modules. Tools and skills for analysing circular business models are also taught through the course.

EIT INNOENERGY

Professional Training

Battery Storage Masterclass 3 days mixed format, held in Sweden [60].
Online Small Private Online Course (SPOC) courses run over about 4-weeks at a (low) cost.
Examples of courses offered:

- Materials to Electrodes
- Electrodes to Cells
- Power converters and Efficiency in Battery Applications
- Battery Management Systems
- Battery testing systems
- Understanding energy storage: the battery revolution

INGENJÖR 4.0

The project is part of the strategic innovation program Produktion 2030 [84], where module educations are developed by 13 universities. Ingenjör 4.0 is a web-based upskilling program aimed at employees in the industry with an engineering background. The education answers to the undergoing high-speed digitalization of the industry, and include 15 modules regarding future of production, where each module is expected to take 4 hours per week during a 5-week period.

7. Identified challenges and actions

Securing Sweden's position and competitiveness in a European battery value chain hinges on supplying the Swedish industry with a highly skilled workforce. This requires decisive measures to be made across academia, industry, and government. Companies along the value chain need to build up their future work-force and our findings from the questionnaire, interviews, and workshop suggest they are facing challenges on several fronts. In this chapter, we provide a synthesis of both challenges and proposed actions to bridge the competence gap for a sustainable battery value chain. For brevity purposes, some results from the questionnaire and workshop have been put in the appendix. This includes a ranking of the most important measures from the questionnaire and a feasibility mapping from the workshop of pre-requisite actions for each stakeholder (academia, industry, and government) of selected measures. These can be seen in Appendix A and Appendix C.

The sustainable battery value chain is elemental to Sweden's transition towards a fossil-free and net-zero society. The sheer volume of compe-tence needed in such a short time for this transition requires adaptive and dynamic solutions to address the ever-changing competence needs. The development of a sustainable battery value chain puts the Swedish education system to the test. There is a general need for more coordi-nation, collaboration, and sharing of knowledge to be able to develop the right competences and ensure competitiveness. As such, adapting the current education system to ac-commodate more flexible programmes will be needed. The education sector experiences capacity shortages in several areas, such as teachers, staff, researchers and students, and the industry express an overall need to improve the attractiveness of working in the battery value chain. Further-more, the data suggest a need for more long-term investment, funding, and incentives for Sweden to have any realistic possibility to scale their position in the emerging European battery value chain. However, no entity can drive this alone and all stakeholders in the Swedish (and Nordic) battery value chain need to work together to bridge the competence gap.

For this to happen, some key conditions and challenges need to be addressed first:

1. **Need for coordinated efforts for the battery value chain**
   a. Lack of national and Nordic coordination
   b. Lack of national plan
   c. Lack of interest and understanding of the battery value chain

2. **Challenges within the education system**
   a. A need of a more dynamic and modular education system
   b. Different credit systems within academia
   c. Student compensation system

Keeping quality while increasing availability and capacity of education
   a. Insufficient competence management across the value chain
   b. Lack of research infrastructure and practical experience
   c. Lack of infrastructure to transfer knowledge between academia and industry

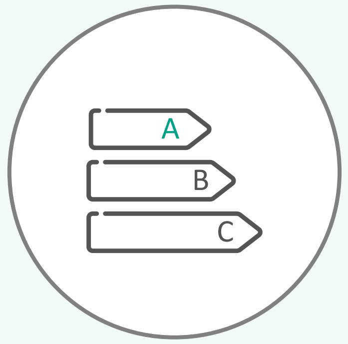
7.1. Need for coordinated efforts for the battery value chain

This chapter will discuss the need of coordinated efforts on national and Nordic level, the need for a national plan and the need for increased interest and understanding of the battery value chain.

7.1.1. Lack of national and Nordic coordination

There is a lack of national coordination for competence supply efforts related to the battery value chain. Further, the competences and resources needed for a sustainable battery value chain are spread out across various actors, both in Sweden and across the Nordic region. Currently, there are several ongoing initiatives. However, these have smaller and somewhat overlapping scope due to lack of coordination. These initiatives will most likely be valuable in the municipalities or regions where they take place. In addition, they could also bring value to others and accelerate new initiatives by sharing insights and/or extending collaborative efforts between regions or competence areas, while reducing the risk of reinventing the wheel. National coordination is needed to define, gather, structure, and ensure accessibility of data and insights from current and planned initiatives and activities lined to competence supply throughout Sweden. Without coordination, there is a risk that Sweden will be too slow, and efforts are made sub-optimally.

Today, the different value chain steps have various strengths and accessibility to funding and research infrastructure but are dependent on one another. Industry has had difficulties in describing and communicating their current, future, and/or changes in competence needs to academia. This struggle is amplified due to the fast-paced and evolving market. For example, sometimes a requested course from the industry is already available, or it can be offered by minor changes in existing courses, but due to the lack of communication a new course is created. Developingnew education material is very timeconsuming. A need for better understanding of available education connected to the battery value chain was also expressed by both industry and academia. One alternative discussed during the workshop was to develop a website, similar to kompetensmatchning.se, for visualising all available education. Having a comprehensive overview of all efforts related to the entire battery value chain is key to understand potential gaps or opportunities for enhanced collaboration and build a competitive advantage. It is important to continuously monitor and analyse the competence need across the value chain and involve all relevant actors in the process. Institutions such as municipalities, upper secondary school, vocational education, and adult (VUX) education have expressed that they often are left outside the ecosystem but are important pieces in the puzzle to close the gap. Most likely, Sweden will not have time to build up and acquire the required competences for a sustainable battery value chain organically. To stay competitive, Sweden needs to further develop and leverage both comparative and complementary strengths in the Nordic region. Thus, strategic multistakeholder partnerships and applying a system thinking will be key to both propel current initiatives, stimulate the battery market, and persistently build up key competences throughout the value chain and education system.



A national coordinator is believed to be the best solution to realise the coordination and facilitation needed to address the competence gap throughout the battery value chain. Due to the fast-paced environment, ambiguity, and complex context of the battery value chain, it will not be enough to use existing platforms for coordinating and gathering of information and share knowledge to cope with the competence gap. Further, looking at lessons learned from Region Västra Götaland, representatives have expressed the importance of a designated project manager with no association to an interest group who can ensure progress, endurance, and balance the interests and engagement of stakeholders from the public and private sector. A national coordinator needs to have the right mandate and tools to succeed and realise needs. For example, a course or program might need to be quickly developed to ensure competitiveness and the national coordinator should be able to realise the request without decisions getting stuck in bureaucracy. Moreover, having a more structured overview of initiatives and the overall status of both education and industry advancements in Sweden creates better prerequisites for collaboration on a Nordic and/or international level. This could help to gain more consensus regarding strengths and weaknesses in Sweden, and in what areas we can help or need help for developing the competence needed. Throughout the study, building on the accessibility of local, regional, and national strengths in the Nordic region has been highlighted as important to ensure that Sweden's battery value chain remains competitive. There is also a need for collaboration on both national and Nordic level to attract and leverage research and labor force from other countries.

SUGGESTED ACTIONS:

- Introduce study counselling for professionals to guide industry in finding and matching the right competence across education programs nationally
- Develop and implement metrics and digital tools to continuously gather data, monitor, analyse and adjust corresponding actions to manage the competence demand.
- Develop and implement processes, methods, ways-of-working, and prerequisites for actors (i.e., schools and municipalities) to receive, implement, evaluate, and continuously learn from "packaged" education programs

- **Mapping and visualisation of available education:**
  - Create standardised mapping models to ensure coherency.
  - Continuous mapping of demand and supply.
  - Development of APIs for efficient data gathering of available education.
  - Industry need provide the input of what kind of competence and capacity needed from academia and clarify what will be done in-house.
  - Continuous dialog between industry and academia on future needs

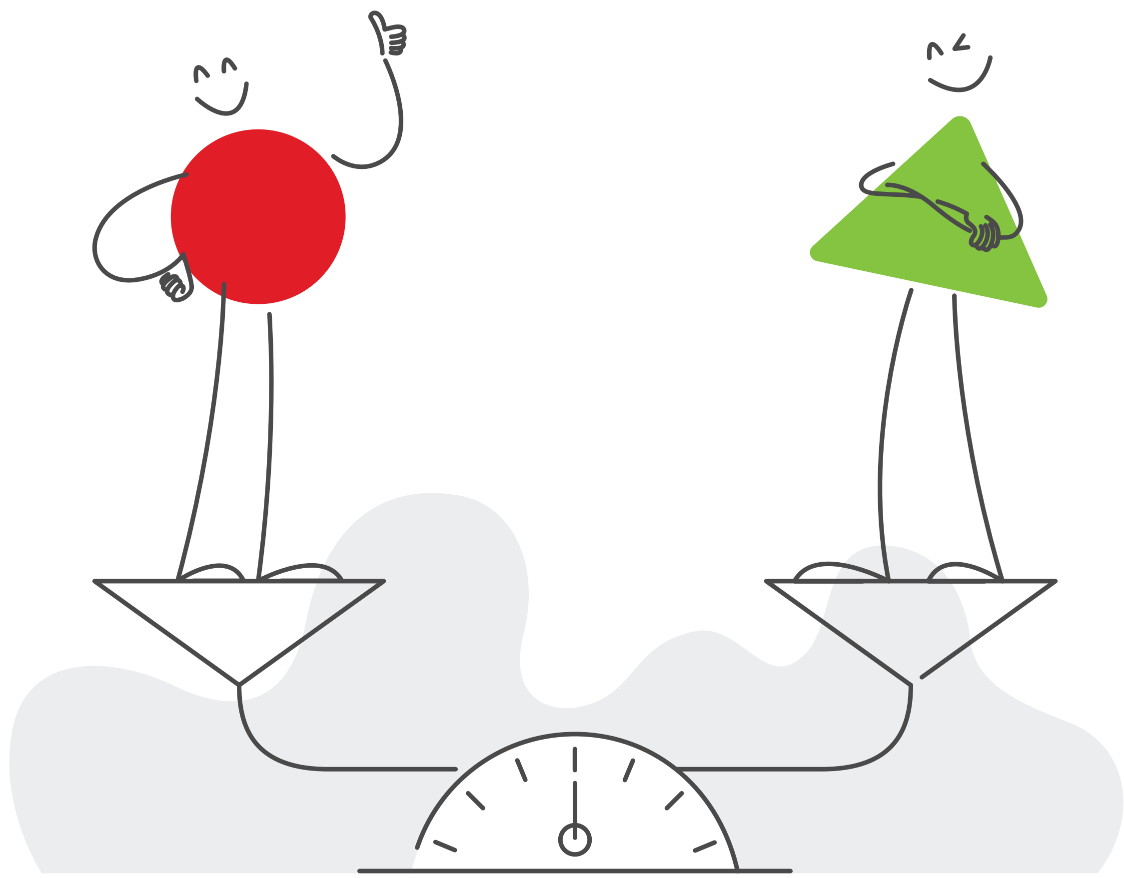
- **It is suggested that Sweden appoints a national coordinator who needs to:**
  - Be a person or team, with no association with an interest group, who understands the ecosystem and can effectively implement changes.
  - Have an understanding of the incentives and funding models of different levels of the education sector
  - Have support and trust, a sufficient budget, and mandate to realise needs. In addition, work to continuously improve the collective understanding of the competence needs and supply of the battery value chain.
  - Involve key actors from industry and academia to agree on common educational needs.
  - Ensure that research and innovation initiatives increasingly develop models for the entire value chain and not just each individual step.

7.1.2. Lack of national plan

Connected to the need for national coordination there is a need for a national plan. The plan does not necessarily have to be a document per se. The important aspect is a coordinated approach where each actor knows what to do and there is a common strategy and ability to execute. Sweden currently does not have a national plan or strategy for competence supply and demand connected to the battery value chain. Having a plan would create a common reference point to govern competence development for the education sector and provide the stability and security the industry needs to make investments in the area.

SUGGESTED ACTIONS:

- Find sufficient performance metrics and implement these in a control loop to continuously evaluate the system performance and outcome of a national plan to ensure execution power.
- Develop actionable plans and strategies that enable increased collaboration, resource utilisation, and digital infrastructure at the forefront to increase availability, dynamics, and volume.



7.1.3. Lack of interest and understanding of the battery value chain

Several stakeholders are emphasizing the lack of interest from students and the general workforce in Sweden. Relevant courses and educations programs exist for parts of the battery value chain and the electrification transition. These have often been developed together with key industry players to ensure relevance, targeting both working professionals and students currently enrolled in the education system. However, the academia experiences a lack of commitment and incentives from the industry to send staff on trainings and/or encourage them to complete courses/programs. This leads to low enrolment capacity and consequently limited funding where schools either choose to close the program or stop continuous refinement of the content. This illustrates conflicting signals from the industry who requests more education programs. If working professionals need further education, why is not the industry supporting academia? Or does the problem lie elsewhere? Further investigation is needed to understand where the obstacles to increased involvement are. However, several potential root causes to the problem have been raised during the interviews and workshop. This may be due to numerous reasons such as: inexperience in working continuously and strategically with further education within the framework of the existing (public) education system, lack of relevance of the education, insufficient abilities to identify its competence needs and match that need with corresponding education, as well as inflexible forms of providing the education. Another perspective as to why it is difficult to fill the spots highlighted in the interviews is that the potential workforce is not convinced that battery-related courses and education programmes will land them a job. The fear of investing time and effort (and sometimes money) in a battery value chain-related education and not secure employment afterwards is legitimate. People make a judgment call with the available information at hand, and we do not know if Sweden will succeed to create an internationally competitive environment in the long-term. Efforts to increase the understanding of the battery value chain and encourage further education is seen as necessary. Whereas some see a need for more marketing efforts for specific parts of the battery value chain, others see a need for marketing the entire industry to help gain interest to apply for education and jobs in the field. There is also a need for simplifying further education of working professionals. This is a crucial aspect that needs to be taken into consideration, as efforts to increase competence within this field will not be successful if the interest in applying and working in the industry is low. Marketing of the battery industry as well as further education has not only been recognized as a needed effort in a Swedish context, but also at a European level, to increase awareness of an industry that has a history of mainly existing in Asia.

SUGGESTED ACTIONS:

- Develop incentives and increase opportunities for distance learning for professionals and existing workforce within industry to further educate by increased digital education
- Develop a “Education package”, stating what competences are needed and related job opportunities to guide students and professionals to “employ themselves” based on the industry demand.
- Leverage and market digital initiatives such kompetensmatchning.se, for visualising all available educations to help the industry and academia to understand available education and what gaps exist
- Increased marketing efforts showcasing potential job opportunities, career paths, and industries connected to different education programmes.
- Develop long-term strategies and increase efforts for marketing to younger people to increase the attractiveness of the industry over time.

7.2. Utmaningar inom utbildningssystemet

This chapter will discuss the challenges of the current education system and need for a more dynamic and modular education system, the challenges connected to different credit system in academia and the difficulty of developing niched education due to the student compensation system.

7.2.1. A need of a more dynamic and modular education system

The transition towards a sustainable battery value chain, along with other fast-moving transitions in areas related to the electrification of society, has increased pressure on educating and reskilling a substantial volume of the workforce at a more rapid pace than what has been demanded historically. Digital tools provide new opportunities to collaborate and flexibility to scale education efforts in volume. Thus, digital courses developed by few experts and teachers throughout the international battery value chain could be integrated as modular components in existing education programs. This could allow the Swedish education system to “build the ship while sailing” and offer relevant competences while choosing where it is strategically sound to sharpen expert education capabilities. Further, there are implications that the foundation of battery value chain-related education is in place, but programs may have to be re-packaged and tailored to fit the current needs of the battery value chain. However, the current education systems are perceived as rigid with little degree of flexibility with long internal lead-times. It can take two (2) years to update and/or introduce larger changes to current courses and programs. Although continuous and incremental improvements of existing courses are less effected – it slows down opportunities to collaborate and use the existing infrastructure as a basis to incorporate specific and/or external courses as modular pieces in existing programs.

In addition, the data suggests that upper secondary school programs are often managed and created based on the idea that the competences needed in different industries can be taught as separated silos. However, the competences needed to specialise towards the battery value chain are spread out across different disciplines. The system is more flexible for vocational education and adult (VUX) education. Together with the industry, they have developed tailored programs and courses (i.e., MOOCs related to batteries) to reskill current professionals. However, municipalities who offer the VUX and tailored content to reskill professionals need to prioritise individuals who are far from the labour market.

SUGGESTED ACTIONS:

- Develop fast track visa for international expertise to increase capacity.
- Usage of digital tools to make education more available.
- Academia should continuously engage in industry/academia collaboration regarding the transition/development of a sustainable battery value chain.
- Create incentives for meeting demand in the early stages of the transition towards a sustainable battery value chain, e.g., when demand is low but strategic knowledge is valuable.
- Develop a system that brings industry closer to participating in research and teaching, and support those affiliations both in short- and long-term.
- Academia needs to be able to react fast and execute on new coordinated initiatives, and with a higher degree of digital education when possible, to enable more participants.
- Financial incentives and adequate mandate to simplify the starting of and/or reintroduction of an education program and/or course.
- Higher degree of financial incentives and adequate mandates to run strategically important education programs (often with few student spots) focusing on the first steps of the battery value chain.
- Enable temporary increase of application period/student intake for targeted programs/courses to e.g., four (4) times per year instead of once a year to increase adaptability of new knowledge.

7.2.2. Different credit systems within academia

Vocational school and higher education are two siloed systems with different credit systems. This has been highlighted as a challenge by some, whilst others have been positive about the structure. Having two siloed systems makes it difficult for people to further their education after attending vocational school. Participants in the interviews raised the concern that education from vocational schools is seen as less valuable due to the different credit systems. In addition, there is no translation of credits enabling a seamless exchange between different education levels. Furthermore, there is no set standard for validating knowledge gained at vocational schools or of people working in the industry. Validating knowledge for people in need of upskilling or reskilling has been acknowledged by the European Education Area, where developments of a European standard for micro-credentials has been suggested for validating knowledge gained through shorter learning modules.

SUGGESTED ACTIONS:

- Develop standardized models for validating existing knowledge.
- Increased knowledge sharing between different education levels to strengthen education from vocational schools.
- Strengthen the image of vocational school.
- Participate in the EU initiative on the development of a common framework for micro credentials

7.2.3. Student compensation system

The financial incentive model in the Swedish education sector - also referred to as "studentpengen" - has been highlighted as challenging when specific competences or areas are being demanded from industry. Today, the enrolment capacity is “fairly distributed” between different areas of competence. Niched education programs with a low number of students are more expensive to develop and maintain than broader education programmes, one such example is education programs upstream in the battery value chain. Due to this it can be challenging to keep the education in place even though the enrolment is enough to meet the demand. It is important to acknowledge that certain education programmes might be crucial in order to build a competitive and sustainable battery value chain, even though the number of people educated is low. When considering competence and capacity, there are some areas that will require a large number of workers, such as process operators, whereas other fields require less people with more specific competence needs. Further, it will be key to understand the overall market dynamic to avoid cannibalization of neighbouring industries or deplete competences and workers from I.e., health and care institutions. Cancelling education programmes and courses could potentially lead to losing education opportunities that are or will be crucial for developing a sustainable battery value chain. One example brought up was mining education being closed in large parts of Europe, which could potentially lead to large gaps in competence in this area in the future. Consequently, teachers experience difficulties of prioritizing and matching programs and courses to the industry’s capacity and competence need due to current incentive structures in the education system. It is challenging to scale up in capacity even if the competences exist within the education sectors and there is a demand from the industry. Furthermore, the Higher Education Ordinance in 1993 reformed higher education to be based on individual choice of education rather than labour demand from the industry. There is thus an overhanging risk that courses and programs risk being cancelled, even though the industry demand is high, if student motivation to apply is low.

SUGGESTED ACTIONS:

- Government should create incentives for universities to take help/subcontract one-another for specific courses to share resources.
- Analysis of niched education necessary for the development of the battery value chain.
- Targeted funding from industry and/or government towards education demanded by industry.
- Government should ensure that universities can still conduct important courses and programs even though there are few students attending.

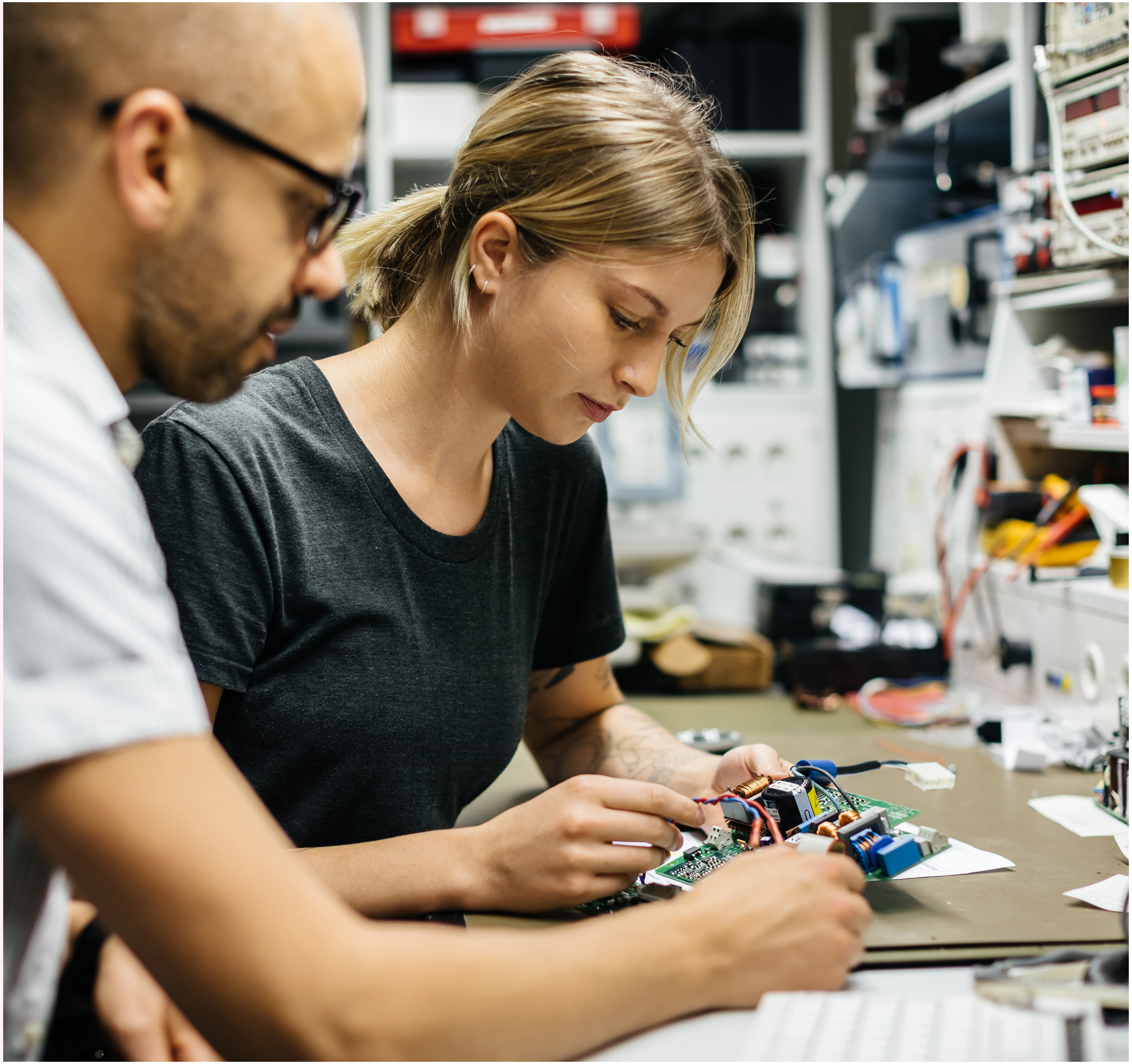
7.3. Keeping quality while increasing availability and capacity of education

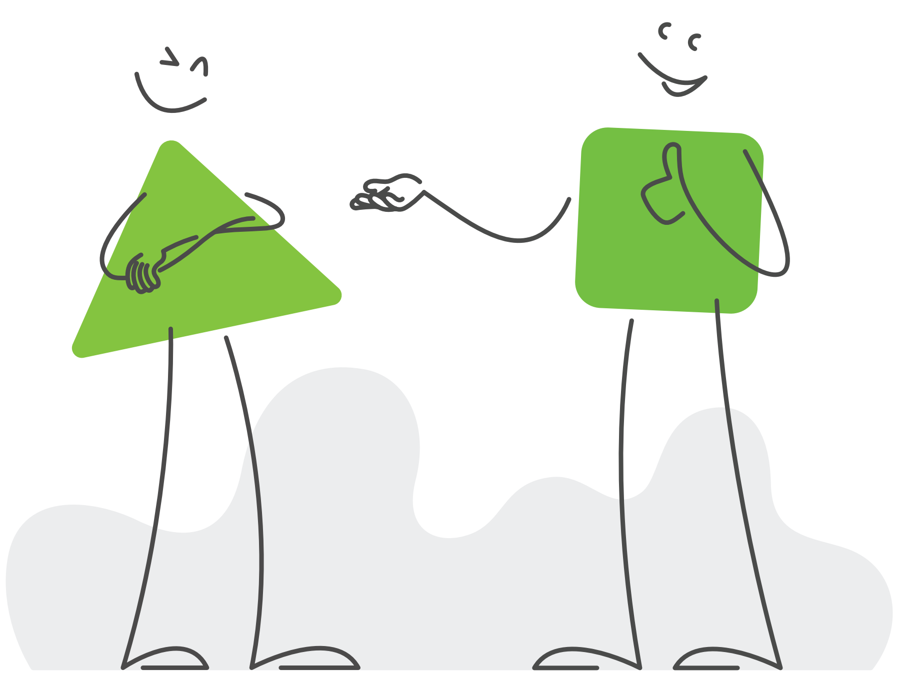
This chapter will discuss the need for increased human and structural resource effectiveness regarding upscaling education efforts whilst keeping the quality.

7.3.1. Insufficient competence management across the value chain

Sweden experiences a shortage of educational resources, not only volume but also the (right) quality/competence of teachers across the value chain. Thus, the academia is experiencing a shortage of teachers to both develop and teach programs and courses that are deemed valuable and attractive by the industry. With the fast-paced nature of battery-related research, academic scholars must spend a lot of time just to keeping up with and contributing to the state-of-the-art in research. Adding on teaching duties, this leaves little to no time for developing new course material on more elemental (but much needed) aspects of battery-related subject. In addition, several respondents within academia are experiencing an increase in administrative tasks. Collaboration between Nordic countries to (in the short-term) address the teacher gaps throughout the value chain is a plausible solution Commission training is another possible solution due to the long lead-times within academia. However, a consequence of such one-time efforts is that academia struggles to keep the competence and resources after the training program is completed.

The need for long-term investment in both research and development of education programmes has been highlighted throughout the data collection. Educating the amount of people needed for the short-term without jeopardizing on quality or knowledge retention in the long run is difficult. Projects funded for developing specific education programmes or courses are a good way of providing needed education quicker. However, universities and vocational schools have challenges maintaining and further developing the education after the project, and therefore funding, is ended. There are several reasons for this, from lack of teachers to lack of competence within the university or vocational school, which could be funded during the project period. This raises challenges in terms of keeping competence in the subject area, as well as further developing the education and related research in the field, and thereby keeping or increasing the quality. This makes it difficult to invest in education programmes that are more costly to develop and maintain (due to for example laboratory equipment or complex competence needs), since there is a risk of losing internal competence. Another stated problem is the lack of structured models for further education of teachers at different education levels.





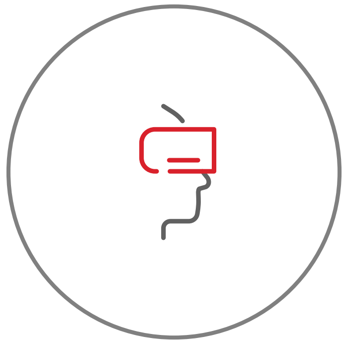
SUGGESTED ACTIONS:

- Examine possibility to involve teachers from industry in courses.
- Stimulate incentives to "train the trainer" across the value chain to distribute competences both nationally and between different education levels.
- Stimulate incentives to develop, implement, and continuously evaluate common "digital packages" of specific and certified competences/programs which are continuously updated (and connected to top research if applicable) to be distributed nationally - so that each school does not have to build up similar competences at each campus and to ensure the quality of the education.
- Develop incentives to promote the sharing and leverage of resources, such as research and innovation infrastructure, teachers, and researchers digitally.

7.3.2. Lack of research infrastructure and practical experience

Several universities pointed at a lack of laboratory capacity and/or industrial infrastructure needed for research and educating students in more practical areas related to the battery value chain. Examples of areas brought up are cell manufacturing and process chemistry. The practical experience and knowledge gained from laboratories and practice facilities are seen as highly valuable for preparing the future workforce. This applies to both vocational and higher academic education. The lack of laboratory facilities in areas such as process chemistry may be because this type of battery manufacturing is quite a new area in Sweden. Funding has been highlighted as one of the main challenges, as the establishment and maintenance of infrastructure is costly. Universities witness of laboratory equipment being sold since it is not financially possible to maintain and pay the rent for facilities. In addition, there are blank spots of the battery value chain where no economic entities are active yet. Thus, only common/public resources can be used for education. A crucial education environment may have to be created physically, virtually or shared with other countries to meet the intent to accelerate the establishment of a healthy value chain.

There are possibilities seen in collaborating with the industry in this matter. However, the challenge in this case may be that the industry needs their laboratory infrastructure for their day-to-day work tasks. If Sweden is to develop competitive competence within fields such as process chemistry, practical experience is said to be crucial. Digital solutions can also help the development of practical experience and help offload the need for physical infrastructure. One alternative is to use virtual reality (VR) solutions to develop online environments simulating industries or laboratories. It was however also highlighted that VR solutions may not be able to cover all different areas and there will most likely always be a need for practical experience, at least in the near future.



SUGGESTED ACTIONS:

- Long-term investment in industrial scale laboratory equipment/industrial infrastructure that is open and available for academia
- Investigate opportunities for industry to open their internal educational equipment to be used by students during parts of the year
- Strengthen Nordic collaboration on laboratory infrastructure
- Development of VR (virtual reality) solutions to reduce the need for laboratory equipment/industrial infrastructure. Further analyse opportunities to develop VR solutions on national, Nordic and/or European level.
  - Industry has to specify their needs and be open or agree on a level of openness about their processes and share data for accurate development of VR solutions.
  - Academia needs to increase openness and be willing to use new technologies, such as VR solutions.
  - Government needs to help with funding and hosting of a national databases for VR environments.

7.3.3. Lack of infrastructure to transfer knowledge between academia and industry

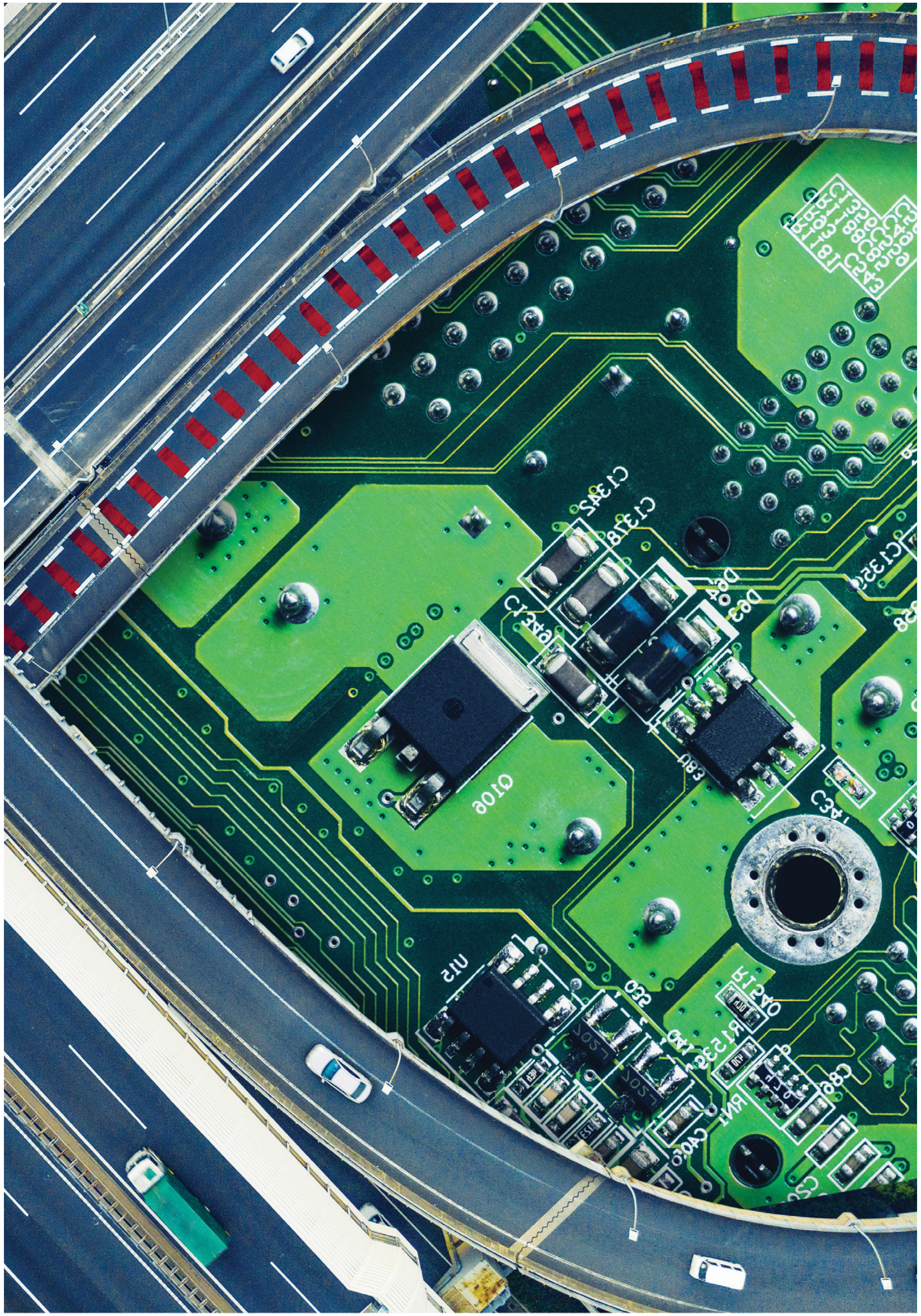
There is a lack of knowledge transfer between academia and industry. Both the competences needed for the gap and the insights on how to close the gap are spread out across different industry actors, higher education institutions, and agencies. During both interviews and the workshop, it was highlighted that there is an acute perceived shortage of both funding and long-term investments in infrastructure to foster research and innovation. It is crucial to understand the connection between research, innovation and education for a future workforce and new companies in a sustainable battery value chain. The competence needed is both new and existing knowledge, but the battery value chain is a relatively new area currently under development, and a sustainable battery value chain is adding to new competences being demanded by the industry. Given this, research is highly important for developing new competences and being in the forefront in a new industry. Funding is therefore needed for both research and for developing new education programmes and courses. It is sometimes hard to distinguish between the two areas, as the competence gained from research is to be transferred into education.

There is often a lack of infrastructure for distribution and exchange of key insights, data and knowledge derived from innovation environments to the education sector on national and Nordic level. Further initiatives to share data can be hindered if data is generated in silos or shared in separated parts of the value chain where research and innovation opportunities, as well as interdisciplinary research and education, may be missed. It is key that data is defined, structured, and available in a format which makes it useful to ensure scalability. Further, processes and methodologies need to be implemented as an integral part of ways-of-working to ensure the collection, understanding, and documentation of the type of data you manage.

Without collaboration, new research might already be old news for the industry. As resources are scarce and time is of essence, academia and industry need to have consensus of what needs to be done to ensure that academia can keep developing existing knowledge and understand future areas for competence development. Furthermore, there are only a few examples of structured collaboration and competence transfer between the university and/or industry to upper secondary school, vocational education, and adult (VUX) education. This needs to be strengthened as most of the workforce will be on the vocational level.

SUGGESTED ACTIONS:

- Need for long-term investment and continuous funding of research since its closely linked to education and the development of a future workforce in a sustainable battery value chain.
- Higher degree of knowledge sharing between industry and academia. Industry is sometimes ahead due to recruitment of (international) expertise.
- Usage of digital tools to distribute the output and key insights from innovation environments. Furthermore, implement measures to structure knowledge to increase availability and reach.
- Development of environments for sharing knowledge, such as research and competence centres. Research and competence centres need to share knowledge to a broader audience and not only between academia and industry.
- Create a coordination network with mechanisms providing merits for constructive and active participation by academia and industry.



8. Conclusions

Below follows an overview of the recommendations linked to the conclusions and proposed actions to close the competence gap. The insights have emerged from the study and should be seen as input in the continued work to close the gap and require further investigation. The actions suggested in this study are scoped to also be of relevance for other current and future technology shifts and competence transitions.

Towards a sustainable battery value chain. Developing a sustainable battery value chain is key to achieving Sweden's goal of a fossil-free welfare society, net zero emissions, and ensuring the future (sustainable) competitiveness of the Swedish industry. Hence, it is critical to ensure that the batteries themselves also become sustainable. How these batteries are designed, manufactured, and integrated into the economy will define their environmental impact for years to come. Therefore, creating a sustainable circular economy for batteries is crucial to prevent one of the solutions to the current environmental crisis from becoming the cause of another. Further, it can strengthen Swedish competitiveness by offering new pathways for dematerialized value creation (decoupling value creation from resource consumption). However, the complexity and multifaceted nature of this transition require multiple pathways to be developed in parallel. Common to all these pathways is the need for competence.

An unprecedented challenge for education. With the goal of self-sufficiency and an unbroken European (EV) battery value chain by 2025, production capacities are being built up at a rapid pace across Europe. However, as the market is still dominated by Asia, skilled workers, and competence to deliver on this goal is in short supply in Europe. In fact, the sheer volume of competence needed in such a short time, is a first for Europe's (and Sweden's) education and training ecosystem. To even be within reach to adequately scale Sweden's role in the European battery value chain, substantial efforts need to be made on multiple fronts. From reinforcing and fast-tracking existing competence supply structures to designing new flexible education programmes and strengthening Nordic collaboration.

8.1. Need for holistic understanding to make the battery value chain sustainable

While several steps of the battery value chain rely heavily on specialized knowledge, there is a strong need for holistic understanding and knowledge to safeguard the sustainability of the battery value chain. Developing individuals with systems thinking capabilities and general knowledge of the whole battery value chain, who also handle specific disciplines related to the value chain, will be crucial. This is particularly important for ensuring the circularity of the battery value chain as companies need to understand both upstream and downstream impacts of their operation and be able to adapt to new (digital) technologies and battery chemistries in the future. Apart from these general competences of circular economy, methodological and digital competence, there are two groups of competences that are seen as particularly important. The first is competences on how batteries are manufactured, function, and are integrated into different systems. The second is competences on how to increase the lifespan of batteries, enabling good recycling practices (e.g., through design-for-recycling and -disassembly) and end-of-life management. See Figure 20 for an overview of general and specific skills connected to the sustainable battery value chain.

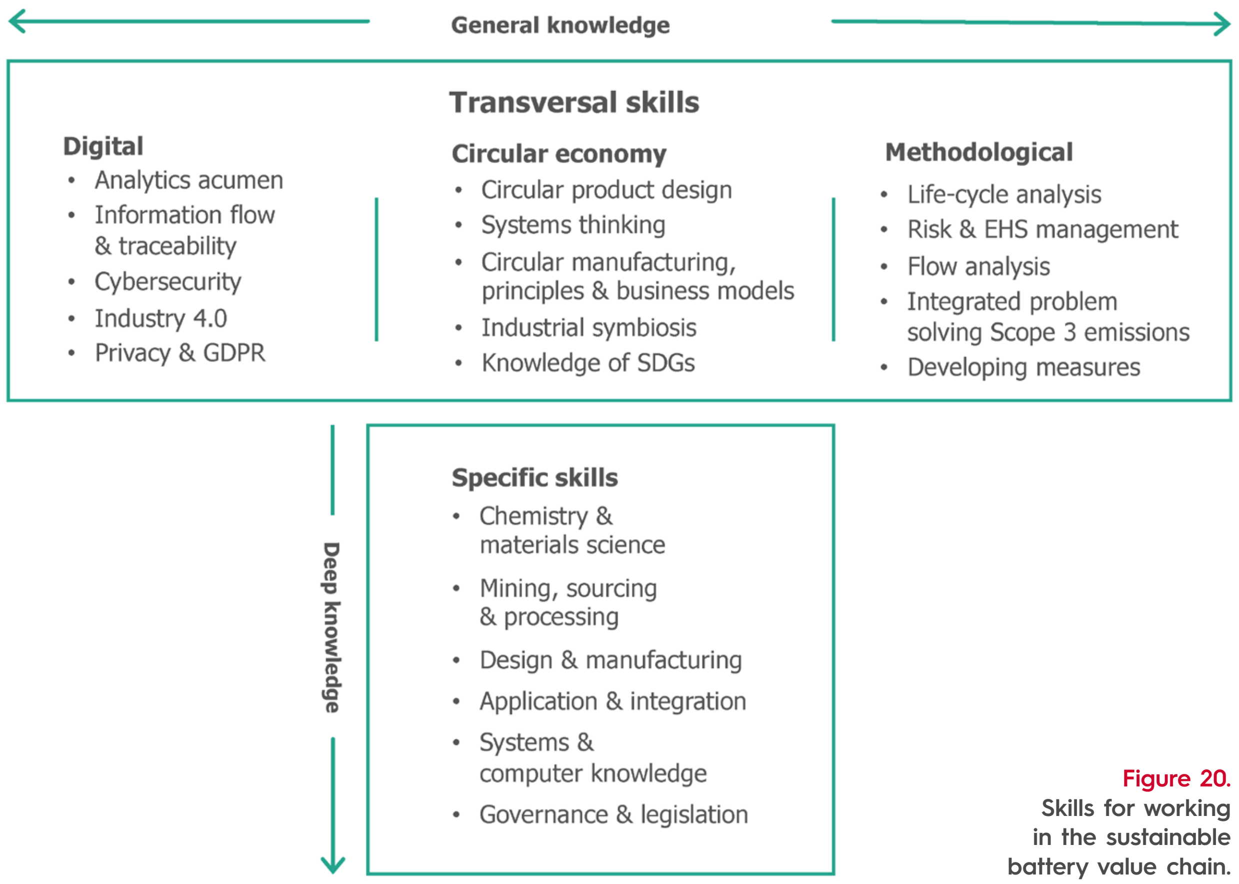


Figure 20. Skills for working in the sustainable battery value chain.

8.2. Identified challenges and actions

To develop the aforementioned skills and bridge the competence gap for battery value chain, this study points to three main areas (see Chapter 7) that need strengthening, these are:

Need for coordinated efforts for the battery value chain

a. Lack of national and Nordic coordination
b. Lack of national plan
c. Lack of interest and understanding of the battery value chain

Challenges within the education system

a. A need of a more dynamic and modular education system
b. Different credit systems within academia
c. Student compensation system

Keeping quality while increasing availability and capacity of education

a. Insufficient competence management across the value chain
b. Lack of research infrastructure and practical experience
c. Lack of infrastructure to transfer knowledge between academia and industry

Recognizing the half-life of knowledge, some of the specific subject-matter competences detailed for the sustainable battery value chain are likely to change over time. At the same time, the gap between supply and demand is already large and without action, the gap can increase. To continuously investigate and follow up the need for skills supply, national and Nordic coordination is needed in the area. The ability to deliver the competence required for change and competitiveness has a strong relationship to competence nodes for research, innovation, and demonstration. Therefore, it is justified to strengthen appropriate competence nodes and infrastructures, establish national and Nordic coordination, and promote flexibility in the education system through modular programs and increased accessibility for students and working professionals, both physical and virtual.

8.3. Potential impacts

Strengthened coordination at national and Nordic level creates the conditions for quickly bridging skills gaps along the value chain, strengthening Nordic competitive advantages and the opportunity to offer a more complete range of education in a fast and dynamic way. Furthermore, fostering a Nordic approach also strengthens research and innovation cooperation within the region and can serve as a pilot for increased international cooperation in research, innovation, and the supply of skills. Strong and competitive research and innovation environments create conditions for increased access to teachers and doctoral students with the right skills.

Developing already strong environments and organizing the development of skills as well as access to education, both physical and virtual, is crucial to meet the great demand that exists in the business community and thereby ensure Swedish competitiveness and welfare.

Creating the conditions for a modular and dynamic range of courses, which can be adapted as needed and where it is possible to move seamlessly between different levels of education will be crucial for the ability to offer students and working professionals the right education with a high degree of accessibility, regardless of geographical residence.

Increasing the share of research and innovation infrastructure as well as increasing accessibility to these environments, also for students and working professionals, greatly affects Sweden's ability to meet the need for research and innovation, but also the supply of skills. This infrastructure should be available regardless of the residence and level of education of students.

8.4. Bridging the gap

To help bridge the competence gap there is a need for long-term investment and a coordination assignment to ensure continuous support to foster a stable environment for industry and academia, which includes:

- A coordination node for the actors, strong competence nodes and business representatives, and relevant authorities in the area, to continuously develop and follow up labor and competence needs and supply, ensure coordination and accessibility from a national and Nordic perspective, and need for and accessibility to research and innovation infrastructure.

- An initial investigation regarding the need for and accessibility to research and innovation infrastructure. The inquiry shall contain prioritized actions.

- An initial investigation regarding increased accessibility and flexibility to education, including the potential and possibility of offering modular and dynamic courses. The inquiry shall contain prioritized actions.

9. References

[1] Transport Environment, «How clean are electric cars?» Available: https://www.transportenvironment.org/discover/how-clean-are-electric-cars/

[2] EIT RawMaterials and Fraunhofer , "Future experts needs in battery sector," Available: https://eitrawmaterials.eu/wp-content/uploads/2021/03/EIT-RawMaterials-Fraunhofer-Report-Battery-Expert-Needs-March-2021.pdf

[3] European Commission, "Sustainable batteries in their full life-cycle," European Union, Available: https://ec.europa.eu/commission/presscorner/detail/en/fs_20_2359. [Accessed 24 01 2022]

[4] European Commission, "Press corner: Green Deal: Sustainable batteries for a circular and climate neutral economy," European Union, 10 December 2020. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_2312

[5] European Commission, "Circular Economy Action Plan - For a cleaner and more competitive Europe," Available: https://ec.europa.eu/environment/pdf/circular-economy/new_circular_economy_action_plan.pdf

[6] Fossilfritt Sverige, "Strategi för fossilfri konkurrenskraft - en hållbar batterivärdekedja," Available: https://fossilfrittsverige.se/wp-content/uploads/2020/12/Strategi-for-en-hallbar-batterivardekedja.pdf

[7] European Commission, "Education and Skills Task Force Position Paper," Available: https://ec.europa.eu/energy/sites/default/files/documents/education_and_skills_task_force_position_paper.pdf

[8] BattKOMP, "Kompetansebehov i batteriindustrien (Norway)," 2021. Available: https://www.norskindustri.no/dette-jobber-vi-med/energi-og-klima/batteriindustrien/battkomp/

[9] ALBATTS, "Alliance for Batteries Technology, Training and Skills," Available: https://www.project-albatts.eu/en/home

[10] European Battery Alliance, "About Eba250: Value Chain," InnoEnergy, Available: https://www.eba250.com/about-eba250/value-chain/. [Accessed 24 01 2022]

[11] Nordiska Ministerrådet, "Vår vision 2030, De nordiska statsministrarna, Samarbetsministrarna," Available: https://www.norden.org/sv

[12] Energimyndigheten, "Den nordiska batterivärdekedjan," Available: http://www.energimyndigheten.se/globalassets/forskning--innovation/affu/dokument/energimyndigheten_den-nordiska-batteriervardekedjan_del-1_final-rapport_2021-02-24.pdf

[13] Business Finland, Business Sweden, Innovation Norway and EBA250 – EIT InnoEnergy, "Nordic Battery Thursdays," Available: https://nordic-battery-thursdays.b2match.io/home

[14] F. Blomsma and G. Brennan, "The emergence of circular economy: a new framing around prolonging resource productivity," Journal of Industrial Ecology, 21(3), 603-614., 2017.

[15] ISO/TC 323 Circular Economy. Available: https://www.iso.org/committee/7203984.html

[16] J. Kirchherr, D. Reike and M. Hekkert , "Conceptualizing the circular economy: An analysis of 114 definitions.," Resources, conservation and recycling, 127, 221-232., 2017.

[17] M. Geissdoerfer, P. Savaget, N. M. Bocken and E. J. Hultink, "The Circular Economy–A new sustainability paradigm?," Journal of cleaner production, 143, 757-768., 2017.

[18] Ellen MacArthur Foundation, "Towards a Circular Economy and Business Rationale for an Accelerated Transitio," Available: https://ellenmacarthurfoundation.org/towards-a-circular-economy-business-rationale-for-an-accelerated-transition

[19] Ellen MacArthur Foundation, "Growth within: a circular economy vision for a competitive Europe," Available: https://ellenmacarthurfoundation.org/growth-within-a-circular-economy-vision-for-a-competitive-europe.

[20] W. Stahel, The performance economy, 2010.

[21] Regeringskansliet, "Cirkulär ekonomi - strategi för omställningen i Sverige," Available: https://www.regeringen.se/4a3baa/contentassets/619d1bb3588446deb6dac198f2fe4120/200814_ce_webb.pdf

[22] Tillvaxtanalys, "Marknadsbarriärer för återvinning av metaller," Available: https://www.tillvaxtanalys.se/download/18.7e06da27178d7492376d597b/1624540057541/Rapport_AU_2022_03_01_Marknadsbarri%C3%A4rer_f%C3%B6r_%C3%A5tervinning_av_metaller.pdf

[23] C. Westblom, Towards a Circular Economy in Sweden-Barriers for new business models and the need for policy intervention, IEEE Master thesis, 2015.

[24] Royal Swedish Academy of Engineering Sciences, "Resource Effectiveness and the Circular Economy - Synthesis Report," Available: https://www.iva.se/globalassets/rapporter/resurseffektivitet-och-cirkular-ekonomi/202004-iva-rece-syntesrapport-english-c.pdf

[25] E. Kristoffersen, F. Blomsma, P. Mikalef and J. Li, "A digital-enabled circular strategies framework for manufacturing companies," Journal of Business Research, 120, 241-261., 2020.

[26] European Policy Centre, "The circular economy: Goind digital," 2020. Available: https://www.epc.eu/content/PDF/2020/DRCE_web.pdf

[27] European Commission, "Batteries and accumulators," Available: https://ec.europa.eu/environment/topics/waste-and-recycling/batteries-and-accumulators_en

[28] Bloomberg New Energy Finance, "Electric Vehicle Outlook 2021," Available: https://about.bnef.com/electric-vehicle-outlook/

[29] Prosess21, "Batteriverdikjeden: Prosess21 Ekspertnotat (Norway)," Available: https://www.prosess21.no/contentassets/39713b28868a41858fc2c8a5ff347c0b/prosess21_ekspertnotat_batteriverdikjeden_211220.pdf

[30] Ş. e. a. Önsel, «A new perspective on the competitiveness of nations,» Socio-Economic Planning Sciences, vol. 42.4, pp. 221-246, 2008.

[31] A. J. Smith, «The competitive advantage of nations: is Porter's Diamond Framework a new theory that explains the international competitiveness of countries?,» Southern African business review, vol. 14, nr. 1, 2010.

[32] M. E. Porter, Competitive advantage of nations: creating and sustaining superior performance., simon and schuster, 2011.

[33] E. M. Porter og M. R. Kramer, «Creating shared value,» Managing sustainable business, pp. 323-346, 2019.

[34] European Commission, "European skills agenda for sustainable competitiveness, social fairness and resilience," Available: https://ec.europa.eu/social/BlobServlet?docId=22832&langId=en

[35] A. Wiek, L. Withycombe and C. L. Redman, "Key competencies in sustainability: a reference framework for academic program development," Sustainability science, 6(2), 203-218., 2011.

[36] K. Brundiers, M. Barth , G. Cebrián , M. Cohen , L. Diaz , S. Doucette-Remington, W. Dripps , G. Habron , N. Harré , M. Jarchow and K. Losch , "Key competencies in sustainability in higher education—toward an agreed-upon reference framework," Sustainability Science, 16(1), 13-29., 2021.

[37] UNESCO, "Education for Sustainable Development Goals: learning objectives," Available: https://unesdoc.unesco.org/ark:/48223/pf0000247444

[38] NTNU, "Bærekraftig Kompetanse (Norway)," Available: https://www.ntnu.no/documents/1286373847/1289915220/FTS+delrapport+1+-+B%C3%A6rekraftig+kompetanse.pdf/d4084ed0-2220-5d9d-82ca-19cd984ded-9d?t=1593197367498

[39] Circle Economy and Goldschmeding Foundation, "Closing the skills gap: Vocational education & training for the circular economy," Available: https://assets.website-files.com/5d26d80e8836af2d12ed1269/608c0aa6fec4df0fa7bd78e4_20210422%20-%20CJI%20VET%20Paper%202%20-%20297x210mm.pdf

[40] VET Toolbox, "Transferable skills in vocational education and training," Available: https://www.vettoolbox.eu/drupal_files/public/2019-08/Transferable%20skills.pdf

[41] R. K. Yin, "Case study research and applications.," Sage, 2018.

[42] E. E. Area, «Micro Credentials,» European Education Area, 2022. Available: https://education.ec.europa.eu/education-levels/higher-education/micro-credentials. [Funnet 20 06 2022]

[43] European Training Network POLYSTORAGE;, "European platform for outstanding doctoral training in the field of innovative polymers for next-generation electrochemical energy storage," Available: https://www.polystorage-etn.eu/

[44] DESTINY, "Doctoral Programme on Emerging Battery Storage Technologies Inspiring Young Scientist," Available: https://www.destiny-phd.eu/

[45] Universitets- och högskolerådet, "Referensramar för svenska kvalifikationer och examina," Available: https://www.uhr.se/bedomning-av-utlandsk-utbildning/enic-naric-sverige/referensramar-for-svenska-kvalifikationer/

[46] Nordiska Ministerrådet, "Upper secondary education in Sweden," Available: https://www.norden.org/en/info-norden/upper-secondary-education-sweden

[47] Regeringskansliet, "Ökad validering inom komvux ska stärka kompetensförsörjningen," Available: https://www.regeringen.se/pressmeddelanden/2022/01/okad-validering-inom-komvux-ska-starka-kompetensforsorjningen/

[48] Universitets- och högskolerådet, "Det svenska utbildningssystemet," Available: https://www.uhr.se/bedomning-av-utlandsk-utbildning/enic-naric-sverige/Det-svenska-utbildningssystemet/

[49] Myndigheten för yrkeshögskolan, "För arbetslivet," Available: https://www.myh.se/yrkeshogskolan/for-arbetslivet

[50] Myndigheten för yrkeshögskolan , "Energi: Områdesanalys och inriktning I 2020," Available: https://assets.myh.se/docs/publikationer/omradesanalyser/omradesanalys-2020-energi.pdf

[51] Regeringskansliet, "Regeringen tillsätter en utredning om framtidens yrkeshögskola," Available: https://www.regeringen.se/pressmeddelanden/2021/10/regeringen-tillsatter-en-utredning-om-framtidens-yrkeshogskola/

[52] Tillväxtverket, "Strategisk kompetensförsörjning," Available: https://publector.org/publication/Strategisk-kompetensforsorjning/6.3.1_Systemhinder_for_att_anpassa_innehall_i_formella_utbildningar_efter_arbetslivets_behov_

[53] Universitets- och högskolerådet, "Examina på forskarnivå," Available: https://www.uhr.se/studier-och-antagning/tilltrade-till-hogskolan/Examina-pa-universitet-och-hogskola/Examina-pa-forskarniva/

[54] Universitetskanslersämbetet, "Vad kostar forskarutbildningen?," Available: https://www.uka.se/download/18.3834ed6a176840e14a513a67/1613994639755/Statistisk-analys-20210222-Vad-kostar-forskarutbildningen.pdf

[55] Luleå University of Technology., "Record investments in the north and the University's important role in the supply of skills," Available: https://www.ltu.se/ltu/Organisation/Rektor/blogg/Om-miljardinvesteringarna-i-norr-och-universitetets-viktiga-roll-for-kompetensforsorjningen-1.206765?l=en

[56] MindDig, "Find your Dream Job in one of the happiest places on Earth," Available: https://www.minddig.com/

[57] Universitetskanslersämbetet, “Öppna nätbaserade kurser (MOOCs) i svensk högskola,” Available: https://www.uka.se/download/18.12f25798156a345894e4c98/1487841871418/rapport-2016-01-26-oppna-natbaserade-kurser-mooc-utskriftsversion.pdf

[58] Luleå University of Technology, “Batteries for a sustainable society: from raw materials to battery cells,” Available: https://www.ltu.se/edu/course/K70/K7006K/K7006K-Batterier-for-ett-hallbart-samhalle-fran-ramaterial-till-battericeller-1.196612?l=en

[59] Uppsala Universitet, “Beräkningsmodellering av energirelaterade material,” Available: https://www.uu.se/utbildning/utbildningar/selma/kurser/?kKod=1FA662&typ=1

[60] EIT InnoEnergy, “EIT InnoEnergy online learning platform,” no. https://sea.innoenergy.com/learn

[61] Skolverket, “High School Engineer - production technique,” Available: https://www.skolverket.se/undervisning/gymnasieskolan/laroplan-program-och-amnen-i-gymnasieskolan/gymnasieprogrammen/program/gymnasieingenjor---vidareutbildning-i-form-av-ett-fjarde-tekniskt-ar?url=-996270488%2Fsyllabuscw%2Fjsp%2Fprogram.htm%3FprogramCode

[62] Uppsala Universitet, “Litium-jon-batterier - Institutionen för kemi - Ångström,” Available: https://kemi.uu.se/angstrom/forskning/strukturkemi/aabc/forskningsomr%C3%A5den/li-jon-batterier

[63] Uppsala Universitet, “Master's Programme in Battery Technology and Energy Storage,” Available: https://www.uu.se/en/admissions/master/selma/program/?pKod=T-BT2M

[64] Lunds universitet, “Miljösystemanalys, livscykelanalys,” Available: https://www.lu.se/lubas/i-uoh-lu-TFRP65

[65] Chalmers, “MicroMasters programmeme,” Available: https://www.chalmers.se/en/education/moocs/MicroMasters/Pages/default.aspx

[66] Universitetskanslersämbetet, “Kartläggning av lärosätenas uppdragsutbildningar,” Available: https://www.uka.se/download/18.464f60a6172ea-9b7ed01c4d6/1600152487684/kartl%C3%A4ggning%20av%20l%C3%A4ros%C3%A4tenas%20uppdragsutbildningar.pdf

[67] Skellefteå kommun, “Produktionstekniker Automatiserade tillverkningsprocesser,” Available: https://skelleftea.se/invanare/startsida/barn-och-utbildning/vuxenutbildning-och-hogre-utbildning/yrkeshogskolan/vara-utbildningar/produktionstekniker-automatiserade-tillverkningsprocesser

[68] Skellefteå kommun, “Batteries, Fuel Cells, and their Role in Modern Society,” Available: https://skelleftea.se/platsen/campus-skelleftea/startsida-campus-skelleftea/arkiv/utbildningar-case/2021-12-01-batteries-fuel-cells-and-their-role-in-modern-society

[69] Skellefteå kommun, “Automationsoperatör,” Available: https://skelleftea.se/invanare/startsida/barn-och-utbildning/vuxenutbildning-och-hogre-utbildning/vux/yrkesutbildningar/yrkesutbildningar/vux-utbildningar/2021-09-15-automationsoperator

[70] PROMPT, “Academic courses for industrial competence development,” Available: http://www.promptedu.se/

[71] Munkedals kommun, “Processteknik,” Available: https://www.munkedal.se/download/18.248ba3f-817924f73876357ad/1620121243242/Infoblad%20Process%202122.pdf

[72] Lund University, “Circular Economy: Sustainable Materials Management,” Available: https://www.iiiee.lu.se/moocs-iiiee/circular-economy-sustainable-materials-management

[73] Luleå tekniska universitet , “Civilingenjör Hållbar process- och kemiteknik,” Available: https://www.ltu.se/edu/program/TCKPA/TCKPA-Civilingenjor-Hallbar-process-och-kemiteknik-1.168844

[74] Hermods, “Automations- och robotingenjör med industri 4.0,” Available: https://hermods.se/utbildningar/automations-och-robotingenjor-med-industri-4-0/

[75] Creando, “Yrkeshögskoleutbildning Innehåll,” Available: https://www.creando.se/drifttekniker-processoperator/yrkeshogskoleutb/

[76] Chalmers, “News item,” Available: https://www.chalmers.se/en/centres/ccr/news/Pages/default.aspx

[77] Chalmers, “Industrial Materials Recycling,” Available: https://www.chalmers.se/en/departments/chem/research/energy-materials/imr/Pages/Industrial-Materials-Recycling.aspx

[78] Chalmers, “Circular and greener processes for Li-ion batteries recycling and production,” Available: https://www.chalmers.se/en/projects/Pages/Circular-and-greener-processes-for-Li-ion-batteries-recycling.aspx

[79] Lunds Universitet, “Vätgas, batterier och bränsleceller,” Available: https://kurser.lth.se/kursplaner/21_22%20eng/MVKP25.html

[80] Uppsala Universitet, “Syllabus for Batteries and Storage,” Available: https://www.uu.se/en/admissions/master/selma/kursplan/?kKod=1KB274&lasar=

[81] Olofström kommun, “Automations- och robotingenjör,” Available: https://olofstrom.se/utbildning-och-barnomsorg/vuxenutbildning/yrkeshogskolan-syd-olofstrom/automations--och-robotingenjor

[82] S. E. Centre, “About Us - Swedish Electromobility Centre,” Swedish Electromobility Centre, 2022. Available: https://emobilitycentre.se/about-us/. [Accessed 20 06 2022]

[83] B. Sweden, «About us - Batteries Sweden,» Batteries Sweden, 2022. Available: https://www.batteriessweden.se/about-us/. [Funnet 20 06 2022]

[84] «About Ingenjör 4.0,» Ingenjör 4.0, 2022. Available: https://www.ingenjor40.se/about-ingenjor4-0/. [Funnet 20 06 2022]

Appendix A

Ranked measures from the questionnaire

In the questionnaire the stakeholders were asked to rank European measures (identified in the literature review) on a short-, mid-, and long-term perspective and propose alternative measures were seen fit. The measures presented in this section were mainly inspired by the two reports Future Expert Needs in the Battery Sector [2] and Strategy for fossil-free competitiveness – a sustainable battery value chain [6]. The measures have been tailored to be on the same level and fit the scope of the report. This implies that some measures have been broadened to encompass one or more measures and others have been divided into more than one measure.
The sources for the measures are the following:

- The measures of ***development of research hubs close to the industry, improve attractiveness of Sweden for foreign workforce and re-skilling and re-training measures from other industries*** are a combination of measures from **both reports** [2] [6].

- The measures of ***integrate relevant battery value chain competence in existing education programmes, establish battery specific education programmes, integrate relevant circular economy competence in existing education programmes*** and ***support for in-house training measures*** were inspired by **Future Expert Needs in the Battery Sector** [2].

- The measures of ***more investment in battery value chain related research and developing mining, sourcing and processing industries*** were inspired by the report **Strategy for fossil-free competitiveness – a sustainable battery value chain** [6].

Respondents also had the opportunity to elaborate on the measures and add additional comments. **In general, these comments revolved around the following measures:**

- Important to act immediately as it takes a long time to educate students with relevant competences.

- Important to work transdisciplinary and attract and leverage research and workforce from other countries. Collaboration across borders.

- Important to understand how Sweden can contribute the most in a global perspective.

- Important for collaboration between industries and universities.

- Important to help research, innovation, and start-ups financially.

- There is a need for large up-front investments in manufacturing equipment etc. to help catalyse the initial growth phase.

- Development of AI/robots for recycling/battery dismantling.

Short term (2022-2025)

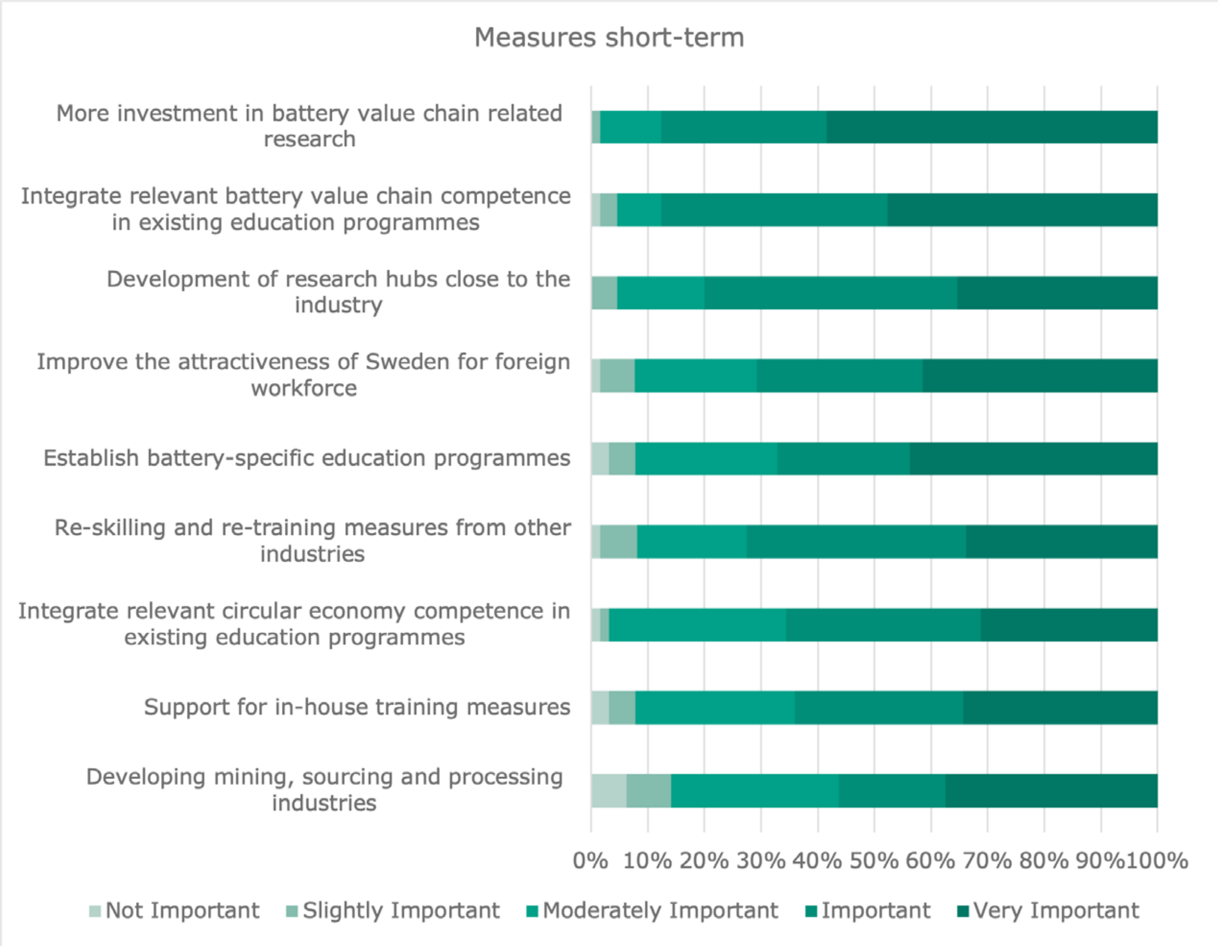


Figure 21.
The importance of different measures in the short-term (2022-2025) for a sustainable battery value chain is based on the answers from the questionnaire.

The measures *more investment in battery value chain related research* (4,45), *integrate relevant battery value chain competence in existing education programmes* (4,29) and *development of research hubs close to the industry* (4,11) are seen as the most important measures in the short-term for creating a sustainable battery value chain.

IMPLICATIONS AND CONCRETE STATEMENTS:

+ The three most important measures are:

1. More investment in battery value chain related research
2. Integrate relevant battery value chain competence in existing education programmes
3. Development of research hubs close to the industry

- The three least important measures are:

1. Developing mining, sourcing and processing industries
2. Support for in-house training measures
3. Integrate relevant circular economy competence in existing education programmes

IN ADDITION TO THE SUGGESTED MEASURES PRESENTED ABOVE, THE FOLLOWING MEASURES WERE SUGGESTED FROM THE INDUSTRY FOR THE SHORT-TERM:

- Further education for engineers to develop competences needed for the battery value chain
- Educating people with both knowledge of patent law and strategy and the battery value chain
- Life-long learning for people working in the battery value chain.
- Better cooperation between the industry, education and politics
- Sweden's attractiveness is not a large problem, but rather a problem with permits and migration
- Important to support research and open innovation. Important in the short-, mid- and long-term.
- As things move so quickly, short-term can be seen as "what happened yesterday"

Mid-term (2025-2030)

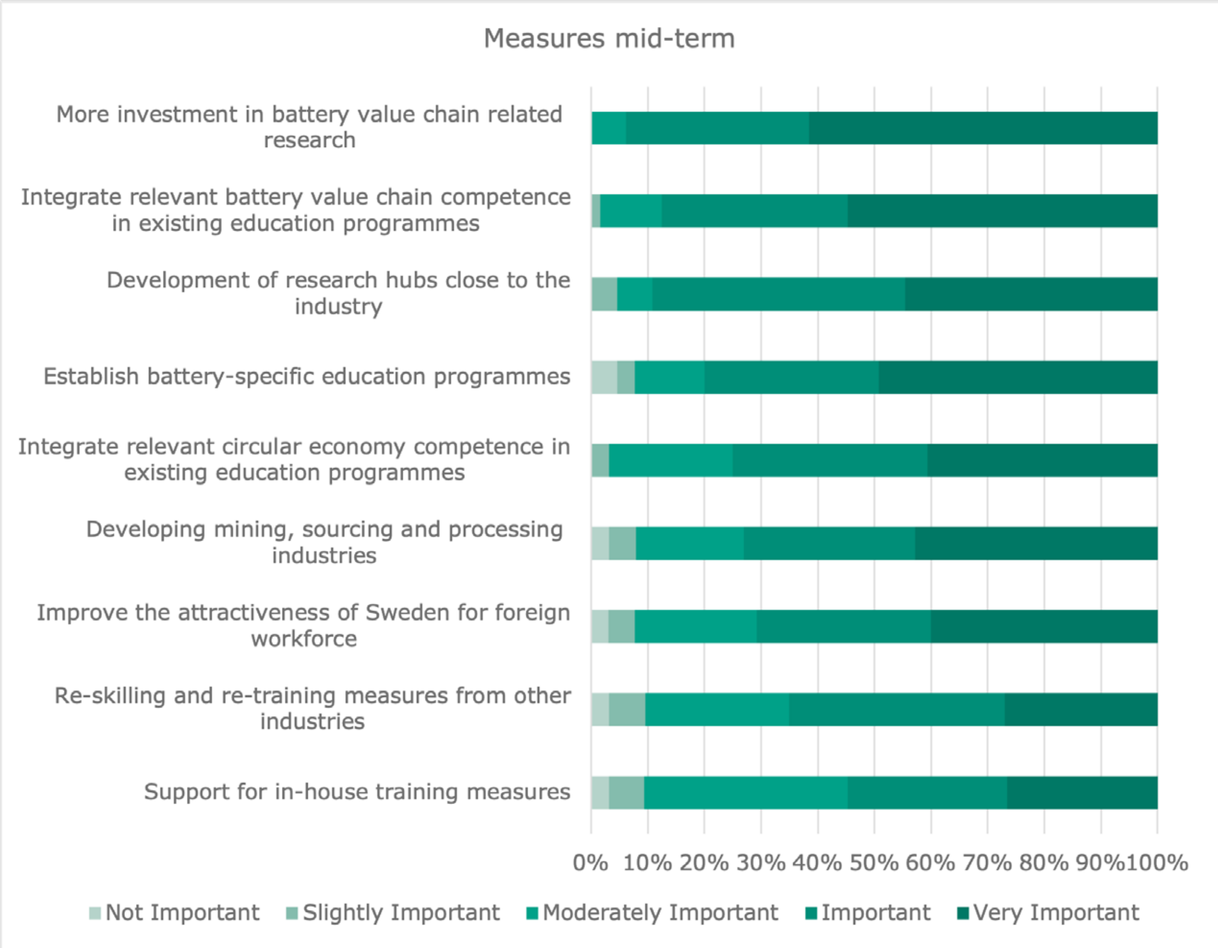


Figure 22.
The importance of different measures in the mid-term (2025-2030) for a sustainable battery value chain is based on the answers from the questionnaire.

The measures *more investment in battery value chain related research* (4,55), *integrate relevant battery value chain competence in existing education programmes* (4,41) *and development of research hubs close to the industry* (4,29) are seen as the most important measures in the mid-term for creating a sustainable battery value chain. These are the same as for the short-term and they have all increased in importance with *development of research hubs close to the industry increasing the most* (+0,18).

IMPLICATIONS AND CONCRETE STATEMENTS:

+ The three **most important** measures are:

1. More investment in battery value chain related research
2. Integrate relevant battery value chain competence in existing education programmes
3. Development of research hubs close to the industry

- The three **least important** measures are:

1. Support for in-house training measures
2. Re-skilling and re-training measures from other industries
3. Improve attractiveness of Sweden for foreign workforce

Long-term (2030+)

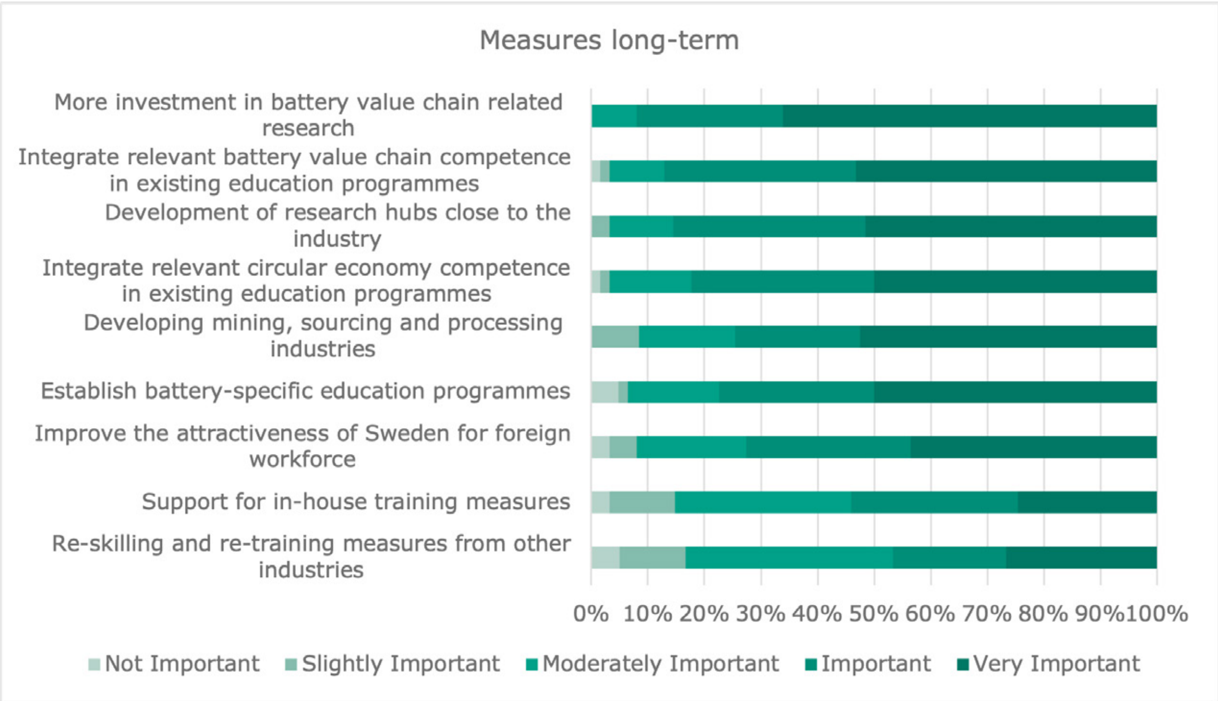


Figure 23.
The importance of different measures in the long-term (2030+) for a sustainable battery value chain based on the answers from the questionnaire.

The measures *more investment in battery value chain related research* (4,58), *integrate relevant battery value chain competence in existing education programmes* (4,35) and *development of research hubs close to the industry* (4,34) are seen as the most important measures in the long-term for creating a sustainable battery value chain. These are the same as for the short-term and the mid-term. The importance of *investment in battery value chain related research and development of research hubs close to the industry* both increased by 0,03 and 0,05, respectively. Whilst *integrate relevant battery value chain competence in existing education programmes* decreased by 0,06.

IMPLICATIONS AND CONCRETE STATEMENTS:

+ De tre **viktigaste** åtgärderna är:

1. More investment in battery value chain related research
2. Integrate relevant battery value chain competence in existing education programmes
3. Development of research hubs close to the industry

- The three **least important** measures are:

1. Re-skilling and re-training measures from other industries
2. Support for in-house training measure.
3. Improve attractiveness of Sweden for foreign workforce

IN ADDITION TO THE SUGGESTED MEASURES PRESENTED ABOVE, THE FOLLOWING MEASURES WERE SUGGESTED FROM THE INDUSTRY FOR THE LONG-TERM:

- Development of simulation-based education
- High school education programmes do not have to be industry specific. It is important to focus on developing generalists (that specialise in specific subjects) to cope with the expected technological development.
- Long-term flexible competence needs to be developed to enable a sustainable battery value chain.

Appendix B

Key competences for sustainability

Descriptions from [38].

Systems thinking competency
the abilities to recognize and understand relationships; to analyse complex systems; to think of how systems are embedded within different domains and different scales; and to deal with uncertainty.

Anticipatory competency
the abilities to understand and evaluate multiple futures – possible, probable and desirable; to create one's own visions for the future; to apply the precautionary principle; to assess the consequences of actions; and to deal with risks and changes.

Normative competency
the abilities to understand and reflect on the norms and values that underlie one's actions; and to negotiate sustainability values, principles, goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions.

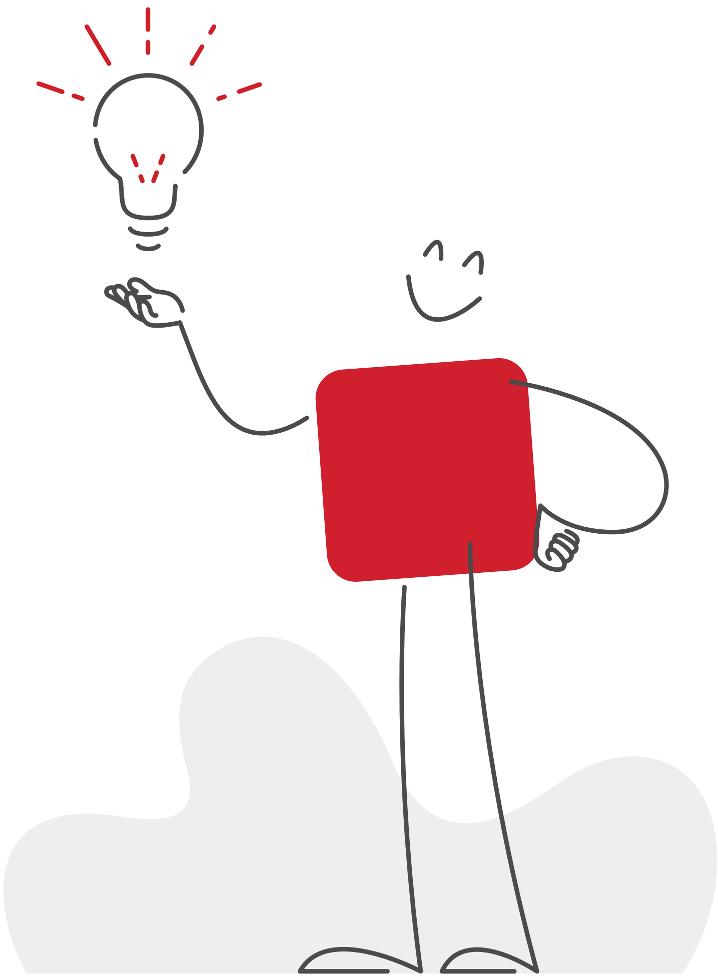
Strategic competency
the abilities to collectively develop and implement innovative actions that further sustainability at the local level and further afield.

Collaboration competency
the abilities to learn from others; to understand and respect the needs, perspectives and actions of others (empathy); to understand, relate to and be sensitive to others (empathic leadership); to deal with conflicts in a group; and to facilitate collaborative and participatory problem solving.

Critical thinking competency
the ability to question norms, practices and opinions; to reflect on own one's values, perceptions and actions; and to take a position in the sustainability discourse.

Self-awareness competency
the ability to reflect on one's own role in the local community and (global) society; to continually evaluate and further motivate one's actions; and to deal with one's feelings and desires.

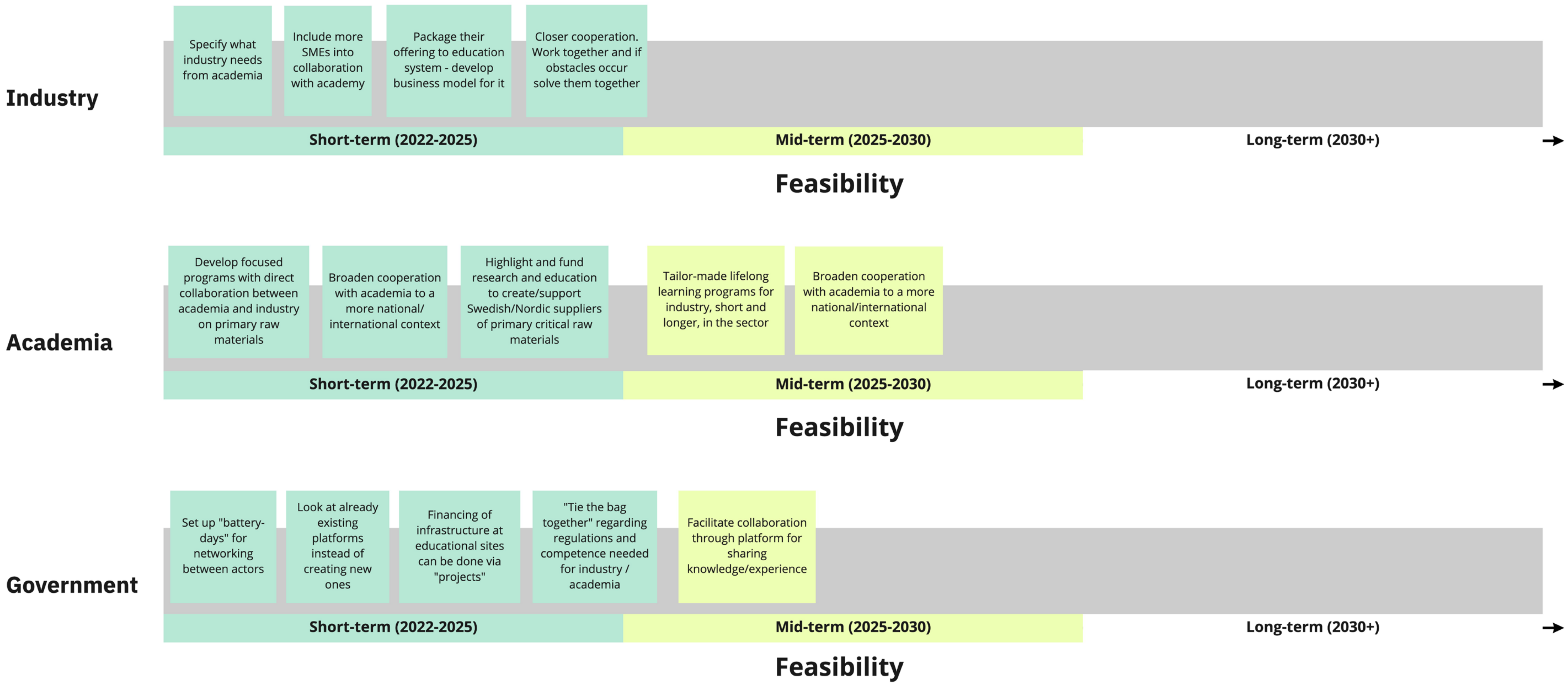
Integrated problem-solving competency
the overarching ability to apply different problem-solving frameworks to complex sustainability problems and develop viable, inclusive and equitable solution options that promote sustainable development, integrating the above-mentioned competences.



Appendix C

Prerequisite actions and responsibilities

Create prerequisites for industry to share experience/ knowledge with academia



Usage of virtual reality (VR) solutions (online simulated environments) for practical experience (e.g., laboratory)

Industry

Short-term (2022-2025)
- 'Wish list' from industry on competence, skills and infrastructure
- Share data to build reality solutions
- Contribute to co-finance these environments

Mid-term (2025-2030)
- Use VR applications also for recruitment
- Industry has to agree to be open about their processes
- Industry should let VR creators use their digital twins

Long-term (2030+)
- Have digital twins as "everything" both in training platforms and in operation

Feasibility

Academia

Short-term (2022-2025)
- Academia should (to a larger extent) integrate new ICTs in teaching
- Better collaboration between VR departments and "other" departments that need the tools

Mid-term (2025-2030)
- Industry VR environments should align with academia for students to better meet competence requirements in industry
- More collaboration between national and international VR environments

Long-term (2030+)

Feasibility

Government

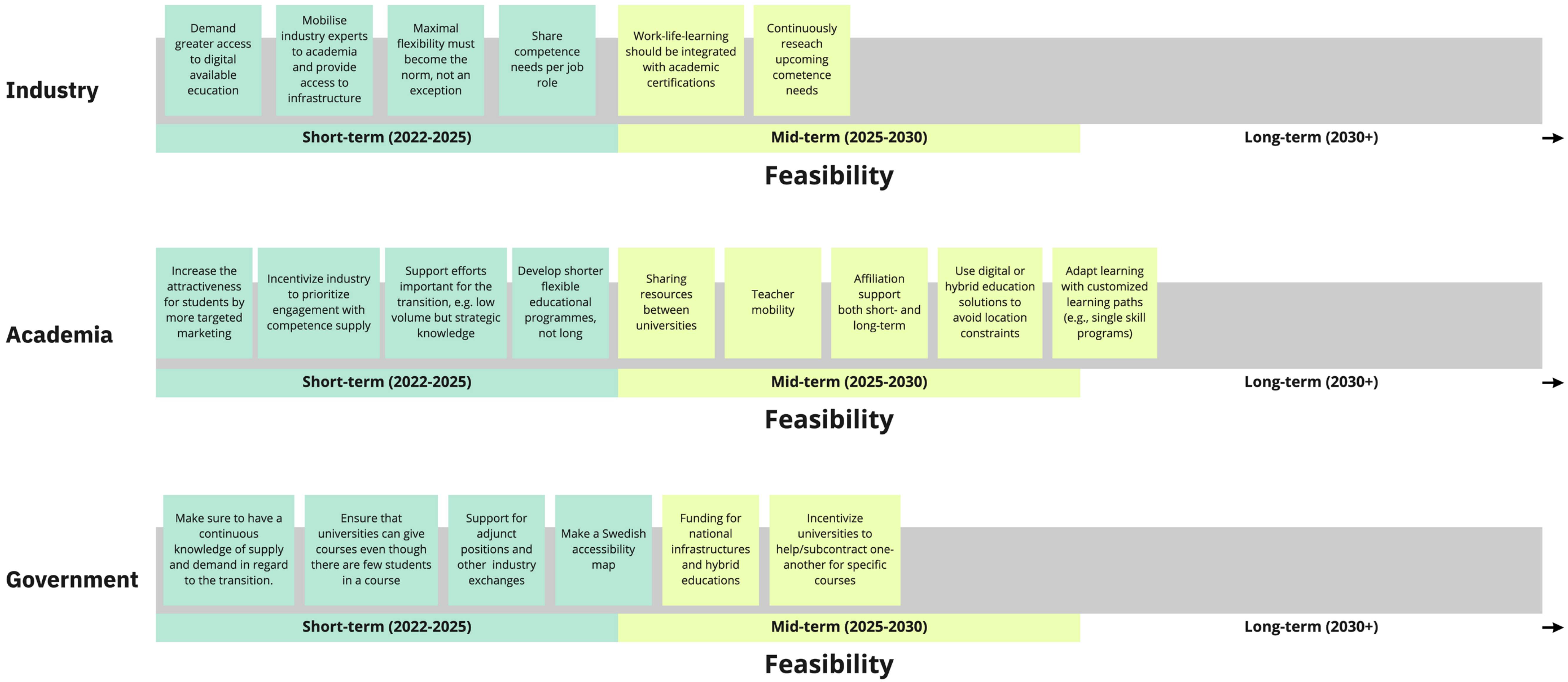
Short-term (2022-2025)
- Include VR in a national strategy for education in the battery value chain
- Develop a more data driven approach to tackle the transition
- Monetary support to co-finance VR tools and apps

Mid-term (2025-2030)
- Should get IPCEI to finance
- Fund development of a national database/center of VR environments
- Dedicated national funding schemes for development of VR solutions

Long-term (2030+)

Feasibility

Development of a flexible education system to cope with the fluctuation of supply/demand of the market for different competences



Development of a flexible education system to cope with the fluctuation of supply/demand of the market for different competences

Industry

- Demand greater access to digital available ecucation
- Mobilise industry experts to academia and provide access to infrastructure
- Maximal flexibility must become the norm, not an exception
- Share competence needs per job role
- Work-life-learning should be integrated with academic certifications
- Continuously reseach upcoming cometence needs

Short-term (2022-2025) | **Mid-term (2025-2030)** | **Long-term (2030+)** →

Feasibility

Academia

- Increase the attractiveness for students by more targeted marketing
- Incentivize industry to prioritize engagement with competence supply
- Support efforts important for the transition, e.g. low volume but strategic knowledge
- Develop shorter flexible educational programmes, not long
- Sharing resources between universities
- Teacher mobility
- Affiliation support both short- and long-term
- Use digital or hybrid education solutions to avoid location constraints
- Adapt learning with customized learning paths (e.g., single skill programs)

Short-term (2022-2025) | **Mid-term (2025-2030)** | **Long-term (2030+)** →

Feasibility

Government

- Make sure to have a continuous knowledge of supply and demand in regard to the transition.
- Ensure that universities can give courses even though there are few students in a course
- Support for adjunct positions and other industry exchanges
- Make a Swedish accessibility map
- Funding for national infrastructures and hybrid educations
- Incentivize universities to help/subcontract one-another for specific courses

Short-term (2022-2025) | **Mid-term (2025-2030)** | **Long-term (2030+)** →

Feasibility

Platforms (e.g., kompetensmatchning.se) that visualise available educations connected to the industry (demand)

Industry

- Map current and future competence and volumes (national and international)
- Agreement on what should be solved by industry vs education
- Industry-academia collaboration for targeted upskilling
- Willingness to further educate employees
- Sweden has a lot of manufacturers of yellow machines. Technology step is very challenging due smaller company's with low volume

Short-term (2022-2025) | **Mid-term (2025-2030)** | **Long-term (2030+)** →

Feasibility

Academia

- Increase flexibility and reaction speed for new initiatives with digital tools
- Local anchoring where labor is needed
- Basic course (for lower levels) in electric drivelines, battery systems etc.
- Possibility to get APIs so that info from the publicly funded system can be loaded

Short-term (2022-2025) | **Mid-term (2025-2030)** | **Long-term (2030+)** →

Feasibility

Government

- Focus resources and efforts on a clear group, which is more industrially oriented than academic
- Funding & government assignments

Short-term (2022-2025) | **Mid-term (2025-2030)** | **Long-term (2030+)** →

Feasibility

National plan and strategy for how battery-related competences should be developed