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Critical electromobility milestones: learnings from a triple helix workshop in Sweden

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Executive Summary

This paper reports the results of an extensive workshop conducted with the Swedish Electromobility Centre partners network and other relevant participants in the electromobility ecosystem. The purpose of the workshop was to identify the most critical milestones necessary for electrifying the transport system. The results give a unique insight of the perspectives of a wide array of stakeholders, experts and decision makers at the forefront of electromobility in one of the leading markets in the world, Sweden. Thirty-three key milestones were selected and clustered into twelve different groups within three broad areas: vehicle, infrastructure and production. Furthermore, an indicative timeline for these milestones was drawn up to 2050.

Keywords: trends and forecasting of e-mobility, electric vehicles, supply and value chain, environmental impact, smart grid integration and grid management

1 Background

Sweden is a small country of approximately 10 million inhabitants. Despite its small size Sweden have played an outsized role in the development of electromobility. In 2023 the market share for EVs (BEV and PHEV) reached close to 60 % [1]. Extensive periods of high EV market shares in Sweden have meant that EVs now make up approximately 13 % of the total passenger vehicle fleet [2]. In addition, Sweden plays an important role in the European automotive development by being the home base for several large and leading automotive OEMs and suppliers, with extensive R&D conducted locally. For example, Volvo Group and Scania offer electric medium and heavy electric trucks developed in Sweden in several different freight applications. Volvo Cars are one of the market leaders in passenger electric vehicles with a significant sales share for both Plug-in Electric Vehicles (PHEV) and Battery Electric Vehicles (BEV), many of which have been developed in Sweden. Moreover, Sweden has traditionally been strong in the development of electric power technology, with companies like ASEA (later ABB) and Vattenfall. This, together with a very open and collaborative research environment, and generous public research funding programmes by organizations like the Swedish Energy Agency and the Swedish Innovation Agency, have gained Sweden a leading position in the development of electromobility technology and in research aimed at understanding continuous market diffusion of EVs.

The Nordic countries have traditionally exhibited a high acceptance for new technologies, especially if they align with sustainability goals and help in addressing societal challenges such as climate change and urbanization. This is reflected in for example that Sweden, Denmark and Finland consistently ranks at the top in the Digital Economy and Society Index (DESI) [3]. Additionally, these countries have had, and continue to possess, a high environmental awareness, with a large majority of their citizens acknowledging the importance of environmental protection, resulting in progressive environmental policies on emissions, renewable energies, waste reduction and green transportation.

Situated in the middle of this vibrant eco-system for electromobility in Sweden and the larger Nordic region is the Swedish Electromobility Centre (SEC) [4]. SEC is a national competence center that focuses on advancing electromobility technologies for road, rail, air and maritime transport, with the aim of accelerating the transition to an electrified transport system. SEC was established in 2007 to foster collaboration between academia, industry, and the public sector. With 28 partners currently, SEC comprises the most prominent Swedish universities (e.g. Chalmers, The Royal Institute of Technology KTH, and the universities of Linköping, Lund and Uppsala), research institutes (e.g. Research Institutes of Sweden RISE and The Swedish National Road and Transport Research Institute VTI), as well as the most relevant industrial actors within electromobility (e.g. Volvo Group, Volvo Cars, Scania and Zeekr).

Today, SEC is the main knowledge hub for electromobility in Sweden. The research conducted at the Center spans over multiple disciplines, both technical, such as batteries, power electronics and electrical machines, and social, like user acceptance, policies and incentives. As the Centre evolves, new partners are added to cover new research areas. This unique combination of partners in SEC as well as the context of being in a leading electromobility market ensures that the research produced stays current and relevant.

This paper discusses the results of an extensive workshop that was held among the SEC network of partners and other relevant participants in the electromobility ecosystem in Gothenburg, Sweden, in March 2024. The workshop was designed to co-develop the most critical milestones necessary for electrifying the transport system. The results give a unique insight of the perspectives of a wide array of stakeholders, experts and decision makers at the forefront of electromobility in Sweden.

2 Method

To identify the milestones needed for guiding large-scale implementation of electromobility the center planned and conducted a large cross-thematic workshop engaging senior experts from industry, academia and government organizations. As the center gathers all the main actors in the field in Sweden, these experts represent the leading Swedish competence in the area of electromobility.

Fifty-eight participants attended the workshop, a majority coming from academia (59 %) followed by industry (37 %) and then other actors. The participants were given the task of back cast what needs to happen and when, to achieve the following hypothesizes for the future:

- The sustainable transport of the future will require that a large part of / all the transport system will be electrified.
- Swedish actors have contributed to this process, for it to happen in a meaningful way. Sweden stands strong within electromobility.
- Where electrification is the optimal solution, it is implemented in the best way.

The result of this workshop was a compilation of milestones, reflecting the participants view on what needs to be achieved to reach sufficiently widespread electrification to reach goals on sustainable transport by 2050.

The workshop started with a positive and open-minded discussion to generate first iterations of milestones in ten smaller groups of about 6 people in each, based on the participants' expertise. The groups were then re-arranged to foster cross-disciplinary discussions, aiming to prioritize and describe the milestones in more detail. The milestones were mapped on a physical wall mounted timeline. One representative from each group presented their group's most prioritized milestones. Thereafter a final selection of milestones was selected by voting among all participants in the workshop. Following the workshop, strategic research leaders and the Center's management processed the outcome, compiled definitions, and refined the timeline. At a follow-up meeting, the processed results were presented. Further detailing, descriptions and timing were made in joint discussions, resulting in the definitions and timeline presented in this paper.

Figure 1: Photos from the workshop showing one of the groups working (top) and the wall with milestones before aggregation (bottom). Photo: Marcus Folino

3 Results

The process resulted in thirty-three milestones that have been clustered into twelve different categories within three broadly defined areas: vehicle, infrastructure and production and resources, as illustrated in Fig. 1. The resulting twelve categories are briefly described below, including proposed milestones in each of them.

The vehicle area involves the whole vehicle; the onboard vehicular systems and components, and relates to total cost of ownership, recyclability, efficiency etc. The infrastructure area involves the infrastructure needed to support a growing fleet of electric vehicles: charging infrastructure, communication protocols and the electric power grid. The production and resources area deals with supply chain, manufacturing, competence and working conditions.

3.1 Vehicle

- **Affordable EVs:** Affordability is a key factor to enable diffusion of EVs. A crucial component of affordability is Total cost of ownership (TCO), but purchase price is also important for consumer acceptance. TCO for EVs should or need to be comparable to or preferably lower than equivalent Internal Combustion Engine Vehicles (ICEV). Achieving lower or equivalent TCO can be completed in several ways. For example, through scale economies in production driven by increase in demand and government incentives. These incentives can target multiple aspects, including support for EV adoption, increased costs/taxes on fossil fuels, road taxes and support for industry to compensate for investments and higher production costs. Affordability for consumers must also be combined with profitability for actors within the vehicle value stream, such as OEMs and suppliers, in order to reach long term economic sustainability in vehicle production.

Included milestones:

- Make sure it's profitable to transition
- Cost and performance shouldn't be a barrier for EV adoption.

- **Reliable EVs:** High reliability is an important factor for gaining the public's trust in e-mobility systems. One important aspect of reliability for EVs is trust that the vehicle can perform the users expected operating range. One plausible solution is for automotive OEMs to communicate the lowest guaranteed range in the extreme ends of the temperature range for a fully charged vehicle. Ideally this should take into account the different stages in the vehicle's lifetime and apply realistic trip use cases. Failure to provide reliable operating range estimates to consumers could lead to poor consumer experience. In addition, estimates of EV and its components' longevity ought to be improved. This requires battery health management systems and systems for other components that enable predictive maintenance and history and estimate lifetime to support, use, re-use (second life) and recycling. Steps to achieve this are safety certification of energy storage systems, onboard system for storing anonymized vehicle data, and standardization of parameters to record.

  Included milestones:

  - Certification and prognostics of components for e-mobility
  - Reliable operation range in extreme temperature

- **Resource-effective EVs:** There is a need to improve the resource efficiency of EVs. Resource effective EVs should have high efficiency in terms of material and energy turnover but are also designed as "fit for the purpose". The design process is not just related to the properties of the material and functions of components, but also to the entire life cycle including production and circular strategies for material flows with possibilities to maintain in use for as long as possible, reuse parts and recycle materials to high quality secondary inputs. There needs to be sustainability ratings that cover resource use and the impact on climate, as well as other environmental impacts, and social aspects. Fit for the purpose relates to specifying vehicles to the actual needs of users, which often would entail smaller and more resource efficient vehicles.

  Included milestones:

  - Standardized tools/labels for rating "EV sustainability" established in EU
  - Vehicle "sustainable value chain" – both upstream and downstream – established as industry practice
  - "Rightsizing" of vehicles established as an industrial best practice

- **Recyclable EVs:** Metals and minerals which are critical and strategic for coming generations of EVs, with special attention to battery cells and other parts of the electric powertrain, must be recycled to secure secondary resources and overall circularity. There is a need to identify knowledge gaps, design lock-ins, and bottlenecks in the complete life cycle of EVs which can be addressed through technology advances, regulation and market mechanism.

  Included milestones:

  - Incentives for recycling of key electric drive train components
  - Sufficient recycling of critical and strategic EV materials in Europe to handle European demand
  - Vehicles with "design for full recyclability" showcased in industry
  - Full recyclability of key electric drive train components established as an industrial best practice

3.2 Infrastructure

- **Robust power grid:** As EVs become more popular, new strategies to handle the extra strain on the power grid are needed. Grid reinforcements will likely be required at different voltage levels, together with grid support services to help maintain grid stability. Local grid management plays an important part in a robust power grid.

  Creating market platforms for trading flexibility, energy, and grid support services will encourage efficient energy use. Establishing communication standards will be necessary. Incentivizing smart charging can encourage consumers to adjust their charging habits to benefit the local grid. This includes promoting vehicle-to-home (V2H), vehicle-to-building (V2B), and potentially vehicle-to-grid (V2G) technologies. Providing educational resources and fostering new business models within local grids will empower consumers and communities.

  In the long run, the power grid will consist of integrated smart distribution systems, such as microgrids, resulting in higher robustness and flexibility and allowing for better prediction of energy demands.

  Included milestones:

  - Enhance grid stability through physical grid reinforcements and smart grid management
  - Establish market platforms/mechanisms for trading flexibility, energy and support services
  - Enforce mandatory grid capacity for residential buildings to accommodate charging needs and promote local grid management
  - Evolve towards a cellular power grid with model-based control on all levels

- **Accessible and reliable charging infrastructure:** The charging infrastructure needs to be flexible, reliable, available, of high quality, user friendly, accessible for all, and robust. High-power charging stations for road vehicles will continue to be deployed on main Swedish corridors according to the objectives set by EU regulation AFIR for 2025, 2027, 2030 and 2035. Appropriate charging infrastructure is likely a more important mental enabler to reach "full EV deployment" compared to a 1000 km range EV.

  All (relevant) vehicle types must have access to sufficient charging power when needed. A real-time updated central database of the available charging infrastructure and their operational status is needed, especially for commercial transport. To maximize the potential for electric vehicles to contribute towards a more robust power grid, bidirectional charging should be enabled on all relevant charging points.

  Included milestones:

  - High power public charging infrastructure
  - Accessible and reliable charging infrastructure everywhere

- **Standardized communication:** Communication between vehicles and infrastructure needs to be in place to offer efficient transport solutions for individual vehicles, fleets and charging station operators. Moreover, business models for charging and flexible customer services require information, and the system needs to be transparent.

  Communication protocol needs to be decided, and standards implemented on how and what information should be shared between different actors and technologies. This includes technologies within smart and bidirectional charging, as well as standards for vehicle to vehicle and vehicle to infrastructure communication.

  Included milestones:

  - Smart charging equipment
  - Standardized charging software interface
  - Standards and regulations for energy in bidirectional charging systems
  - Standardized communication protocols

- **Effectively integrated EVs in the grid:** All new EVs should be integrated with the electric power grid and considered as an active resource in the grid. EVs can help integrate renewable energy sources and contribute to an efficient utilization of the power grid. This is achieved by appropriately controlled charging and discharging, that matches the needs and conditions in the grid.

  Included milestones:

  - Deep integration of vehicles in the electric power infrastructure
  - Each additional EV sold has a neutral or positive effect on grid stability and resilience

3.3 Production and resources

- **Sufficient competence supply:** Access to competence in the whole value chain for e-mobility is crucial for accelerating the transition. The systems are all interlinked in the transition and therefore specific competences needed range from the supply chain of products and the infrastructure needed to the adoption of technology. Competence is hence needed in a wide variety of areas: production, policymaking, academia as well as society as a whole.

  There are several key areas that deserve special focus. Engineering and engineering education is crucial but also other professions and connected training such as electricians, policy makers and industry workers are vital for the transition. Reeducation of workers and worker mobility, from both within Sweden and in attracting international talent will be necessary to fill the competence supply.

  Finally, society as a whole, including citizens, users, and customers' needs to be informed about the consequences of their mobility consumption.

  Included milestones:

  - Increase competence for both professionals and consumers and sufficient competence supply to cover the needs of industry

- **Healthy working conditions:** Sustainability ratings cover resource use, the impact on climate, as well as other environmental impacts, and social aspects. Healthy working conditions is an area related to extraction and processing of raw materials needed for electromobility. This milestone is furthermore connected to two of the UN Sustainability development goals (SDGs); SDG 3 Ensure healthy lives and promote well-being for all at all ages; and SDG 8 Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.

  Included milestones:

  - "Vision Zero" for health impacts and compliance with human rights in the mineral resource supply chain
  - Standardized tools/labels for rating "EV sustainablity" established in EU
  - Vehicle "sustainable value chain" – both upstream and downstream – established as industry practice

- **Self-sufficient semi-conductor production:** Semiconductors are vital for all electrification and there is a need to break the dependence on external production and development. Covid-19 and the Suez Canal tanker accident are examples of how the global trade system can be disrupted.

  Included milestones:

  - Strong commitment for investing in semi-conductor competence, development and research
  - Increase semi-conductor manufacturing in Europe

- **Self-sufficient battery production:** Self-sufficiency in batteries requires a fully European-based supply of mineral resources, material production, refining facilities, and cell production. Vital cell production expertise, that meets the industry needs, can be secured through the education of battery master students and engineers. Mineral resource extraction capacity must match the cell production capacity.

Included milestones:

- Material production and refining facilities in Europe
- Sufficient knowledge of battery cell production to meet industry needs
- Mineral resource supply capacity meets cell production capacity
- Local production of batteries in Europe meets 100% demand to EV fleet

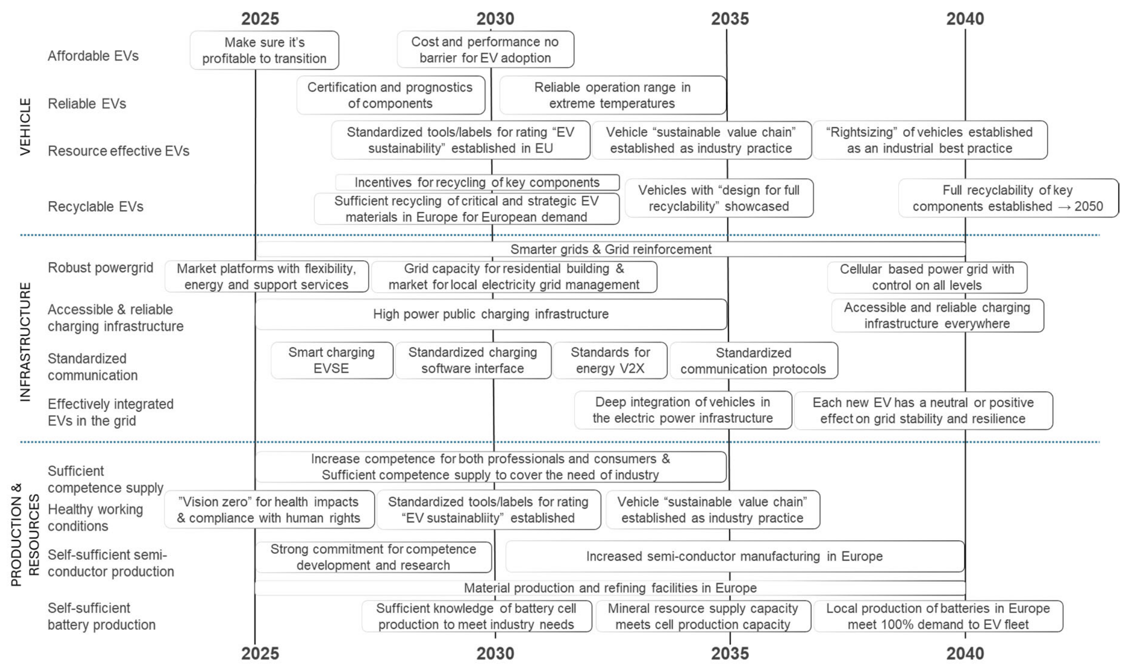

Figure 2: Thirty-three milestones were selected and clustered into twelve different groups within roughly three defined areas. The right end of each milestone box represents the time the milestone is expected to be reached, the length of the box indicates ongoing work to reach the milestone.

4 Reflections and Discussion

Sweden is one of the leading e-mobility countries in the world, with a unique combination of high EV uptake, active government participation, extensive academic research and a significant home-grown automotive industry. The only other country in the world that combines these properties, other significant differences aside, is probably China. This blend of market maturity, research, policy and industry was well represented in the workshop reported in this paper. In this section, the authors of this paper discuss how the method (the workshop process) may have influenced the results. Moreover, they provide their own reflections on the value and further validity of the results in light of recent global developments.

The workshop presented in this paper has created value in two ways: first, by creating a unique occasion for many different experts to work together, fostering active participation and in-depth discussions that hardly happen otherwise in their daily work. Secondly, by delivering a set of milestones on a timeline, the workshop has contributed to a better understanding of the needs in the area. This has been valuable both for SEC and the entire ecosystem of actors within electromobility in Sweden, providing an anchored strategy for the future which will help identifying interesting research questions, as well as setting the grounds and directions for future development within industry, academia, policy, etc. The timeline with its milestones has also been a valuable basis for international discussions about the conditions and priorities of different countries.

4.1 The method's impact on the result

4.1.1 Framing the study: the importance of the initial hypothesis

The process may have affected the results in different ways. A first reflection is that the presented hypothesis (see section 2) likely had a large influence on the discussions at the workshop. This hypothesis was formulated by the SEC management team consisting of researchers from the center´s academic partners.

The first statement of the hypothesis claims that a sustainable transport system will require a “a large part of / all” transport being electrified. Such extensive electrification provides advantages in scalability and a larger market for those industries that can handle the transition to electricity. Therefore, this part of the hypothesis should impact the timeline positively for the milestones in the vehicle and infrastructure areas, as there is a market drive and lower costs for the products. Most likely this should also impact the production and resource area positively, because a large electrification will attract investments also in competence development and production facilities.

The second statement in the hypothesis takes on the Swedish perspective, the contribution from Swedish actors and the strength of Swedish competitiveness. However, being a member of the European union, a Swedish perspective also means a European perspective to a large extent. The Draghi report, with its clear message on European competitiveness, was published on September 9th, 2024, thus after the workshop [5]. However, already before that, the Swedish automotive industry was well aware of the strong Chinese competition. Furthermore, Covid-19 and the Suez Canal tanker accident caused severe disruptions in global supply chains and highlighted the need for European control of crucial materials and components.

The third statement of the hypothesis establishes that, whenever electrification is the optimal solution, it is implemented in the best possible way. This should impact on the timing of the sustainability rating and healthy working conditions positively.

4.1.2 Who? Influence of the participants’ professional focus

The second reflection concerns the influence of the professional background of the workshop participants on the results. Most participants were technical experts and/or strategic leaders from academia and industry. One potential limitation is that the workshop lacked participation from local governments at regional and municipal levels and consumer organizations. It is plausible that these actors would have brought a different perspective to the workshop, placing a larger emphasis on user-focused milestones. In contrast, the academic and industrial participants focused on engineering, products and resources which to a large degree reflect their professional focus.

4.1.3 How? The design of group work and aggregation of preliminary results

The third reflection addresses the influence of the instructions and arrangements concerning the workshop group work. At first, groups in which group participants shared the same area of expertise were created and asked to identify as many important milestones within their area as they could. Then, the groups were re-arranged into more heterogeneous groups with diverse expertise. These new groups were given the task of prioritizing strictly to narrow the list of milestones down. In this phase, milestones started to be aggregated. The aggregation of milestones continued in the further processing in the next phase.

As the goal was to create a clear timeline with milestones, further aggregation was required to reach the final result presented in Figure 2. However, there is a risk that, during the aggregation and processing of the group work outputs, important information and details could be lost. Generalization usually leads to the loss of depth, which in turn complicates subsequent analyses of the results, such as the one presented below.

4.2 Developments since the workshop

While by the time the workshop took place the Russian invasion of Ukraine had already been going on for over 2 years, the COVID-19 pandemic and the Suez Canal incident were overcome, and the strong Chinese competition in the electromobility sector was well known, it is safe to state that at least two profound changes have occurred since the workshop was conducted, partly motivated by the change on the US government. First, the EU is expected to take more responsibility over its own territorial security. Second, the EU needs to increase focus on economic competitiveness in order to remain a relevant actor in comparison to the US and China [6].

Both of these developments imply a change of priorities in EU policy, which will likely be reflected in the budget, favoring the posts allocated to defense and economic competitiveness in detriment of e.g. sustainability and environmental research and development. For this reason, the proposed timeline in Figure 2 may be altered, and some of the milestones may not be realizable by the proposed time.

Moreover, the change in focus may also affect the future development of the transport system, prioritizing robustness and resilience in different crisis scenarios over energy efficiency and sustainability. This may be used as an argument to delay or even prevent the electrification of transport. However, it is the authors' opinion that, if properly implemented, an electrified transport system has the potential to not only be more resilient than the current fossil-fuel based (given that very few countries in Europe have domestic oil production), but also will contribute to the robustness of the electric power system, with vehicles acting as flexibility resources, enabling higher renewable energy penetration [7]. Given the role of SEC in the Swedish electromobility ecosystem, this opens up an interesting opportunity for the center to further develop knowledge and competence in how transport electrification can contribute to a more robust and resilient society.

5 Conclusions

The work presented has created value for SEC in different ways. Firstly, the workshop itself was a unique occasion for many different experts to work together. Secondly, delivering a set of milestones on a timeline has contributed to a better understanding of the needs in the area and constitutes a valuable basis for discussions.

The impact of the chosen method on the results has been discussed from several perspectives above and it is evident that the background of the participants, the formulation of the hypothesis, and the process could all have influence on the results in various ways.

Based on the milestones presented and the associated timeline, there are some reflections and conclusions to be made. The first one is that much needs to happen, and soon, to meet climate goals. A sustainable value chain must be established. Here, research has a strong role in achieving fully sustainable transportation once vehicles have been decoupled from direct use of fossil fuels.

Full circularity will take time. Despite being a popular research and discussion topic, there is limited practical action on designing and planning for full circularity and recyclability. Modularity and extension of lifetime is important. The batteries in new EVs will likely stay in the vehicles for 10-15 years, then may go on to serve in second life applications. In that case, the materials will not be available for recycling until 20-30 years from now.

Grid efficiency standards and communication protocols must be decided, and new business models need to be developed. To build resilience in the energy system, local electricity cells must be built. Cybersecurity and data protection are increasingly important as the transport system gets integrated into the energy system and the need for security and resilience is increasing.

Since the workshop was held in the spring of 2024, geopolitical tensions have become more pronounced and the start of the second term of Trump administration has created significant turbulence and instability from the European perspective. These changes may have impacts on the results, primarily on the timeline, and some of the milestones may not be realizable by the proposed time. The changes of focus may also lead to new prioritizations on robustness and resilience in the transport system. Electrification of transport opens possibilities of not only resilience in transportation but also robustness of the electric power system, with vehicles acting as flexibility resources, enabling higher renewable energy penetration. Thus, future transport electrification efforts will be driven not only by climate, sustainability, and economics but also by the robustness and resilience of future societies.

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Presenter Biography

Linda Olofsson is a physicist with extensive experience in leading research and coordinating industrial parties and researchers to find common solutions to complex technical challenges. After her PhD, she started a company based on her research and then she brought the experience from these years as start-up leader to the RISE, where she held several leading roles before taking over the leadership of the Swedish Electromobility Centre.