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The Transition to Electric Buses in Public Transport

Lessons learned from Sweden, Norway, and the Netherlands

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Preface

In recent years, electric buses have become an increasingly common feature of urban public transport. The rate of introduction has been high, and there is a need to learn from experiences that various actors involved in the transition to electric buses have gained in the past few years. In this report, we summarize lessons learned from transition processes of procured public transport in some Swedish, Norwegian, and Dutch cities. The report was originally written and published in Swedish for the research project e(+)bus, which was funded by the Swedish Transport Administration, the Swedish Bus and Coach Association, and the Swedish Energy Agency from 2020 to 2023. To make the results from the project accessible to a wider audience, K2 funding was made available to rework and translate the report to English in the fall of 2024.

Lund, Sweden, January 2025

Fredrik Pettersson-Löfstedt

Project manager

Summary

In recent years, the electrification of buses in public transport systems has increased in both scale and pace. Today, there are several examples of how this transition has been handled in public transport, with partly or fully electrified bus fleets in regular operations in many cities.

The research project e(+)bus has focused on how the transition to electric buses has been handled in six Swedish cities (Stockholm, Malmö, Gothenburg, Jönköping, Ystad and Piteå), gathering experiences and lessons learned from diverse geographical settings, organisational contexts, and varying fleet sizes and stages of transition. The project has also had an international outlook, including cities in both Norway (Oslo and Trondheim) and the Netherlands (Eindhoven) in the scope of the study.

Electrification of the buses challenges established ways of working in the public transport system in several ways. The project has identified experiences and lessons learned from how these challenges have been handled with regard to, for example, procurement, ownership, business models, urban planning, and operations of electric buses. The results have been collated and presented in reports and articles. In this K2 Outreach report, we have phrased lessons learned and experiences, based on previous publications within the project, that we consider relevant in other contexts, too, where the transition may be in its early stages.

The lessons learned − experiences and reflections on the handling of challenges during the transition – centre around four themes. Firstly, lessons learned regarding *procurement and planning of electric bus services.* This theme highlights the importance of clear ownership structures, the importance of proactive planning for adaptation and establishment of depots and charging infrastructure, the need for continuous development of competence, and the role of the electric bus as a symbol for a green transition – requiring a broad and holistic perspective on sustainability.

The second theme, lessons learned *prior to services start and daily operations* brings attention to the need to potentially revise or revisit established timeframes in planning and procurement processes. For example, the time between awarding the contract and the start of services is insufficient and affects the opportunities for collaboration and coordination between a range of different actors. Also, contract length and technical lifespan of vehicles and batteries are misaligned, which can pose challenges both in terms of how to practically manage this, and the circularity and sustainability of the transition. A need for clear boundaries and interfaces between actor responsibilities to efficiently solve any operational issues and how daily and seasonal variations of electricity pricing affect costs are further learnings on this theme.

Future perspectives are also discussed. Assuming that the technical lifespan of an electric is longer than non-electric bus, there may be reasons to revise contract lengths to align timeframes. The longer technical lifespan also means that agreements to take over or repurchase vehicles and chargers can be relevant in the future. We also find that current

requirements of maximal average age for buses can come into conflict with the opportunity to utilise the technology over its entire technical lifespan.

Finally, the last theme looks outward and gathers *European perspectives* on the transition. In Norway, using both requirements and award criteria in procurement was considered a successful approach. This is compared to Sweden, where the use of award criteria is far less common. Further, in both Norway and the Netherlands, contracts include clauses that open for the possibility of testing new technology or changing technology during the contractual period to manage future technological developments, concerning electric buses as well as other zero-emission technologies. Another learning from the Netherlands was that a common agreement to transition to zero-emission technology between the country's public transport authorities can give power and direction to the transition.

Based on these lessons learned, we conclude with four *recommendations* for the public transport sector, together with research, to ensure that the continued transition is both efficient and sustainable.

1. Public Transport Authorities should develop long-term strategies for the ownership of chargers and depots.
2. Actors in the public transport sector should be attentive to and considerate of the handling of different timeframes in the transition; for example, contract length, technical lifespan, the timeframe of different planning processes, and technical development over time.
3. To enable continuous development of competencies within the sector, public transport actors ought to initiate a platform or arena to share knowledge and experiences of the transition.
4. During the project, the conditions for and arena of the transition to electric buses have changed several times. In a world of constant change, there is a need for further research on the transition to electric buses.

1. Transition to electric buses is in progress

Electrification of the transportation system is a transition characterised by different paces and technological choices for different modes and means of transport. The transition to electric buses in public transport involves risks associated with the introduction of new technology which need to be handled. For example, altered relationship and balance between investment- and operational costs, a longer technical lifespan of vehicles, and adjustment and establishment of depots and chargers to mention a few. The transition therefore involves challenges for established ways of working within the sector, from planning and procurement of bus services to daily operations and maintenance. In recent years, the electrification of bus services in public transport has increased in pace and today there are many examples of how these challenges have been handled.

In spring of 2020 the project e(+)bus was initiated, financed by the Swedish Transport Authority, the Swedish Bus and Coach Federation, and the Swedish Energy Agency. The project aimed to learn from ongoing transitions to electric buses in urban public transport, and to disseminate and contribute to the exchange of knowledge and experience between authorities, industry, and academia.

Within the project, we selected six Swedish cities where parts of the whole bus fleet are electrified. These cities (Stockholm, Gothenburg, Malmö, Jönköping, Ystad, and Piteå) comprised the cases of this study, and through interviews with involved actors and analysis of procurement documents, contracts, strategies, and other policy documents we have explored the transition from various perspectives, such as procurement, ownership, business models, urban planning, and operations. In addition, we included international cases, Norway (Oslo and Trondheim) and the Netherlands (Eindhoven), to better understand which experiences are specific to the Swedish context and which are relevant in other contexts.

We found both similarities and differences between the cases in how this transition and associated challenges have been handled. Based on this, we have phrased a set of what we refer to as lessons learned – experiences and takeaways from the transition – that we consider relevant in other contexts, too, and cities where the transition is in its early stages, or where it is yet to be initiated. The lessons learned are categorised into different stages of the transition as we interpret it based on the studied cases; Procurement and planning of electric bus services, Before starting services and daily operations, and Future perspectives. We have also included some lessons learned from the Norwegian and Dutch cases that we find valuable in other contexts. Based on these lessons learned, we conclude by presenting four recommendations we see as necessary to continuously follow the transition to electric buses in public transport.

2. Electrification of bus services – what does it mean?

The introduction of electric buses into public transport requires that the system adapts to electric operations. For instance, the transition could require procurement processes to change and contracts to be adjusted. Planning of services and scheduling of staff may need to be adjusted to include charging times of electric buses. In addition, electrification necessitates the coordination of long-term urban planning strategies and the development of the public transport system, for example, to ensure that the electricity grid has enough capacity for the increased energy demand. At the centre of these adjustments and changes to the system lies the new technology that is being introduced – electric buses and chargers.

2.1. The electric bus system – vehicles, batteries and charging infrastructure

In this report, we define an "electric bus" as a battery electric bus that can be charged through an external port. We regard the electric bus as constituting two components – the vehicle and the battery.

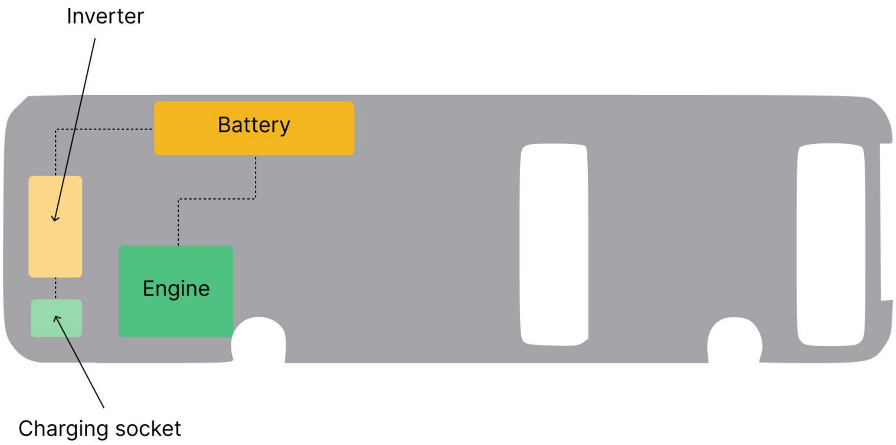

Figure 1. Example of an electric bus. Battery size and placement depend on charging strategy. Adapted from the Swedish Energy Agency, 2019, p 10

What vehicle and battery is the most suitable depends on the local context and conditions, and what charging strategy is to be implemented. The choice of charging strategy affects the size and positioning of the battery, which in turn affects the weight and energy efficiency of the electric bus. A larger battery often requires longer charging time at lower voltage. However, a bus with a larger battery does not require charging as frequently as one with a smaller battery. A bus with a smaller battery can often be rapidly charged at higher voltage but then requires more frequent charging. A smaller battery also weighs less, enabling a higher passenger capacity.

2.2. Charging concept – context and technical choices

How, when, and where the electric bus will be charged are important early questions to address when introducing electric buses into public transport. The best solution largely depends on the local context and what conditions this context allows for. For example, factors such as service frequency, timetabling, routing, hours of operation, size of bus fleet, topography, and depot localisation can influence what type of charging is most suitable.

Two key decisions are what *charging strategy* to implement and what *charging technology* to use. There are different charging strategies to choose from; in Sweden the two most common strategies are depot charging and opportunity charging. There are also different charging technologies to choose from: conductive or inductive technologies. Conductive charging, most common in Sweden, means that the bus is charged through a plug-in technology or via a pantograph. Inductive charging means it is charged wirelessly. Together, the chosen charging strategy and technology form a so-called *charging concept* [1].

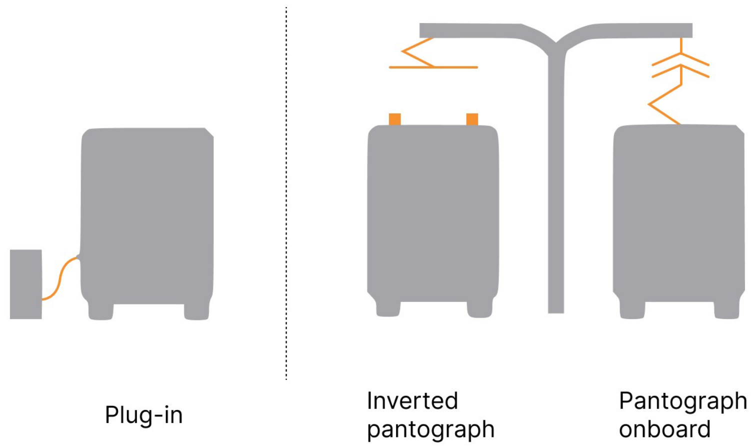

Figure 2. Plug-in charging and opportunity charging with pantograph. Adapted from the Swedish Energy Agency, 2019, p 24 [1]

2.2.1. Depot charging with plug-in technology

Depot charging means that the bus returns to the depot to be charged. Depending on the local context, e.g. the timetable, this can occur both during and outside of operational hours. Depot charging is usually combined with plug-in technology and places demands on the electricity grid at the depot. For example, an electric bus depot requires transformers and substations for the depot, and the installation of the actual chargers at every charging point. Depot charging is regarded as a relatively mature technology with low operational costs and is also considered relatively easy to install. On the other hand, it requires manual handling of chargers and involves additional work duties associated with plugging in the charger to the vehicle.

Depot charging requires larger batteries to cover the energy demand during operations, which affects the weight of the electric bus and passenger capacity. The need for large, powerful batteries should also be seen in the light of sustainability and resource efficiency, as batteries have a large environmental impact during production. On the other hand, depot charging does not require any charging point in the urban environment, only at the depot.

Figure 3. Buses charging at the depot in Trondheim

2.2.2. Opportunity charging with pantographs

Opportunity charging occurs along the bus route, usually either at larger interchange stops or at the end stations where the timetable allows for a slightly longer stop. The most common technology for opportunity charging is via a pantograph (although technologies for in-motion charging also exist). Due to the bus being charged along the route, opportunity charging usually requires a smaller battery compared to depot charging. On the other hand, opportunity charging is often associated with higher investment costs resulting from establishment of several charging stations in the urban environment.

Establishing charging infrastructure in the urban environment involves complex processes for planning and permits. Each charging point requires a grid connection and substation, and the actual pantograph. Opportunity pantograph charging requires less manual handling than plug-in technology but also means that the positioning of the bus under that charger has to be more accurate for charging to start, placing demands on the drivers.

Both depot and opportunity charging reduces the flexibility of the bus service compared to using combustion engine technology. Depot-charged buses have a limited driving range before they need to return to the depot for charging, and opportunity-charged buses are limited to the routes where charging is available.

Figure 4. Buses charging using pantographs in Gothenburg

3. Electric buses in Swedish public transport

3.1. Organisation of public transport in Sweden

Since 1989, public transportation operations in Sweden have undergone a significant change with the introduction of competitive tendering, which has played a prominent role in shaping the market. Since the mid-1990s, competitive tendering has become the primary method of organising the public transport sector.

The Public Transport Act (2010:1065) came into effect in 2012. It requires that each region has a public transport authority (PTA), responsible for long-term and strategic planning. In most cases, it is the PTA that procures public transport services from private sector operators; however, there are instances when the PTA itself operates services. It is also mandatory for PTAs to have a transport supply program, demonstrating how public transport operations and planning contribute to overall societal goals.

There are 21 regions in Sweden, and whilst the PTAs have a sizable responsibility and, to a certain extent, freedom to detail the transport supply program and the long-term direction of public transport, they are not the sole public actors that influence the public transport sector; Sweden's 290 municipalities also play an important role. Municipalities are responsible for land use and transport planning locally. They have what is referred to as a "planning monopoly" and have the authority to greatly influence public transport – especially related to infrastructure such as the localisation of depots and, in the case of electrification, the localisation of chargers and charging infrastructure.

Ninety per cent of the bus market in public transport is currently publicly procured [2], and in turn, operated by private-public transport operators (PTOs). As such it is not only public actors which play an important role in the public transport system. According to the Swedish Bus and Coach Federation (2021), there are around 240 private sector bus operators in the Swedish market, a majority of which can be categorised as small companies with less than 50 employees. Two per cent of the companies have over 500 employees, of which four larger companies control most of the market [2]. The PTOs compete for tenders of various sizes, from single routes to fleets of hundreds of buses. In 2022, the regions where Sweden's three largest cities are located, Region of Stockholm, Region of Västra Götaland, and Region Skåne, accounted for roughly 50% of supply [2].

The organisation of public transport in Sweden thus highlights the role of the PTAs in detailing how public transport can contribute to the achievement of a range of societal goals, such as social and environmental sustainability. Of course, they are also influenced by national policies and regulations setting the agenda. Sweden has set a goal to achieve carbon neutrality by 2050, and to support this objective, the aim is to establish a vehicle fleet that is independent of fossil fuels by 2030 (SOU 2013:84). The public transport sector has already taken significant steps towards adopting fossil-free or low-carbon alternatives. In 2022, over 90% of all vehicle km by public transport buses ran on renewable fuel [4].

3.2. From test and demonstration projects to regular services

In 2016, a K2 report was published, presenting a review of ongoing electric bus projects in Sweden and Europe [5]. The review showed that many of the ongoing projects were test projects, outside the scope of traditional procurement of bus services, with separate contracts between authorities and transport companies drawn up for the sole purpose of the test project. The aim of these test or demonstration projects was to gain experience with different technologies and solutions, and at the time electric buses were not a common part of regular operations.

Three years later, in 2019, The Swedish Transport Administration published an overview [1], highlighting that there was substantial interest in electric buses in Sweden and that there had been a shift from test and demonstration projects to electric buses being part of regular operations and services. However, it was noted that the transition was still in its early stages.

Since 2019, the number of electric buses in Swedish public transport has increased from 268 to over 1,200 [6, 7, 8]. There have also been developments concerning the process of transitioning to electric buses, from initiating test projects to now primarily introducing electric buses through public procurement. We also find that many upcoming procurements include a large number of electric buses [9];, therefore, it is reasonable to assume that the rapid increase in the number of electric buses in bus fleets will continue.

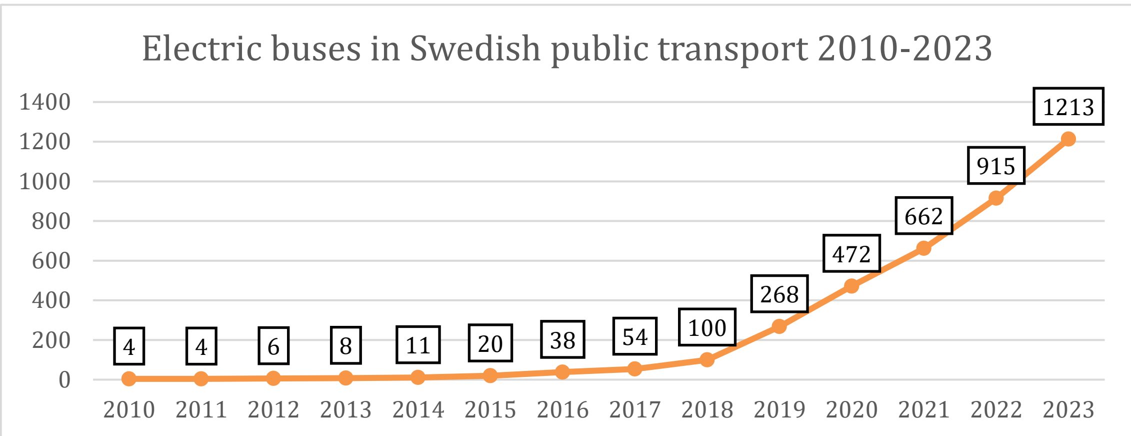

Figure 5. Electric buses in Swedish public transport [5, 6, 7]

Breaking this down over the 21 regions in Sweden, Västra Götaland and Skåne are the current frontrunners. The region of Skåne has come furthest regarding the share of electric buses, with 26% of their total bus fleet being accounted for by electric buses. Looking strictly at the number of electric buses, Västra Götaland has 291, representing 16% of the region’s total bus fleet. [4].

Both the number and share of electric buses are expected to increase in the coming years. Many regions have set targets for electrifying the entire urban bus fleet by 2030; for example, the PTA Västtrafik aims to fully electrify its urban bus fleet by 2030. This is also noticeable when looking at the procurement schedule of upcoming tenders, which detail what procurements will include electric buses [9].

Electrification of the transport sector is well underway. Rapid technological developments have removed or reduced many of the early barriers to the electrification of bus services. Electrification is also a major development, and symbolic, of the transition to more sustainable societies, and is pinpointed as a key arena for the achievement of various sustainability goals in the Sweden transport sector.

4. The e(+)bus project

In recent years, the electrification of urban bus services has taken significant steps forward. As contracts have been procured anew, electric buses have been introduced into regular operations at a considerable rate, which we in the e(+)bus project have followed between 2020 and 2023. Below is a brief description of the project's implementation and results.

4.1. Method and materials

We employed a case-based approach for this project, focusing on nine cases where electric buses were introduced into regular operations through public procurement − six cases in Sweden, two in Norway, and one in the Netherlands. The cases themselves refer to specific contracts or procurements, as shown in Table 1.

To gain an understanding of the process of introducing electric buses in this manner, both interviews with involved actors, and document analysis of relevant procurement documents, contracts, strategies, and policy documents were conducted. The exact method for the analysis of interviews and documents has differed between the different activities of the project; in this report we present the general approach to the data collection.

We conducted 29 semi-structured interviews with a total of 36 interviewees over 11 months (July 2021 to May 2022). The choice of interviewees was based on initial desktop research as well as snowball sampling during the interview process. As we aimed to gather a diverse perspective on the transition, both actors from the public sector, such as public transport authorities and municipalities, as well as from the private sector, such as transport companies, were selected. In addition, we strived for a variety of roles to be heard to gain a holistic perspective; it was therefore also important to interview actors across different organisational levels, from strategic planners to actors involved in daily operations.

The interviews followed an interview guide that focused on four themes: (1) Background and decision-making, (2) Contracts, procurement, and collaboration, (3) Experiences from operations and maintenance, and (4) Electric buses and the transport, energy, and urban system.

In parallel to the interviews, we carried out document analysis on a case-by-case basis. What documents were relevant and the method of analysis, as mentioned, differed between the scope and aim of different project activities. For instance, in the study focusing on procurement and ownership, procurement documents and technical requirements were analysed using qualitative content analysis. In a study focusing on electrification and urban planning, planning and strategy documents were of importance.

The method of analysis for the different activities is described in more detail in previously published reports.

Table 1. Cases

City	Procuring actor	Transport company	Contract/Procurement	Charging strategy	Electric bus services start date
Ystad	Skånetrafiken (PTA)	Bergkvarabuss	*Ystad stad*	Depot	August 2019
Piteå	Piteå kommun (municipality)	Nobina	*Piteå stad*	Depot	July 2021
Jönköping	Jönköpings Länstrafik (PTA)	Vy Buss	*Jönköping stad*	Depot and opportunity charging	June 2021
Malmö	Skånetrafiken (PTA)	Nobina	*Malmö Central*	Depot and opportunity charging	June 2021
Gothenburg	Västtrafik (PTA)	Transdev	*Gbg sydväst/ stom/ Partille/ Mölndal/Express*	Depot and opportunity charging	December 2020
Stockholm	Trafikförvaltningen SLL (PTA)	Keolis	*E22 - Sthlm innerstaden/ Lidingö*	Depot	August 2022
Trondheim	AtB (PTA)	Tide Buss	*Stor-Trondheim 2019-2029*	Depot and opportunity charging	August 2019
Oslo	Ruter (PTA)	Norgesbuss & Unibuss	*Oslo Sentrum & Oslo Sør*	Depot and opportunity charging	January & October 2022
Eindhoven	OV Noord-Brabant (PTA)	Hermes	*Concessie Zuidoost Brabant*	Depot and opportunity charging	June 2017

4.2. Project approach and publications

The e(+)bus project has focused on different aspects of the electric bus transition through several project activities. The results from each activity have been published in reports (in Swedish) and scientific articles.

Reports

a) *(Elbussen är här! Lärdomar och kunskapsluckor i forskning om elbussar.)* K2 Outreach 2021:2.
b) *(Omställning till elbussar i svenska städer – Lärdomar om affärsmodeller, ägarskap och upphandling.)* K2 Working Paper 2023:3.
c) *(Energikostnad för depåladdade respektive tilläggsladdade elbussar – Ekonomiska konsekvenser av att ladda elbussar*.) K2 Working Paper 2022:4.
d) *(Elbussar och stadsplanering).*
e) *(Omställning till elbussar).*

Articles

f) *Rationales for transitioning to electric buses in Swedish public transport*. Research in Transportation Economics, 2023, Vol. 100.

g) *Institutional perspectives on Public Procurement in the Electric Bus Transition* [forthcoming].
h) *Navigating electrification in public transport: The role of Public Transport Authorities* [forthcoming].

In this report, we have collated these results, taken a collective approach and overall perspective, and formulated several lessons learned. The lessons learned have been developed in consultation with representatives from the industry, where an important element has been reference group meetings carried out within the project. At the reference group meetings, results from the project have been discussed and put into a practical and concrete context based on the participants' experiences of being involved in the transition process.

5. Lessons learned from the transition to electric buses

In this section, we present lessons learned and experiences from the cases studied within the project, which would also be relevant for other cities before or in the early stages of an ongoing transition. The lessons learned are divided into different phases of the transition as we interpreted it based on the cases. These phases are: “Procurement and planning of electric bus services”, “Before the start of traffic and daily operations”, and “Future perspectives”. In addition, we have included European perspectives – lessons learned from the Norwegian and Dutch cases, which are worth reflecting on in both Swedish and other contexts.

5.1. Procuring and planning electric bus services

5.1.1. Ownership of depots and charging infrastructure influences technical requirements

The transition to electric buses involves new technology and new actors in the public transport system. This in turn means that strategies and processes for how to handle and coordinate these new elements need to be established, adjusting and adapting existing ways of working. The results from the project highlight that ownership of physical infrastructure is a key question for consideration.

Ownership of chargers and depots for electric buses varies across cases. In some instances, these are owned by the transport companies themselves, and in others by a public actor, for example, a public transport authority or municipality. Public ownership of said infrastructure often means that technological solutions are predetermined in procurement. As such, the technical requirements in procurement become more detailed. If ownership of this technology and infrastructure is the responsibility of the transport company, more of the technical solutions can be left open, and there is the possibility of less detailed technical requirements.

In the studied cases, we can see a clear trend towards increased public ownership of charging infrastructure and depots, which could affect the wording of technical requirements in the future. The results indicate that electrification enforces an already existing trend towards increased public ownership of depots, motivated by the idea that public ownership can contribute to better competitive conditions in procurement and, as such, can also contribute to more effective solutions.

On the other hand, public ownership of depots and charging infrastructure for electric buses involves a risk of “over-designed” solutions, and lock-ins in technology, which in turn could mean that the competition in procurement decreases. An important lesson is, therefore, that public ownership and a shift in responsibilities for technological choices ought to be performed in a cost-efficient way.

5.1.2. The infrastructure requires urban space – location of depots and chargers

When, how, and where electric buses should be charged is an important question to consider early in the transition. Which actor decides this depends on the organisational set-up, which differs between contexts. Regardless of which actor makes these decisions, we find that the location of depots and charging infrastructure in the urban environment is a key parameter for consideration. Whatever the technology, be it combustion or electric engine, the aim is to have as few empty runs back and forth to the depot as possible. Therefore, depots should ideally be located close to the routes the buses service. Electrification also means that these locations require sufficient electricity grid transmission capacity to enable charging.

Existing depots may need to be adapted or refitted, and new depots may need to be established to cover any additional capacity necessary when electrifying the bus fleet, as electrification may involve an increase in the size of the bus fleet to cover demand, and as chargers need space at the depot. It is important to ensure that the location of these depots is aligned with long-term planning strategies, both for urban development and for public transport.

If opportunity charging is to be used, suitable locations for this need to be identified. In addition to suitability, these locations also need to be planned according to the timetable and route of the service, and need to harmonise with the urban environment. To realise this, actors involved in urban planning need to be involved in the process of identifying suitable locations early on.

Figure 6. Buses charging by pantograph at the end station in Jönköping

5.1.3. Competency a key issue in tender design and evaluation

The procurers' competence is central to public procurement. Procurement processes and legislation are complex, and it can be challenging to design tender documents that ensure that the procured services will contribute to goal fulfilment. Competence is therefore an important factor, electrification aside.

When new technology such as electric buses is introduced, the results from the cases reveal increased demands on procurer competence and continuous competence development. Procurers are required to have up-to-date and relevant competence to both detail technical requirements in the tender documents and to evaluate bids that include electric buses.

A lesson learned from the project is that procurement of electric bus services differs from procurement of other buses, which then requires a different type of competence. We have seen examples of how procurers handle this. In some instances, dialogue or open meetings with industry actors are organised to gather up-to-date knowledge of the latest technology. In others, charging strategies and technological solutions are designed together with transport companies in collaborations outside of the framework of public procurement. Sharing experiences between authorities in different regions is not uncommon. Dialogue and collaboration between different actors are therefore essential to continuously develop procurement and evaluation of tenders.

However, it is important to stress that competence development is important not only for procurers, but for all actors in the electrification of public transport systems.

A question to consider concerning competence is what actor should make which technological choices in the design of electric bus services. An important aspect in the transition is therefore for actors to also know what competence lies with another actor. In the case studies, we were able to observe, for example, that when it comes to the development of the charging strategy, it was clear that the transport companies had an advantage in terms of competence and current market knowledge. It is, of course, important to take advantage of such knowledge and to ensure that the competence of all actors involved contributes to an efficient transition to electric bus traffic.

5.1.4. The electric bus as a symbol for a green transition – increased importance of environmental requirements

The transition to electric buses is now primarily taking place within the framework of procurement, and we see that electric buses have been introduced into regular services as a result of both specific and functional technical requirements. The potential advantages and disadvantages of different types of requirements are context-dependent, for example, depending on public transport authorities' different strategies and competencies, as well as the resources and experience of transport companies.

In addition to technical requirements for vehicles and chargers, complementary requirements regarding the sustainability of electric bus system components are becoming increasingly important. This is to ensure that the transition to electric buses does not conflict with other sustainability aspects. Requirements for reporting socially and environmentally sustainable supply chains for battery and vehicle production are becoming a pressing issue to ensure that these components are responsibly procured.

There are already examples of how this can be handled within the framework of procurement among Swedish public transport authorities. Currently, these requirements mean that certain suppliers are excluded from procurements.

The handling of spent batteries, either through reuse or recycling, is also becoming an important consideration as batteries are replaced in vehicles. This issue is also being addressed at the EU level. A possible way forward could be to work with other actors to develop strategies for utilising batteries' second life in other sectors, thereby extending battery life. Another suggestion is to set requirements for battery reuse or reporting plans for raw material recycling.

5.1.5. Tendering time may need to be adjusted

A transition to electric buses means that tenderers must consider several new factors before a reliable bid can be submitted. Some procurements are also very large and have requirements for proposals on traffic design, which involves a significant amount of work for the tenderers. The most common timeframe for transport companies to calculate bids is four months. We have also seen examples of shorter deadlines, depending on the timing of the tender document distribution (for example, just before the holiday months during summer). Time constraints can lead to some bidders abstaining and others possibly submitting inadequate bids; no party benefits from this.

A lesson learned from the project is therefore bidders must be given adequate time in which to design and calculate their bid. Authorities should consider that the introduction of electric buses may involve a need to address new issues in the bids that have not been relevant for buses with combustion engines

5.2. Start of services and daily operations

5.2.1. The time between contract award and service start needs to be longer

When introducing electric buses into regular services for the first time, resources such as financing and competence are necessary to establish charging infrastructure and adapt depots. Another resource required is time, which is usually limited due to the period between contract awarding and traffic starting (usually 12-18 months in these cases).

Aside from the actual building and getting it up and running, establishing charging infrastructure in the urban environment entails identifying suitable locations, applying for and being granted building permits, and ordering and taking delivery of vehicles and chargers. This necessitates coordination with a range of actors, for example, municipalities, construction companies, grid owners, and manufacturers.

A lesson learned from the e(+)bus project is that the time between awarding the contract and traffic starting is often insufficient if all these activities are to take place within this timeframe and handled by one actor alone. The procuring authority or involved municipality should therefore make preparations prior to awarding any contract, for example by deciding on suitable locations and preparing permits. The risk of this being unnecessary work and a waste of resources is outweighed by the importance of ensuring that a transition to electric buses works well for passengers, as well as for the public transport authority and transport companies.

5.2.2. Battery replacement may be required during the contractual period

In an electric bus, the batteries constitute a significant part of the investment cost. Electric buses have not yet been in operation long enough for anything definitive to be said about the lifespan of batteries. A basic assumption is that a battery's lifespan is shorter than a vehicle's technical lifespan and shorter than the contract length, which means that battery replacement needs to occur during the contract period. As vehicles are usually owned by the transport company, it can be assumed that it is responsible for battery replacement, as is the case with other components in the buses. How this issue could be handled in practice is not yet fully established. Questions that need to be addressed include whether the battery will have any residual value at the end of the contract or if the vehicle's technical lifespan is extended because of the battery replacement.

5.2.3. Clear interfaces for ownership and responsibility are important for solving any operational issues

Ownership of charging infrastructure affects the daily operation of electric bus traffic. We see that chargers at depots are often owned by the transport companies themselves. In case of problems with chargers or vehicles, it is thus the transport company alone that is responsible for troubleshooting and remediation, which is an example of a clear interface where responsibility and ownership overlap.

There are different ownership structures regarding chargers for opportunity charging. In cases where opportunity chargers are owned by a party other than the transport company, there is a risk that long decision chains and many interfaces between actors' areas of responsibility affect operations during troubleshooting. This can negatively impact daily operations. An important lesson, therefore, is that clear (and preferably few) interfaces between actors are important for the efficient operation of electric buses.

5.2.4. Electricity pricing and the effect on costs and contracts

During the project, world events with consequences for public transport have characterised the context for the studies, for example, reduced revenues due to decreased travel during the pandemic, and high electricity and fuel prices as a result of war and conflict, with subsequent disruptions to energy markets. How to handle the consequences of such events for public transport is a broader issue and not only relevant in connection with electrification.

However, the issue of electricity prices becomes highly relevant in the transition to electric buses, as the price directly affects the cost of operating the buses, and how contracts are designed concerning risk distribution between parties. We see that the total electricity costs depend on the charging strategy, and that variations in electricity prices can affect the cost of depot and opportunity charging differently, depending on the different charging patterns over the day; thus electricity usage is concentrated at times with different electricity prices.

Electricity prices have not previously been given much consideration, but recent price development and variations may change this, according to a survey study conducted within the project. For example, variations in electricity prices affect transport companies' bids as well as which charging technology is chosen. It is important to consider how electricity prices affect the choice of charging strategy in future procurements, and also how increased electricity prices during the contract period are handled in traffic agreements with index regulations.

5.3. Future perspectives

In addition to the lessons learned that have been presented, in the project we also identified additional questions that are relevant to reflect upon in the ongoing transition to electric buses in public transport. While there are still few concrete examples of how these challenges can be resolved, the results indicate that these issues may be important for the continued transition from a future perspective.

5.3.1. The technical lifespan of the bus may alter the contract length

Through the case studies, it appears that electric buses have an expected longer technical lifespan than combustion engine-driven buses. Electric buses are assumed to be able to operate for up to 16 years, given renovations during their life time. This longer lifespan is not solely due to technical aspects but can also be explained by economic reasons, such as production and purchase costs, as well as depreciation of infrastructure.

A longer technical lifespan for electric buses covers more than one contract period, which is typically 10 years. A longer lifespan of the vehicles can justify a longer contract period if the vehicles are only to be in operation during one contract period; this also affects the depreciation period. Additionally, there is the possibility that the vehicles can be used throughout their entire lifespan despite an unchanged contract length if they are renovated and taken over by the succeeding transport company. The question of renovation and takeover is also directly related to the industry's view on reconditioned buses. A lesson for the future is that the industry needs to intensify the current discussion about allowing reconditioned buses.

At the same time, there are risks associated with relying on a longer lifespan and changed contract times. Today's electric buses have not been in operation long enough for anything definitive to be said about their technical lifespan. If it is desirable for electric buses to have a longer lifespan, it becomes important to include takeover clauses with defined prices in contracts to manage and distribute risks related to a longer lifespan. Changed contract times can also affect the market, as large and small bus companies have different conditions for adapting to shorter or longer contract times.

5.3.2. Take-over agreements for vehicles and chargers may become necessary

The lesson about the longer lifespan of electric buses opens up the question of what happens with electric buses and associated charging infrastructure at the end of a contract. Ownership plays a vital role in how this issue is handled. If the transport company owns the vehicles and charging infrastructure, it is natural that it should make the decisions about how this matter is handled. There is also the possibility that vehicles and chargers follow into the next contract by having the procuring authority include guarantees or takeover clauses in the contract, which has occurred in some cases.

At the same time, there is relatively rapid technological development, which means that the technology invested in at the beginning of a contract may not be modern or effective 10 years later. There is therefore a risk of locking oneself into certain technologies if they are contracted to be carried over into the next contract period. How this issue is handled should thus be based on a long-term strategy for the electrification of bus traffic. Ownership of infrastructure and depots is thus an important issue for consideration in the development of such a strategy, as it sets the conditions for development.

5.3.3. Age requirements influence transition

We see examples of cases where average age requirements have been removed and only maximum age requirements are used instead. There is talk of accepting a maximum age of as much as 15-16 years for an electric bus. It is assumed that the vehicle could be renovated so that passenger comfort is maintained. When the electric buses are introduced, often all or a significant portion of buses in the procurement are replaced. If the traffic volume does not increase during the contract period, this means that all buses will be of the same age throughout the contract period. The average age of the buses will then be the same as the contract year. Previously, it has been common to also have an average age requirement of six to seven years in the contracts. Having an average age requirement and at the same time having an allowed maximum age of around 15 years is therefore not possible.

If the transition to electric buses takes place in stages during the contract period, an average age requirement can be combined with a requirement for maximum age. However, this requires that older buses are accepted at the beginning and that a completely new bus fleet at the start is not prioritised in the evaluation of bids.

If the traffic supply increases during the contract period, new buses will be added. These will be younger than the contract period when the contract expires. Consequently, the buses will represent a significant economic value at the end of the contract period. If the depreciation period is to be 15 years in practice, this must be managed in the contract.

5.4. European perspectives

In addition to the six Swedish cases, we have also studied the transition to electric buses in three European cities; two in Norway and one in the Netherlands. Here, we take a European perspective on the transition, addressing some experiences and lessons learned from the above-mentioned cases, with a reflection on how these experiences may differ from the Swedish context.

5.4.1. Award criteria in combination with requirements

In the Norwegian and Netherlands cases, both requirements and specific award criteria have been used in the procurement for the transition. This differs from the Swedish cases where award criteria are not used to the same extent. In Oslo, a point system (0-10) is used, where electric or hydrogen buses in tenders receive 10 points (Euro IV gas or diesel gives three points). In Eindhoven, tenders are evaluated using weighting, dependent on the proportion of zero-emission buses offered, as well as based on the transport companies' plan to electrify the entire vehicle fleet (a total of 20% of the award criteria).

This is described by interviewed parties as a way to procure electric bus traffic without setting specific requirements regarding which technology or solution should be implemented. An important lesson, however, is that this approach places high demands on the competence of procurers, both to design such criteria and evaluate tenders based on these.

5.4.2. Innovation opportunities during contract

In the Norwegian and Dutch cases, there are clauses in the contracts stating that the transport company must participate in innovation and test projects during the contract period to test new technology and other solutions. This was primarily discussed with regard to the technological development taking place for electric vehicles and batteries, but also for hydrogen solutions. We have seen examples of similar approaches in Sweden but without the same explicit consideration for hydrogen, and not to the same extent.

What is described as rapid technological development is taking place for electric buses, but other technologies are also developing. While it is only possible to procure the technology available on the market today, there is a desire for flexibility to be able to test and "keep up" with technological developments. A current issue that arises concerns the handling of uncertainties associated with a technology that is still under development or the handling of technological development that occurs during a contract period. It is quite likely that the electric bus technology available on the market today will become "outdated" or inefficient over a 10-year contract.

As described earlier in the report, the transition to electric buses in regular traffic was preceded by several years of test and pilot projects to test the new technology. This took place outside of procurement, and special agreements were made with transport companies. In Norway and the Netherlands, test and pilot projects have been incorporated into the procurement as a way of managing future technological development.

5.4.3. Norway: Financing for charging infrastructure described as positive

The case studies in Norway show a different set-up for the ownership of charging infrastructure. In Oslo, the transport company owns and is responsible for the charging infrastructure from the awarding of the contract until six months after the start of services. At that point, ownership transfers to the public transport authority and the region (fylkeskommune). In Trondheim, the region owns the charging infrastructure throughout the contract period. This distribution of ownership was a result of the public transport authority and the region applying for state funding for the establishment of charging infrastructure, which is only disbursed if the region is the owner.

The transport companies' ability to influence the choice of charging strategy and responsibility during operation, paired with long-term public ownership of the infrastructure, is described by the interviewed parties as a good set-up. Transport companies have the opportunity to propose and design the charging strategy, but the risks associated with long-term ownership of infrastructure in urban environments are managed by a public entity.

In the Netherlands, grants for a faster and more efficient technology shift have also been discussed. Due to fewer passengers and reduced revenues following the pandemic, it became increasingly difficult to finance new electric buses in public transport. This led the state to launch a new grant form for financing electric buses to stimulate continued transition.

In Sweden, there is no specific funding directed at charging infrastructure for electric buses. The financing options that have been relevant in the cases discussed are the electric bus premium (Elbusspremien) and urban environment agreements (Stadsmiljöavtal). The electric bus premium has also recently been reformed in Sweden, and the urban environment agreements are being phased out. A lesson from the project is that state funding through grants and subsidies plays an important role in influencing the pace, direction, and scale of the transition.

5.4.4. Netherlands: Common agreements from public transport authorities set the developmental direction

In 2016, all public transport authorities in the Netherlands signed a joint agreement (BAZEB − Administrative Agreement on Zero-Emission Buses), which stipulated that all buses in public transport would be emission-free by 2030 and that only zero-emission buses may be purchased after 2025. This agreement has played an important role in gathering actors within the public transport sector in a common direction. It has also meant that involved parties have a timeline and common goals to relate to in their strategic planning (e.g., procurement schedule or transition of vehicle fleet).

In Sweden, there are goals at the national and EU levels regarding the electrification of the transport sector, but there is no common vision for public transport authorities and regions regarding the transition to zero-emission buses. A lesson from the project is that a joint stance from public transport authorities and regions can provide power and direction to the transition.

6. Recommendations

In summary, the project has resulted in several lessons relevant for actors in the sector to consider in the continued transition to electric buses. The lessons we have identified and described in this report are general, and we believe they are applicable in several contexts, but perhaps of varying importance depending on the phase of transition, the scale of transition, and which actor is affected.

Based on the lessons in the previous chapter, we propose below four recommendations that we consider important for the public transport industry and academia to consider in order to jointly contribute to a sustainable transition.

6.1. Develop long-term strategies for ownership

Strategies for how ownership of, for example, chargers and depots is handled in the transition affect a number of issues. For instance, ownership affects what is subject to competition in procurement, and the procurement requirements. The ownership of charging infrastructure also affects the establishment phase, daily operations, and troubleshooting. We have seen that ownership can be handled in different ways. There is no definitive right or wrong way to distribute ownership; it depends on what is most appropriate on a case-by-case basis. However, it is important to have a long-term strategy for ownership of charging infrastructure and depots. This is to ensure that there are routines and working methods in place to manage any difficulties that may arise with a certain set-up, and to ensure that the ownership of infrastructure is handled in accordance with various goals for public transport and urban development.

6.2. Be prepared to consider and coordinate different timeframes

Time appears as another recurring parameter that sets the conditions for the transition: contract length, technical lifespan of various components, time required for different processes, and technological development over time. The results show that the time required to submit tenders, the time between award and start of traffic, and even the time an electric bus can remain in operation can affect the procurement process and contract design. We also note that time on a more general level also plays a role. Technological development during a contract period happens quite quickly, and electric bus technology is considered much more mature today than just a few years ago. It thus becomes relevant to consider the parameters governed by different timeframes within procurement, as well as how the transition is affected over time.

6.3. Enable continuous competence development for the industry

As noted, the transition to electric buses and technological developments place demands on the competence of the actors, both among public transport authorities and municipalities as well as for transport companies and manufacturers of various components. Based on the project results, we conclude that competence is an important part of handling uncertainties that arise in connection with electrification. At the same time, we see that these uncertainties have in fact been managed in different ways in different cases. It is more a question of continuous competence development than a lack of current competence that is relevant to the electrification of public transport. A similar conclusion is drawn in a report on the state of knowledge among the transport sector's key actors in electrification [10], which states that for public transport, the first learning phase of electrification has already passed and now it's about managing the new phase of the transition. To ensure continuous competence development, therefore, we recommend that the public transport industry's actors jointly take the initiative to establish a platform for knowledge and experience exchange about the transition to electric buses.

6.4. A world in constant change means a continued need for research

During the project, the conditions and the playing field for transition to electric buses have been redrawn several times. Major world events such as a pandemic, war, and conflict have affected the demand for public transport, with lower revenues due to fewer passengers, as well as the availability of raw materials required for electric buses. Events with a more concrete impact on electrification have also characterised the transition and the project. This applies not least to recent years' high electricity prices and discussions regarding electricity grid capacity, specifically in Sweden. The reformulation of the electric bus premium and the phase-out of urban environment agreements during 2023 are also examples of how the playing field for the transition to electric buses in Sweden has changed. The circumstances that have characterised this project have been, to say the least, changeable and dynamic. Over the past three years, it has been shown that the transition to electric buses is nevertheless progressing and even increasing in pace and scale. With new phases of the transition, there is also a need for additional knowledge. Together with industry actors, we have identified some areas and questions that need to be further investigated and researched in the future.

- Related to the world events mentioned above, there is a need to investigate preparedness related to electrified bus traffic, on both a smaller scale and more large scale. While buses in public transport are being electrified, other vehicles and sectors are also being electrified. The capacity of the electricity grid remains an important issue. An area for further research is therefore the impact of the electric bus on the energy system and how this interacts with other electrification processes.
- In a report, we have touched on the subject of electric buses and urban planning. There is a need to further investigate the role of the electric bus in the sustainable

city, what synergy effects can arise, and what measures are required to realise these. Improved air quality and less noise in cities are often highlighted as reasons for introducing electric buses, but there is little research on how the introduction of electric buses has actually affected the urban environment.

- A recently published report found that there are social risks associated with battery and electric bus manufacturing [11]. Increasingly stringent requirements are being placed on the sustainability of electric buses, not just environmentally. Social and economic sustainability are two important parameters to pay attention to, and often all three need to be addressed to achieve goals and future sustainable public transport. Setting requirements for sustainable supply chains and strategic work with buyback guarantees or takeover clauses is part of this that already plays an important role today. It remains important to evaluate the social and economic consequences of electric buses, as research so far has focused mainly on environmental aspects. There is also a continued need for more knowledge about solutions that require less battery capacity, such as electric roads.
- Related to economic concerns, there is a further need to investigate market consequences as a result of the transition to electric buses. Questions that may be interesting to follow are the impact of electrification on competition in procurement and the development of standards for electric bus technology and traffic at both national and international levels.

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