38th International Electric Vehicle Symposium and Exhibition (EVS38) Göteborg, Sweden, June 15-18, 2025

Three years of experience with wireless charging fleet in Gothenburg Green City Zone

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Executive Summary

From beginning of March 2022, Volvo Cars, together with selected partners, started testing wireless charging in the real city environment of Gothenburg in Sweden. Over a three-year period, a fleet of 20 fully electric Volvo XC40 vehicles with integrated wireless charging technology are studied in taxi operations and charged at dedicated wireless charging stations. During the test period the project stakeholders are collecting data from vehicles and charging operations as well as performing driver and customer feedback surveys. After more than 3 years of operation, the 20 vehicles in the fleet have been running as planned and covered over 4,3 million kilometers. The wireless charging stations over the test period covered 13,5 % of the total fleet energy supply. The study shows that this number can be improved with an increased number of charging stations as improved access likely will result in more drivers using this opportunity. Self-funded by the stakeholders, this wireless charging fleet test is a project outlined within a strategic initiative called Gothenburg Green City Zone, under which appointed areas are used as real-world testbeds for supporting the development of sustainable transport technologies.

Keywords: Electric Vehicles, Consumer Behavior, Consumer Demand, Inductive/Wireless Power Transfer, AC & DC charging technology

1 Introduction

For a period of three years, the stakeholder group in Gothenburg collaborated on a project with focus of studying wireless charging in taxi operations. The project is now reaching the end of the test period, and it is time to take a step back, summarize and look deeper into some of the results. The results are derived from both subjective as well as objective methods to differentiate behavioral anticipations from facts found in the measurement data. The total fleet mileage on April 1st, 2025, is 4,3 million kilometers and the vehicle fleet has accomplished a total of 683 months in service. Most of the taxi owners are confident that the lifetime of the vehicles, including its batteries, will last for a far longer period than 3 years. Many of the transporters have expressed interest in and showing a will to continue driving their cars for an extended test period beyond the planned project, continuing to contribute to an increased knowledge base through further data collection.

In total, the success of the project is a result of a dedicated management team consisting of representatives from a complete stakeholder group where each stakeholder has focus on different responsibilities within the value chain. Through information sharing in the stakeholder group on a weekly basis throughout the project period, aspects such as project documentation, evaluation of vehicle usage and charging data, issues documentation and handling, preparing and holding meetings with the taxi drivers and transporters, planning next quarter activities as well as discussing possible expansion to the next level of engagement, could be addressed. The weekly meeting process guaranteed that all issues were taken care of quickly and created an important transparency and a common knowledge level about project health among all the stakeholder team members.

1.1 Market research

Only a few other fleet tests with wireless charging technology in taxi operations have been carried out, as a complement to the more proven standards of conductive charging. The two most relevant are shortly described below.

The Wireless Charging of Electric Taxis in Nottingham project (WiCET), with nine vehicles [1], whereof five LEVC and four Nissan eNV200 Dynamo taxis, was reported during 2024. From project reports it can be found that drivers faced several challenges regarding **Driver Adaptation**: Drivers struggled with the concept of regular top-up charging, preferring traditional plug-in charging methods. They found the 11kW power rating too low for their needs. The project also faced some **Technical Limitations**: The communication 'handshake' sequence between the vehicle and the ground system was slow, taking around seven seconds to establish a connection. The project has provided valuable insights into the feasibility and benefits of wireless charging for electric taxis, with findings being used for developments of this technology and usage.

Another test attempt with wireless charging taxi fleet was announced in Oslo during 2019. While specific study results from this initiative are not available, the project has been widely recognized for its innovative approach and potential benefits. The collaboration between the City of Oslo, Fortum, and Momentum Dynamics was aiming to demonstrate the feasibility and efficiency of wireless charging technology for electric taxis. A key learning from this project, which never came into full operation, was that it is key to find and align around common goals within a stakeholder consortium.

As a summary of learnings from previous projects, the stakeholder group and a careful vehicle fleet setup, facilitating continuous dialogue and support from project stakeholders, are key factors for success. It is also key to involve service and maintenance organizations that can handle individual service actions when needed to keep an acceptable uptime.

2 Project stakeholder presentation

In the following sections the details about the stakeholder group in the Gothenburg Green City Zone project are presented.

2.1 Project Coordinator (Business Region Göteborg)

Business Region Göteborg (BRG), in the role as project coordinator, managed the continuous knowledge exchange between the stakeholder group, the issue handling process as well as the overall documentation process and meeting structures. BRG acted as representative for the City of Gothenburg for the city development perspectives and contact to city administrations for e.g. regulative questions.

2.2 Car Company (Volvo Cars)

Volvo Cars delivered and tested wireless charging integration into the standard XC40 battery electric cars and has provided service and maintenance identical to a normal customer business relationship. Additional to the operational support Volvo Cars also delivered data collection management and analysis with a focus on vehicle usage. A strong motivation to run this fleet study has been to better understand wireless charging in real life usage and at the same time gather information about EV usage under high milage conditions.

2.3 Taxi company (Cabonline)

Cabonline organizes taxi operations. The role is to serve as a link between taxi customer driving orders, creating a communication hub for taxi drivers and cab owner companies. The reasons mentioned why involve a taxi company in this project is to learn more about the electrification of taxi fleet business including learning more about influences from charging habits and infrastructure. Cabonlines environmental goal is to achieve 40% fossil-independent passenger cars by 2025, utilizing gas and electric vehicles, and reach 100% by 2030.

2.4 Charging system supplier (InductEV)

InductEV (former Momentum Dynamics) delivered all the wireless charging related hardware equipment for the taxi vehicles and the charging stations. During the fleet test, InductEV also delivered data from each charge event to the stakeholders to keep track of the uptime levels of vehicles and wireless charging stations. InductEV has also assisted with software updates on the charging receivers and provided fault tracing when needed.

2.5 Station owner and local grid operator (Göteborg Energi)

Göteborg Energi funded and managed the construction of the two charging stations and managed the grid connection. Göteborg Energi also provided the project with service personnel in case of any electricity distribution failures.

2.6 Charge Point Operator (Vattenfall InCharge)

Vattenfall InCharge delivered charge point administration, measured real time energy sent to each vehicle, handled billing for the used energy and sent information about utilized monthly energy to the taxi companies and transferred payments to the charging station owner. While collecting charged kWh’s per vehicle, billing transactions could be made and directed to each individual vehicle owner.

3 Project preparations and setup

The three-year field test period was initiated through an extensive preparation phase by all the stakeholders. In the following sections, the project preparations, setup, activities and execution are described in a chronological manner.

3.1 Project initiation

The taxi project started off as a discussion among stakeholders during 2020 and went into firm agreements during 2021 with defined stakeholder group agreements. With the agreements set, the project organization, roles and responsibilities and coordination activity were initiated which included weekly stakeholder group meetings, technical and organizational preparations of vehicles and fleet operations, educational and information material, transporter and driver introductory courses as well as planning and installation of charging infrastructure, planning for project launch, communications, etc.

The weekly meeting frequency has been maintained throughout the project period to be able to react quickly to unexpected situations or strategic adjustments. Throughout the project, driver/transporter dialogue meetings have been performed and a master thesis on the topic of technology adaptation in the targeted user group has been supervised.

3.2 Vehicle technical preparations

In parallel to the stakeholder discussions for project setup, InductEV and Volvo Cars worked together on the integration of wireless charging technology and built it into test car versions of the Volvo XC40 battery electric vehicle (BEV). The first battery-electric version of the XC40 was delivered to end customers in the beginning of 2020. To create robustness with the wireless charging technology, three prototype iterations were built and tested before the final factory orders were made for the 20 all new taxi-intended XC40 vehicles. After a normal series manufacturing, the vehicles were shipped to Volvo Cars engineering facilities to be retrofitted with wireless charging equipment. At the workshops, also some additional preparations were made for the vehicles to increase taxi usage values and fulfil service travel contract requirements. Before being delivered to taxi companies the cars were also foiled with a project logo (see next section) and equipped with required taxi metering and exterior taxi signs.

Figure 1: Prototype vehicles, Charging station at Lindholmen Science Park, 1st Taxis ready for delivery

3.3 System integration

The Volvo XC40 battery electric series manufactured vehicle was adapted to wireless charging according to the principal sketches below, see figure 2. A mechanical integration effort was made to attach the wireless receiver to the front underneath the vehicle subframe. Additionally, vehicle cooling system and the high / low voltage connectors were interfaced to the vehicle electrical system. The vehicle subframe was also changed to reach a maximum possible height over ground for the added equipment under the vehicle.

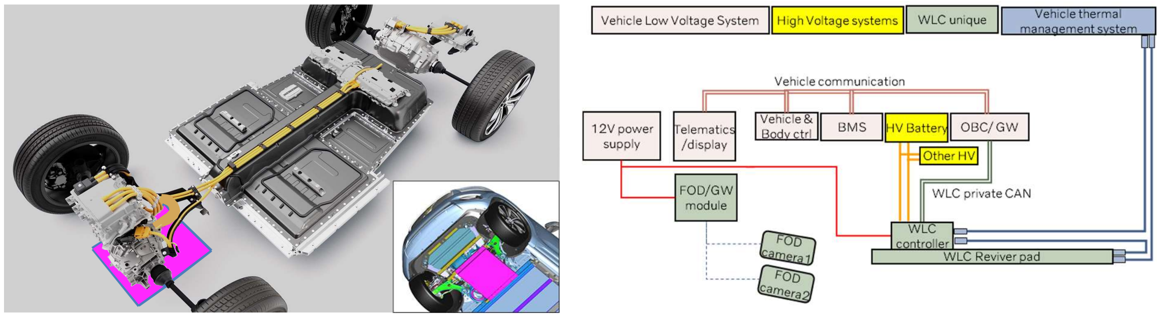

Figure 2: Mechanical and Electrical Integration

Integrating new functionality like wireless charging requires system interfacing and adaptation to existing vehicle software. To limit the need for large scale validation testing, the focus was to keep vehicle systems intact and make the software changes as few as possible. This strategy paid off well since it meant only a few hours spent on validation tests. The major system that was affected by software updates was the on-board charging system which hosted the communication interface between the wireless charging and the vehicle functions. For increasing the user-friendliness and understanding of usage status, the center stack information system was also updated with a display app showing the steps in the charging sequences, simultaneous power levels, and failure diagnostics.

Software and hardware integration to include “foreign object detection” (FOD) was also made. With the help of two IR cameras mounted under the vehicle front, any object on the ground that measured a heat increase of a few degrees caused an immediate power cut from the charging station and resulted in reported warning messages to the driver.

After the vehicles were prepared with the mechanical, electrical and functional integration details, the cars were ready for delivery. As a final step they passed by an exterior foiling company to get a more recognizable look with a printed QR code where interested parties could be linked to a homepage hosted by BRG with further information about the project and the context of Gothenburg Green City Zone.

Figure 3: Foiled vehicle with communicative message

3.4 Introduction of EV vehicles to fleet operators, transporters, and drivers

From the transporters’, i.e. the vehicle owners’, as well as the fleet operator’s perspectives, there is a common business model which is always put under pressure and calls for careful treatment. High vehicle uptime and manageable operational cost are of key importance to keeping the required level of profit margins in a low-margin sector.

For the transporters this means the highest possible focus on effective vehicle maintenance and an expectation of a robust function of the wireless charging stations since this affects both costs and uptime. To lower the engagement threshold and encourage the transporters to move into electric drive with wireless charging capability, the fleet operator, i.e. Cabonline, offered a reduced membership fee to the signed transporters. As a counter performance, it was highlighted that the project requires monitoring of the vehicle's usage and their charging behavior by continuously collecting data and driver feedback.

Keeping a tight dialogue with the vehicle owners was set as an early project goal, to better understand driver's needs in general regarding electric drive, together with preferences in selecting charging method. Since a new charging method was offered to the drivers, the project was interested in continuously monitoring driving and charging patterns, to share information about the project performance but also to get a deeper understanding of why and when wireless charging is a viable choice for daily taxi operations.

Communication with the drivers during the fleet tests was mainly centered on the following activities:

- Information before buying about contracts, support and fleet setup
- Information regarding how to use wireless charging methods, before and during fleet launch
- Information regarding service and failure handling

3.5 Time for launch

After the intensive preparation phase, the project reached launch according to schedule. March 3rd, 2022, the project went public at the new charging station at Lindholmen Science Park in an announced event for invited guests and media. The launch received lots of attention from both local and global media. Together with press releases from all the stakeholder parties, there was a simultaneous spread of news all over the world. News was reported on various media channels. As a direct consequence, information meetings were also held the days after the launch with media houses that wanted to have more information and the opportunity to ask dedicated questions.

During the project period there have been many national and international technical demonstration visits at the charging station at Lindholmen Science Park for e.g. politicians, city developers, or technical staff. On some occasions, these demonstrations have been organized together with presentations regarding the overall transformation into a sustainable and electrified transport system in the City of Gothenburg.

With the launch of the first wireless charging station in Gothenburg, the fleet test started off initially with six Volvo XC40 cars converted to wireless charging taxis. The fleet gradually increased reaching a total number of 20 cars by the end of 2022. Due to the general low knowledge of EV driving in taxi operations in combination with particularly low knowledge about wireless charging technology, the sales process was initially slow. But with the first cars rolled out and activated on the streets and with the first driver testimonials and mouth-to-mouth-propaganda, the rest of the car sales and deliveries went much smoother.

3.6 Regular meetings with drivers

Since the project started off in March 2022, the project has been organizing a total of six dialogue meetings between stakeholders, car owners (transporters) and their drivers. Besides information transfer about project goals and findings, the meetings also served as Q&A sessions for any of the user questions. Additional to the dialogue meetings, a frequent ad hoc exchange between the stakeholder team and transporters/drivers took place, also through frequent field visits. Initially, focus was put into safeguarding knowledge among the drivers on how to align and control the charging procedure. Other frequent questions were related to maintenance and service procedures and some adjustments were made improving the solutions for achieving smother operations at the service workshop.

3.7 Data collection and analysis

During the technical preparations all 20 vehicles were equipped with logging equipment to gather vehicle data throughout the test period. Data has also been collected from the charging stations to monitor wireless charging usage and performance. The collection of data has been vital for evaluating usage, limitations, potential, and robustness of the integrated system in a real-world use case.

3.8 Assessment of user perspectives

A major purpose of the fleet test, beside technology verification, was to gather better understanding of usage preferences and patterns, e.g. regarding the user's charging strategy and driving patterns. Frequent and repeated interviews with the users throughout the test period, aimed at understanding the user perspectives regarding acceptance, adoption, and practical challenges of the wireless charging technology in taxi operations, have been performed. Also, the evaluation of battery electric driving in comparison to conventional fuels (diesel, petrol, biogas) for taxi operations has been considered.

To further investigate and explore barriers, technology adaptation processes, and driver preferences, a master's Thesis [2], conducted at Chalmers University of Technology, was supervised by the stakeholder group. The thesis, performed during the second project year (spring semester 2024), explored the adoption and diffusion of wireless charging technology and electric taxis in the context of the project and Gothenburg Green City Zone.

The research is based on theoretical frameworks such as

- Utilizes models like the Technology Acceptance Model,
- Unified Theory of Acceptance and Use of Technology,
- Diffusion of Innovations Theory, and
- ADKAR model - Focuses on guiding individuals through the change process by addressing five key stages (Awareness, Desire, Knowledge, Ability, Reinforcement)

It aimed to understand the barriers that hinder the widespread adoption of these technologies and how they can be overcome. In the thesis a comparison of past and current challenges faced by electric taxi fleets, especially with integrated 43kW wireless charging, was performed based on deep interviews with drivers/transporters. Results were extracted based on data collection through qualitative interviews with taxi drivers, transporters and stakeholders together with quantitative analysis of charging behaviors.

4 Major project findings

From the city development perspective, wireless charging systems offer an attractive solution for access to charging opportunities in city central areas without requiring disturbing overground installations roadside or on sidewalks. However, enabling charging infrastructure in city central areas can be seen as a conflict of aims considering municipal and societal targets of reducing the amount of road traffic.
Although the convenience and user friendliness of inductive charging, it does introduce a further method of charging, requiring further additional technical installations in the vehicles (i.e. costs) and adding further complexity regarding charging strategies for the vehicle users.

The following sections point out the major findings after the three-year fleet test period, with further findings and explanations based on data analyses as described in section 5.

4.1 Project roll-out

A major learning from the project roll-out is the importance of mutual understanding between technology development and supply (R&D) and the user group of the solution in a real-world application. At project start not completely aligned expectations on project aims and scope could be handled timely thanks to the frequent stakeholder group meetings and transparent processes. For successful adaptation of new technical solutions, the operational conditions must be taken into close consideration.

With the launch of the project and roll-out of new vehicles, many drivers were eager to start using their new vehicles and innovative technology in real operation even before completed introduction and education to the wireless charging handling procedure. This led to incorrect handling and some initial irritation and lack of trust in the new technology. Thanks to the tight dialogue between the stakeholders this could be caught early and handled quickly.

The continuous monitoring of vehicle and charging infrastructure utilization data showed early that reminders to the drivers of using the new charging stations, as also defined in contracts for project participation, were necessary. This mindset and behavioral change among the users have shown to be perhaps the most difficult and sensitive aspect of the fleet test and has prevailed throughout the test period. However, gradually over time, more and more drivers learned and accepted how to use the wireless charging system in a practical way, much based on mouth-to-mouth information exchange among the users (group trust).

Adoption is hampered by interconnected barriers such as technological limitations, economic feasibility, and user acceptance. Addressing these barriers holistically is crucial for broader adoption.

In this project, affiliated transporters were offered attractive assignments within the municipal service travel contracts, i.e. fixed transport assignments such as school or medical transports and taxi services for the disabled. The routes for these transports means did only to a certain extent coincide with the locations of the inductive charging infrastructure, which hence did not offer the convenient support initially expected.

In summary, the frequent dialogue and exchange between stakeholder team and vehicle users (transporters/drivers) have proven very valuable and essential to align expectations, mutual understanding and has gradually led to an improved project execution and increased trust among the parties involved.

4.2 Driver preferences in taxi operations

A major purpose of the test period has been to evaluate wireless charging technology in taxi operations aiming at developing suitable business solutions and offers for electrifying various transport tasks in urban environment. Although wireless charging has been the main topic in this research, it shall be noted that the perception of users with high daily mileage and relatively unexperienced with electric vehicle driving in general, will be even more complex when introducing an extra option for charging methods with specifications (charging speed and usage) somewhere in between more familiar AC- and DC-charging specifications.

Regarding taxi operations, the dominant aspects of charging preferences have shown to be

- Acceptance of technological solution (EV and wireless charging)
- Convenience of usage (access to charging infrastructure and user friendliness)
- Price / price model

As an example regarding choice of charging method, it was found out that preferences will depend on living and workplace distances as well as access to home charging overnight.

The thorough assessment of driver preferences and expectations done in the master's thesis resulted in the following key insights.

Technological Experience

- **Performance**: Drivers generally found wireless charging convenient, but a minority of drivers noted occasional unexpected issues with charging speed and reliability.
- **Ease of Use**: Many drivers appreciated the ease of use, as it eliminated the need for plugging in cables, which was particularly beneficial during busy shifts.

Economic Considerations

- **Cost Concerns**: Drivers expressed concerns about the possible high costs associated with the wireless charging infrastructure and the potential impact on their earnings.
- **Maintenance**: A minority of drivers mentioned the possible need for regular maintenance of wireless charging pads, which could add to operational costs.

Behavioral Aspects

- **Adoption Willingness**: While some drivers were enthusiastic about the technology, others were hesitant due to perceived complexity and lack of familiarity.
- **Training and Support**: Drivers highlighted the importance of training and continuous support to help them fully understand and utilize the technology.

Operational Challenges

- **Availability**: Limited availability of wireless charging stations was a significant barrier, making it difficult for drivers to rely solely on this technology.
- **Downtime**: A minority of drivers experienced vehicle downtime due to technical issues with the charging pads, which affected their daily operations.

Environmental Impact

- **Sustainability**: Drivers recognized the environmental benefits of wireless charging and electric taxis, such as reduced emissions and noise pollution.
- **Urban Integration**: There were mixed opinions on how well wireless charging stations were integrated into the urban environment, with some drivers finding them conveniently located and others facing accessibility issues.

The following diagram shows the interview result comparing the drivers/transporters prioritizing of cost vs charging speed vs charging availability.

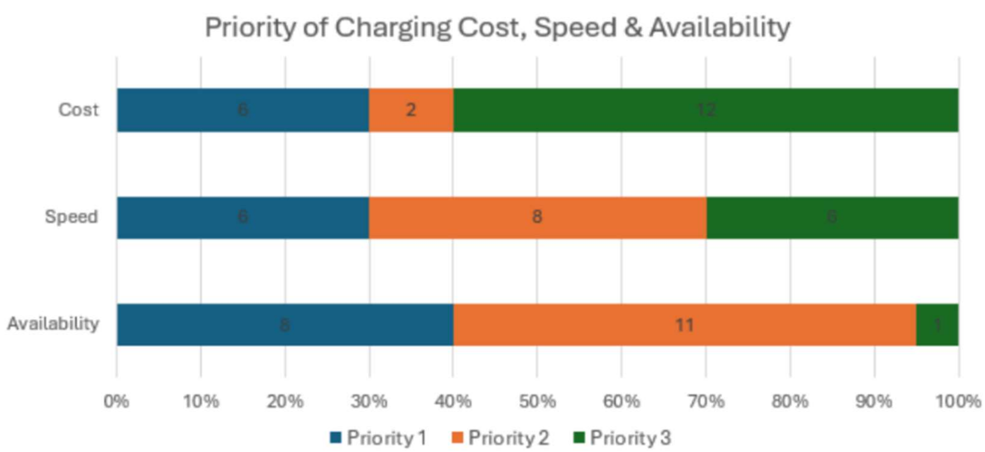

Figure 4: Spread of priorities among the users (cost, speed and availability)

Some interviewees mentioned that the availability of charging stations is an important factor, especially in the areas where they usually have their regular routes. For some, this was the most important factor, and it was only picked once as the last priority as it directly affected their daily logistics route. The charging power was the second most prioritized. Some interviewees argued that high power charging stations enable the drivers to streamline their use of the car, thus reducing waiting times and increasing overall convenience. The cost aspect was also central for many of the interviewees, and some interviewees argued that the high charging costs could undermine the fuel cost benefits of choosing an electric car, making the pricing structure of charging a deciding factor.

It has shown clear that concerns and priorities differ between transporters (vehicle owners and business owners) and their drivers. The transporters prioritize the business case in larger extension, while the drivers tend to prioritize convenience and speed (immediate access and charging speed). This can be directly related to the respective business models.

In summary, once accepted and integrated in daily taxi operations, the test period has shown that wireless charging and electric taxis offer significant operational and environmental benefits.

4.3 Opportunity Charging

The occupational pattern for the taxis shows that they are mostly occupied during morning and afternoon hours, a time when transport needs are higher for school and medical care visits. Charging during midday between 10:00-14:00 is shown to be normal behavior and fits well with usage of wireless charging, specifically if there has been an overnight slow charging prior to morning trips.

The dialogue with the drivers and transporters as well as collected data have clearly shown that the location of the charging station is vital for the function as "opportunity" charging and a high utilization. Opportunity charging is also a necessary method to keep the battery within recommended SOC limits and therefore keep a longer battery life for high utilization vehicles.
Since there were only two charging stations available in the taxi fleet project it was not obvious that the drivers used wireless charging as an opportunity charging method.

4.4 Benefits of wireless charging versus conductive charging

From a station owner's perspective wireless charging system proves to be beneficial in many ways.
Maintenance has proven to be very low, as without physical connection points there's no wear and tear on connectors and cables. The risk of damage of charging EVSE's is infinite. The integration of charging transmitters in road surface has worked very well in winter conditions and has been robust with snow removal services. A positive aspect of charging transmitters in the ground is that there is no maintenance required at the ground installation areas where the vehicles are charged. In comparison, street organized conductive charging can be problematic regarding maintenance needs but also regarding the cable handling and their risk of being run over.

4.5 City development and business models

Regarding city development, wireless charging technology offers an attractive solution to ease the use of pure electric vehicles in urban areas. Not only for taxi services but all kinds of commercial transport. The advantages are related to e.g.

- battery size – influencing vehicle cost and lost pay load capacity due to heavy batteries positively
- convenience – user friendly automatized charging sessions, and
- city scaping – no disturbing curbside installations

The fleet test period has shown that further wireless charging stations are needed to fulfil the charging energy needs of taxi vehicles, which in turn would require a larger user collective, i.e. other urban transport tasks, to achieve a sustainable business case for the technology.

The general development of public fast charging infrastructure during the project period has been rapid, and since project start the amount of fast DC charging has greatly increased. In comparison to the fair number of 150 kW DC chargers available today in Gothenburg, the taxi fleet tends to prefer these over the 43 kW wireless chargers, especially at peak traffic periods (morning and afternoon hours). The project's trials with adjusted price models have shown a limited effect.

The test period has confirmed that various charging methods are requested from the users to fulfil the daily charging needs, from slow (AC) overnight charging opportunities in the residential areas, over convenient wireless top-up charging and fast DC-charging during work shifts. Deeper investigations imply that a faster development of AC-charging in city districts with low socio-economic status is requested. I.e. areas where most of the active transport companies are registered and drivers reside.

In general, the strategies for development and build-out of charging infrastructure are relatively unmature in society today with a lack of data for the actual charging needs of various user groups. Inadequate coordination between urban planners, land/real estate owners, fleet users and charging point operators prevents a strategic roll-out of charging infrastructure.

5 Data Analysis

This chapter describes the analysis information and some conclusions from the statistical data gathered. In many ways, the data confirms that wireless charging is very much an individual aspect of adoption, but similar differences can be found regarding usage AC and DC conductive charging. With the fleet test and its massive data acquisition, it was found that there is a spread of individual usage patterns and together with interviews and regular feedback, the picture becomes a bit clearer.

5.1 Data concerning the fleet operations

During the fleet test a lot of data was collected that verified the actual outcome. There were no numerical goals set up for the usage percentage of wireless charging but underlaying expectation was that there should be some demand justified by the increased convenience factor. Over time we understood from interviews and stakeholder meetings that access to several charging stations and their geographical placement play an important role for the individual drivers when deciding which charging method to use.

Two data sources were used to understand wireless charging behavior, data collections from the wireless charging stations and data collection from the individual vehicles representing the vehicles statistical usage. From the statistical data, we develop the understanding about usage factors for the different charging methods per vehicle.

In parallel to the charging usage statistics there was also a substantial amount of data collected with regards to component usage which confirms life and robustness of the EV related components installed in the cars.

5.2 Statistical data from Charging station

From the wireless charging stations there are the following usage statistics reported.

Table 1: Statistics for wireless charging station usage

		Charging stations	
Wireless charging statistics	**Unit**	**Lindholmen**	**Medicinaregatan**
Energy transferred	MWh	35 (26%)	100 (74%)
Charging sessions	number	2200	6700
Uptime	%	99,8	100

Comments on the data: Drivers seemed to favor the station located at a car park area at Medicinaregatan due to its closeness to Sahlgrenska hospital. A virtual queue system for customer assignments doesn’t require the taxis to line up in front of the hospital entrance and the wireless charging station, located in a car park area, just a few minutes away from the hospital was found very attractive.

When it comes to Lindholmen station, the first charging station that was ready for fleet launch, this station area turned out to be more populated with competitor taxi companies and less close to Gothenburg central areas. With this background knowledge in mind, we learned that both the number of stations and placement of charging stations is important when setting up small fleets such as the wireless charging test fleet. We could also see that more and more public DC charging stations were set up in different places around Gothenburg areas during the fleet tests period which also might explain that access to charging in general increased but not necessarily in favor of the wireless alternative.

5.3 Vehicle mileage and usage

Total mileage for the fleet, 1st of April 2025, showed 4,3 million km which means about 100 times around the world. This is equivalent with an average of 314 km daily calculating on 5 usage days per week.

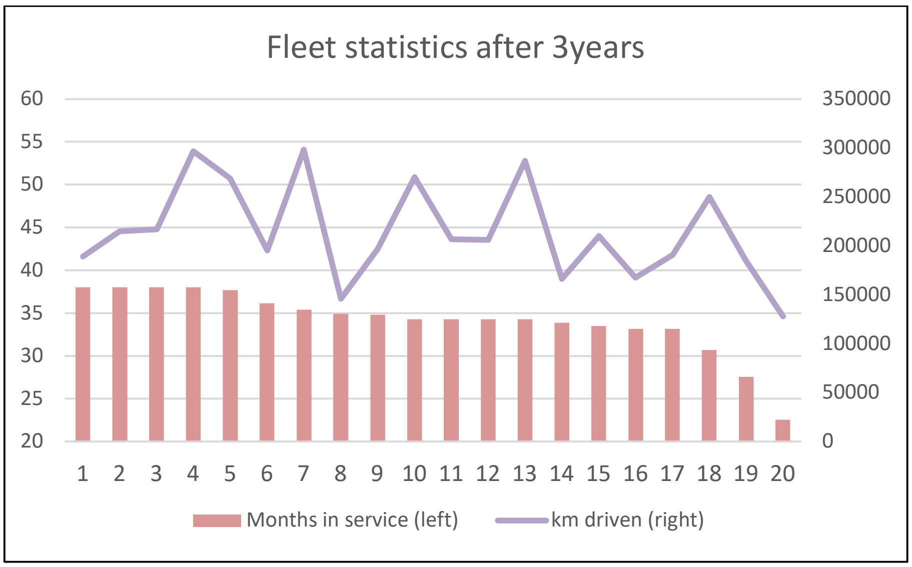

Figure 5: Driving statistics and months in service

The driving statistics can also be summarized in Table 2 below:
The major reason for milage difference is the age of cars e.g. month in service where the first six cars went into taxi traffic in February 2022 and the last car was delivered to a taxi company in May 2023.

Table 2: Driving statistics on fleet level

			Car	
Car average usage statistics	**Unit**	**Total fleet**	**Average**	**Maximum**
Total mileage	* 1000 km	4300	214	298
Months in service	number	683	34	38
Monthly distance	km	125678	6284	8427
Daily driven distance	km	6280	314	421

5.4 Wireless Charging usage percentage among the 20 drivers

The outcome from the fleet test regarding usage percentage of the wireless charging stations is one of the more interesting aspects in this study. In Figure 6, below it can be found that 5 drivers use wireless charging to a greater extent than average, which ends up to 13,5%. This usage comparison is based on individual wireless energy usage compared with the total energy usage.

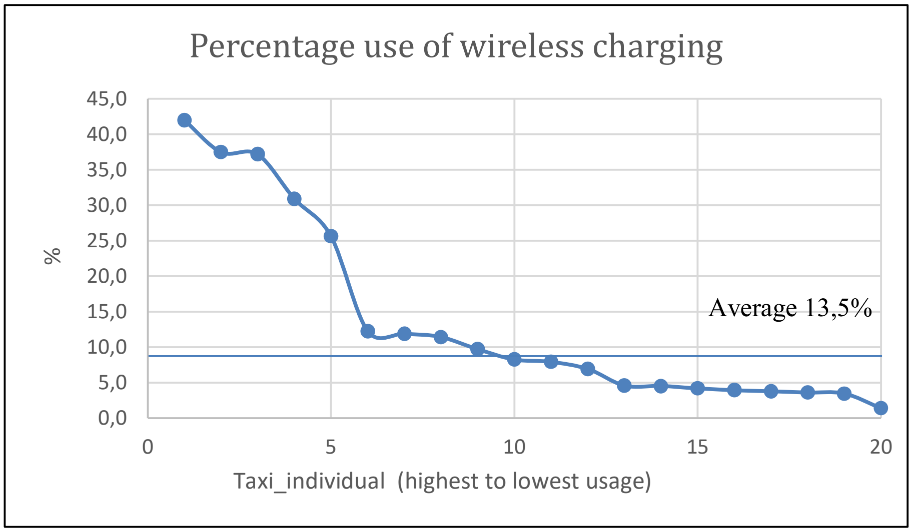

Figure 6: Statistics for individual vehicle energy usage of wireless charging

Comments on figure 6: The two vehicle owners with the highest percentage wireless charging are using AC charging to a very big extent which points to the fact that home charging is beneficial for taxi drivers, starting off with a fully charged battery in the morning, whereas vehicle owners which are forced to use public charging, might need to charge their vehicles with higher speed more frequently. Another perspective for charging frequency analysis is divided into fleet study periods. This analysis clearly shows that wireless charging usage as well as vehicle usage is lower during big holiday seasons such as new year and summer holidays. The natural explanation for this is that lots of taxi usage is made during weeks where schools are open (publicly contracted service travel) and when people are working under a normal 5-day week.

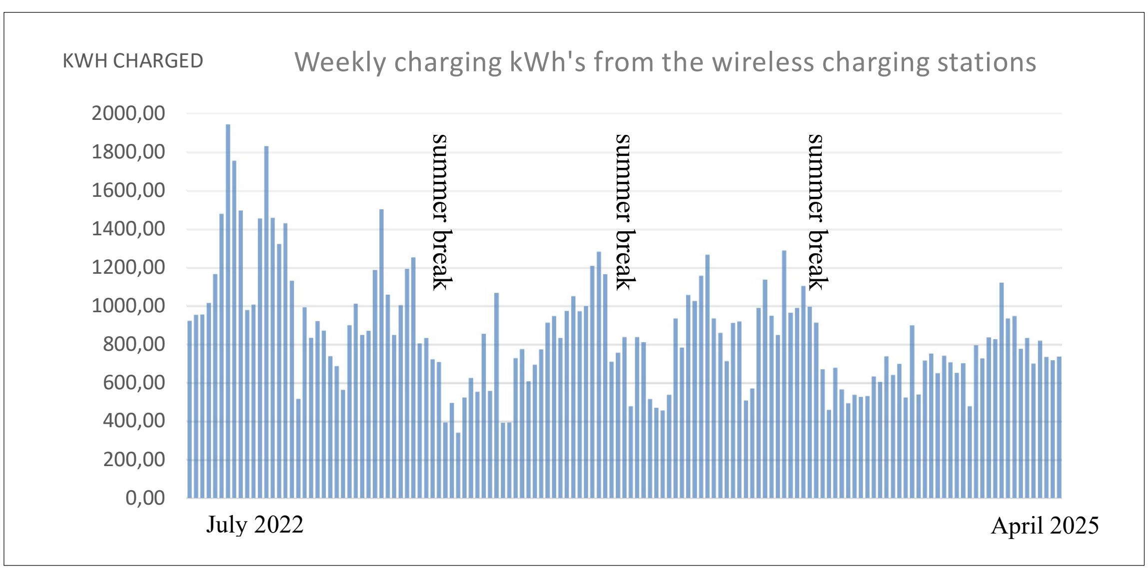

Figure 7: Weekly total energy usage of wireless charging

5.5 Share of available charging method (DC, AC, Wireless 43 kW)

One of the more important questions in the fleet is around how the drivers have selected between the 3 different charging methods. We have understood that there are several underlaying mechanisms behind the selection of charging methods such as car ownership or employee only, but also driver living situations with or without access to home charging are influencing factors. Also driving routes in the daily environment are important.

Some drivers connected to the Cabonline membership were also located in regional sites outside Gothenburg, which makes both driving distances and access to wireless charging more difficult. We can therefore expect that there will be some differences in usage percentage.

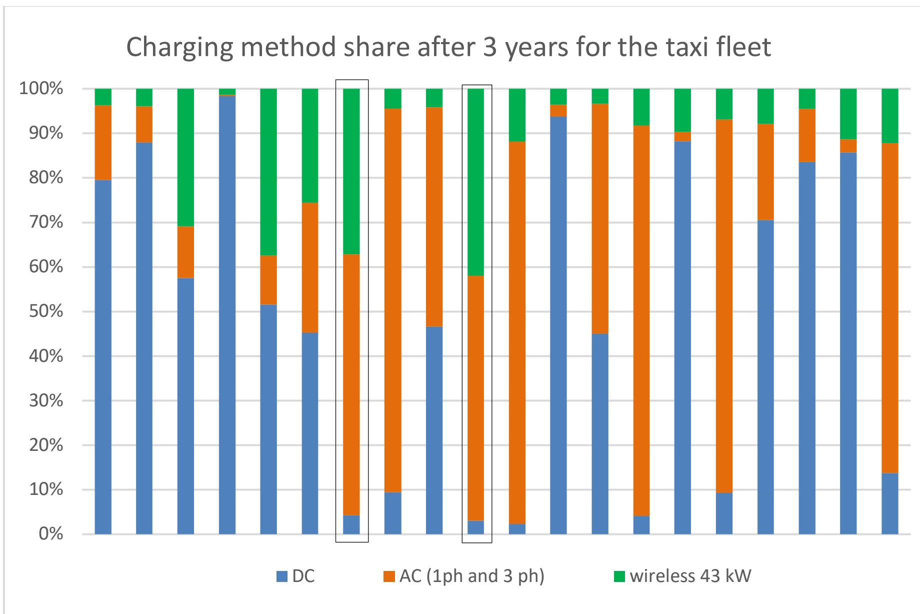

Figure 8: percentage use of wireless charging

Through various qualitative analyses the project has shown that taxi drivers in general prioritize charging power and location of charging rather than the energy cost. Convenience of the charging experience is valued, but in real traffic and based on the available locations of wireless charging this is lower prioritized than location and speed. A variation can be seen between high traffic intensity vs low traffic intensity, where charging cost perspective is rated higher during low traffic intensity periods.

5.6 Health and status of the components

It has been found that the wireless charging technology is robust and has served the users well. For the drivers the major challenge has been related to alignment and sometimes ecosystem acceptance of the chargers. A few cases of faulty charging receivers are noted but these cannot be seen as systematic failures. The fact that the vehicle assemblies were integrated into vehicle base that was not designed for wireless from beginning caused the vehicle height somewhat reduced under the front wheels which potentially increased the exposure to hits on vehicle underbody. Learning from the component installation is that the FOD cameras were in an area with more exposure to external damage. It cannot be excluded that some drivers are less cautious about their vehicle than others, especially if they are only driving, not owning, their taxi vehicles.

The operational availability (uptime) of the charging stations has been very high. See 5.2.

Vehicle receiver failures have been limited to 5 cars over the total fleet period meaning that cars were taken out of traffic for a charging receiver change. Usually, the resulting downtime, including logistics, takes less than 1 week. There were two types of reasons for the need to exchange receiver pads. Those reasons were internal hardware failures and external shock forces from vehicles hitting external objects. Given the mileage of 4,3 million km. an expected receiver failure occurs at 860.000 km which is excellent for a test fleet at a TRL level around 7 mainly given by given a prototype vehicle integration.

One of the more interesting aspects of a high milage battery electric vehicle fleet is the remaining life of the batteries for vehicles in taxi environment. The conclusion from the vehicle collected data is that vehicle mileage at 300.000 km is not any cause for battery life limits. Battery health data shows that most of the batteries are still at an high SOH level (State of Health) at 90% or more.

5.7 EMC Tests

EMC (Electromagnetic Compatibility) is naturally a major concern when it comes to wireless charging. Questions about the spread of electromagnetic fields in the near proximity of the wireless equipment during usage as well as possible interference with radio communication was of detailed interest Several tests was performed at Volvo Cars development facilities regarding magnitude of electromagnetic field strength around and inside the vehicle which resulted in internal reports. An external report regarding a radio frequency interference performed at Volvo proving ground is found in [3]

6 Conclusions and outlook

In summary, the three-year test period with the 20 taxis in normal traffic has shown great potential for wireless charging for taxi operations, both regarding business case, convenience and attractive urban scaping to a more sustainable transport system. The performed study has contributed to understanding the integration of advanced technologies in sustainable urban mobility and offered valuable insights for future research and policy development.

However, to achieve a scale-up of the solution, a number of parameters need to be considered and managed, primarily the number and distribution of wireless charging locations, the charging speed, the number of users and user groups, as well as strong connection to municipal urban planning strategies.

Further investigations of the potential for wireless charging usefulness for taxi services involve an increased number of wireless charging stations covering a larger geography. An increased wireless charging network would require further use cases other than taxi services to assure utilization and ROI for the CPO.

For further identification of potential user groups including analysis of wireless charging opportunity for optimizing transport efficiency in energy, load capacity and time planning perspectives, more investigations are needed. Such investigations also need to include the city development perspective and the potential for wireless charging technology to support cities in reaching their overlaying climate goal but offering access to roads for installing wireless charging equipment for public access.

Regarding user preferences the fleet test results can be summarized in the following recommendations:

- **Enhancing Reliability:**
  High reliability and high wireless charging power is key to meeting drivers' operational needs.
- **Cost Management:**
  Providing financial incentives or subsidies to offset the high initial costs.
- **Comprehensive Training:**
  Offering detailed training programs and continuous support to increase driver confidence and adoption.

Expanding Infrastructure:
Increasing the number of wireless charging stations to ensure better availability.

- **Urban Planning:**
  Ensuring that wireless charging stations are strategically placed to maximize convenience and accessibility for drivers.

For scaling up the solution, a particular focus on mass deployment of wireless chargers is needed. For this, extended investigations on scalability, economics feasibility, and impact on the power grid are beneficial. Partly to provide practical insights for policymakers and industry stakeholders.

6.1 Autonomy of charging

The fleet studied concentrated on taxi usage where the charging method used was found to depend on the charger density and geographical placement of chargers. In the future, when autonomous driving enters the mobility market it is likely that autonomous charging methods, where wireless charging is a strong candidate, will be needed and further developed.

6.2 Value of clean streets in double meaning

An important argument for promoting wireless charging solutions in urban areas is the fact that most of the infrastructure can be hidden underground. This prevents disturbing and exposed installations along curbsides and sidewalks that could cause trip hazards or just undesirable esthetics. However, each additional underground installation in urban environment risks conflict with all other existing and necessary underground installations (piping, district heating, electricity, sewage, etc) and must be closely investigated at each potential location.

Nonetheless, wireless charging offers attractive access to charging infrastructure for several user groups of (predominantly commercial) transport in urban areas, simplifying both the charging process and vehicle charging strategy with a comprehensive network of stations. The solution can take the burden off both the investments in electric vehicles as a smaller battery is sufficient as well as the driver through the semi-automized process. And as a result, the solution has the potential to support clean streets with regard to both installations and emissions.

6.3 Outlook

To make use of the projects learnings and to meet the needs of further investigations and expanded user groups, an extension of the project is under consideration.
The aim is a continued project with an increased number of charging stations and vehicles including other use cases and vehicle categories and brands. The current interest for technology and usage is motivating for a potential prolongation of the current project within 2-3 years.

Acknowledgements

In a project like this it is impossible to acknowledge all the people involved. Without mentioning specific people, a big applause should be sent to all the enthusiastic people inside Volvo Cars and the project team inside the stakeholder companies. The willingness to support has been outstanding, which has led to great results and learning.

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Presenter Biography

Robert Eriksson has a M.Sc. in Electrical Engineering from Chalmers University. Robert has more than 30 years of experience at Volvo Cars working with various electrification research and development programs and holds a role as Senior Technical Leader in the field of Electric Propulsion Architecture and Electromobility. Robert is actively leading several activities with external partners in the global arena closely related to the automotive industry transformation with a sustainable society at focus

Anne Piegsa, M.Sc. in Engineering Physics, PhD in Automotive Mechatronics, is since 2020 Process Manager at Business Region Goteborg, City of Gothenburg, responsible for coordinating the city´s transition to an electrified transport system. Anne has an additional 10 years´ of industrial experience in electromobility R&D as well as 10 years´ of academic experience within R&D in vehicle control systems including systems simulation focusing on-road and off-road electromobility.

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Gabriel Samuelsson has for the last ten years worked with Wireless Charging development for Qualcomm Halo, CEVT, NEVS, SiNIX and InductEV. He has developed, designed and integrated wireless charging systems for more than 20 vehicle models from some of the largest OEMs in the world. During the last four years, Samuelsson led InductEV’s high power wireless charging system installations in Oslo and Gothenburg. He is also the inventor of a dozen patents in the field of magnetic design for wireless charging. Furthermore, he has a Master of Science degree in Mechanical Engineering from The Royal Institute of Technology and Chalmers University in Sweden.

Samra Galled has been an integral part of Cabonline, the leading taxi network in the Nordics, for over 15 years. Throughout her tenure, she has demonstrated a strong dedication to sustainability and diversity across various roles within the company. Currently, Samra serves as the Area Manager for the South and West regions, where she continues to drive excellence and innovation.