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Feasible charging infrastructure for battery electric trucks in Amsterdam

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The municipal of Amsterdam plans to implement a zero emission (ZE) zone by 2025. A plan is required to implement a battery electric truck (BET) charging infrastructure. To derive at the preferred feasible BET charging infrastructures, the research assesses the available BET, available charging methods, stakeholder perception, and BET energy demand in the municipality of Amsterdam. The research suggests a stationary catenary charging infrastructure, with the carrier, shipper, and charging point operator responsible for constructing, maintaining, and operating the charging stations. The municipal should take a pro-active role in the implementation and are advised to postpone the ZE zone implementation to give more time for technology development of BET and stationary catenary, and give more time for the construction of the charging stations.

KEYWORDS
Amsterdam, Battery electric truck, Charging infrastructure, Charging method, and Zero emission zone

1 | INTRODUCTION

The municipality of Amsterdam has the ambition to have the city logistics running on zero emission (ZE) by 2025 [1]. One of the zero emission solutions is the use of battery electric trucks (BET), that require a charging infrastructure to accommodate them with energy [2]. Current literature has little research on the implementation of BET charging infrastructures. This makes it difficult for the municipal to imagine how a feasible BET charging infrastructure would

Abbreviations: 3dSA, Three-Dimensional Stakeholder Analysis; BET, Battery electric truck; FC, functional constraints; FO, functional objectives; NFC, non-functional constraints; NFO, non-functional objectives; RQ, research question; SQ, Sub-question; ZE, zero emission.

look in their municipality and making it difficult to establish a plan of action for the introduction of a full-scale ZE zone inside the ring of A10 in Amsterdam before the end of 2020 [3]. Through literature study and data analyses, this paper will show how large the energy demand of the city logistics in Amsterdam is and how a feasible charging infrastructure which can supply this energy demand would look.

The rest of the paper consists of five sections. Section 2 presents the methodology used in the research. The results of the research are presented in section 3. Followed by the discussion in section 4 and conclusion in section 5. Finally, in section 6 recommendations are given for further research and for the municipal of Amsterdam.

2 | METHODOLOGY

To understand the size of the energy demand in Amsterdam by BET, a case study, using data analysis, is performed for the municipality of Amsterdam. The analysis uses data on the municipality out of 2018 (e.g. number of registered trucks in the municipality and their average annual traveled distance) provided by 'Centraal Bureau voor de Statistiek (CBS)'. The analysis also uses data on the characteristics of a BET (e.g. energy consumption and energy capacity). Equation (1) and (1) are used in the data analysis to calculate the total daily energy demand and the average daily number of charging moments. The location of the charging moment is based on a literature study on the charging strategy of city logistics.

$$E_{total}^{daily} = \frac{d_{N2}^{annual} \cdot n_{N2} \cdot c_{N2} + d_{N3}^{annual} \cdot n_{N3} \cdot c_{N3}}{365} \tag{1}$$

with:

E_{total}^{daily} : Total daily energy demand [kWh]

d_{N2}^{annual} : Average annual traveled distance per N2 [km]

d_{N3}^{annual} : Average annual traveled distance per N3 [km]

n_{N2} : Number of registered N2

n_{N3} : Number of registered N3

c_{N2} : Energy consumption by N2 [kWh/km]

c_{N3} : Energy consumption by N3 [kWh/km]

$$N_{total}^{daily} = \frac{d_{N2}^{annual} \cdot n_{N2} \cdot c_{N2}}{365 \cdot e_{N2}} + \frac{d_{N2}^{annual} \cdot n_{N2} \cdot c_{N2}}{365 \cdot e_{N3}} \tag{2}$$

with:

N_{avg}^{daily} : Average number of charging moment per day

e_{N2} : Energy capacity of a N2 [kWh]

e_{N3} : Energy capacity of a N3 [kWh]

To understand how a feasible charging infrastructure that can supply the energy demand looks, a literature study and a Three-Dimensional Stakeholder Analysis (3dSA) are performed to assess the available BET, available charging methods, and the stakeholder perception. The literature study on the BET and their charging methods will primarily use commercial sources that are developing the technologies. The 3dSA is used on the stakeholders that are affected or affecting the successful implementation of the charging infrastructure. Based on the assessments and the size of the energy demand, the preferred feasible charging infrastructure for Amsterdam is suggested, with the number of the charging stations, using equation (3).

$$S_i = \left\lceil \frac{E_{total}^{daily} \cdot f_{depot}}{P_i \cdot t_{daily}} \right\rceil + \left\lceil \frac{E_{total}^{daily} \cdot f_{road}}{P_i \cdot t_{daily}} \right\rceil \tag{3}$$

$\forall$ i = plug-in or catenary

with:

S_i : Number of required charging stations

f_{depot} : Fraction of the charging moments at depot

f_{road} : Fraction of the charging moments along the road

P_i : Power of the charging station [kW]

t_{daily} : Duration a charging station is used in a day [hour]

3 | RESULTS

3.1 | Size and location of the energy demand

In 2018, a total of 2.502 trucks were registered in the municipality of Amsterdam, consisting of 685 N2 trucks and 1.817 N3 trucks, according to the CBS database. On average an N2 truck travels 16.541 km annually, and an N3 45.758 km. The literature study on BET shows that on average an N2 BET would have an energy consumption of 1 kWh per km with an energy capacity of 150 kWh, and an N3 BET would consume 1,8 kWh per km with an energy capacity of 165 kWh [4][5][6][7][8][9][10][11][12][13]. If all the resisted trucks in 2018 were BET they would have a total energy demand of 440 MWh a day (equivalent to the annual energy demand of 220 households) with the BET using the charging stations 2.700 times a day. Based on the report of Topsector Logistiek [14] that looked at the charging strategy, it can be said that the charging moments, thus energy demand, of city logistics is 80% at the depot and 20% along the road.

3.2 | Available BET

Literature study on the development of BET looked at commercial sources by DAF [4], Volvo [5], Mercedes-benz [6], Scania [7], MAN [8], Transport Topics [9], EMOSS [10], EForce [11], Tesla [12], and Kroon [13]. It shows that current operating BET are N2 diesel trucks that are converted into an N2 BET by companies such as EMOSS. The development of N2 and N3 BET by truck manufacturers (e.g. DAF, Volvo, Mercedes Benz, Scania, MAN, Iveco, and Tesla) are still in the pilot and testing phase. However, it is still unclear when these BET by truck manufacturers will become available on the market, as these manufacturers are currently focused on getting battery electric passenger cars and other smaller vehicles on the market.

3.3 | Available charging methods

A BET at a full stop can be charged using the stationary charging methods: plug-in, battery swap, stationary catenary, and stationary wireless charging. The most promising stationary charging method for the municipality of Amsterdam is the stationary catenary. It has a high power of 600 kW, an efficiency of 97%, lower space requirements than the other charging methods, and most importantly the technology is already in use with some public bus lines in Schiphol, Amsterdam, and other Dutch cities [15][16][17]. It's a downside it the limited modes use, due to its height only buses and BET can use the charging method. Figure 1 illustrates the stationary catenary used with buses. A BET can also be charged when it on the move using the dynamic charging methods: dynamic catenary, third-rail, and dynamic wireless charging. The most promising dynamic charging method for the municipality of Amsterdam is third-rail. It has lower or equal visual distraction, physical obstruction, and high energy efficiency of 97% compared to the other dynamic charging methods. Additionally, the Swedish government is making plans to implement the system nationwide [19][20][21]. Figure 2 illustrates the schematic view of third-rail for BET.

3.4 | Stakeholder perception

Based on the reports by Wolbertus [23] Topsector Logistiek [14], Quak et al. [24], and Rijkswaterstaat [21] the 3dSA is used to identify and to label key players that play a big role in the successful implementation of feasible charging infrastructure as savior or saboteur. Truck manufacturers and gas station operators are labeled saboteur, meaning they have high interest, high power, and a negative/low attitude towards the implementation. The municipal, grid operator and carrier are labeled saviour, meaning they have high interest and high power, with a positive/high attitude towards the implementation.

3.5 | Preferred feasible charging infrastructure

It was found that third-rail charging infrastructure is not feasible for municipality Amsterdam. It requires third-rail to be located on city roads to supply the demand. However, this would use too much space in the city center.

The preferred feasible charging infrastructure uses a stationary catenary charging method, requiring 185 charging stations assuming they operate 6 hours a day. It consist of 160 private charging stations located at depots, shown in figure 3, and 25 public charging stations located along the road. The private charging stations should be owned by carrier or shipper, depending who controls the depot. The public charging stations should be tendered by the municipality and owned by the charging point operator. Owning a charging stations means they will be responsible for constructing, maintaining, and operating the charging stations. The municipality should take

FIGURE 1 Schematic view of stationary catenary charging for bus [18][15][17]

a pro-active role in the implementation by semi-controlling the market, being open for different charging methods, and providing permits, grants, and tendering to encourage the other stakeholders.

A sensitivity analysis on the number of charging stations in Amsterdam showed that a charging power higher than 800 kW does not significantly change the required charging stations anymore. It also showed that the energy consumption of the most dominant truck type (N2 or N3) impacts the number of charging stations the most.

4 | DISCUSSION

Considering the results presented in this paper, showing that there is still a lot of uncertainty and work required for a BET charging infrastructure, the ambition by municipal of Amsterdam to implement a ZE zone by 2025 is not advised.

This suggests preferred feasible charging infrastructure can supply the energy demand of all the diesel trucks registered to the municipality of Amsterdam in 2018 if they were BET. However, it is expected that the energy demand will be higher in 2025, especially when also considering the BET that drives in Amsterdam but registered elsewhere also have an energy demand in the municipality. Due to a lack of detailed information, the influence of cost and construction time was not considered in the research. It is assumed in this research that the BET will only opportunity charge with smart charging, meaning multiple trucks can use charging stations in a day without the peak energy demand affecting the electrical grid. However, smart charging is still in development, even for battery electric passenger cars. It is also assumed that the technical development of BET and the stationary catenary will be fully matured and market ready by 2025. However, it is still a question whether this technology will mature in time, with the market still focusing on battery electric passenger cars.

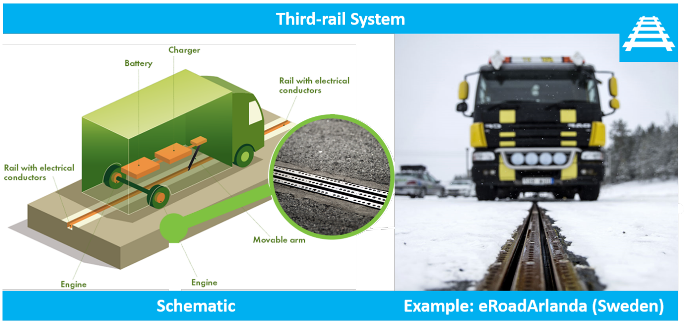

FIGURE 2 Schematic view of third-rail system [22].

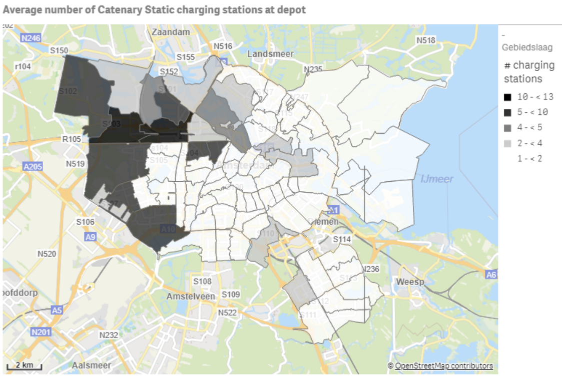

FIGURE 3 The required number of catenary charging stations at depot per Amsterdam 4-zip code, to supply 80% of the 2018 energy demand.

5 | CONCLUSION

Feasible charging infrastructure for the municipality of Amsterdam should use the stationary catenary charging method, with ownership by the carrier, shipper, and charging point operator. The municipality will play a large role in the implementation and should take a pro-active stance. The ambition to implement a full-scale ZE zone inside the ring of A10 in Amsterdam by 2025 is not advised. It would be too fast, giving too little time for the technology development of BET and stationary catenary, and time for the construction that is required after the technology is matured and market-ready.

6 | RECOMMENDATION FOR FURTHER RESEARCH

6.1 | Recommendation for further research

- **Recommendation 1:** Further research should look at a feasible charging infrastructure if ZE is adapted later than 2025. With the rapid speed of innovation, other charging methods may become available (e.g. wireless charging).
- **Recommendation 2:** Further research should consider the influence of other ZE fuel types (e.g. hydrogen) and (last mile) ZE vehicle types (e.g. electric cargo bikes). Additionally, further research should look into the transition phase which uses hybrid trucks, for example.
- **Recommendation 3:** Further research should look at behavioral changes by the city logistics (e.g. routing, transport modes, and truck type use) when they use BET instead of diesel trucks.
- **Recommendation 4:** Further research should look at the influence of external trucks that travel and require charging in Amsterdam but are registered elsewhere.
- **Recommendation 5:** Further research should consider the different uses of charging stations. Companies may want to use overnight charging over opportunity charging, due to the lower electricity cost or the absence of the high charging power.
- **Recommendation 6:** Further research should take detailed characteristics (i.e. cost, construction time, required surface area, grid upgrades, and the number of external truck) into account when they become available, and test if the suggested feasible charging infrastructure is still preferred.
- **Recommendation 7:** Further research should forecast the electricity demand in 2025 and the required feasible charging infrastructure.

6.2 | Recommendation for the municipality of Amsterdam

The current technology development of BET and charging methods are still at the pilot phase, and the construction of the charging infrastructure still has to take place after the technology development has matured. It seems too early to implement a full-scale ZE zone by 2025 and therefore not advised.

The municipal of Amsterdam are urged to construct a detailed plan of action to implement a feasible stationary catenary charging infrastructure and the ZE zone in phases, starting in 2025, at the city center and slowly expanding out. They are also urged to share their knowledge with other municipalities to have a national standardization.

The detailed plan of action should be based on a technical, transportation, and implementation forecast for 2025-2030. The technical forecast should show how the technical development of BET and charging stations will evolve and become available. The transportation forecast should show the change and growth in the transportation market, including the number and type of trucks that will travel in the municipality and the percentage of adaptation of BET, with the influences of other ZE solutions, including hydrogen trucks and electric cargo bikes. The implementation forecast should consist of detailed information for implementing the ZE zone and feasible charging infrastructure that takes the technical and transportation forecast into account. Thus implementation forecast should include the total cost, 6 zip code location, used square meters, grid upgrades, construction time, and type of charging stations used.

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