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Charging and refueling demand for heavy-duty zero emission trucks in Norwegian transport corridors

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Summary

To explore a future sustainable road freight based on battery electric and hydrogen fuel cell electric trucks, the need of infrastructure along the main Norwegian transport corridors was assessed. An annual electricity demand of 156 to 772 GWh in 2050 was identified depending on location, and a peak power demand of 59 to 114 MW considering an optimised energy station with local storage. The sensitivity analysis shows a solution where increased power prices and more volatile demand had the largest impact on the sizing of the energy station components. Grid connection was identified as challenging for some of the locations.

Keywords: Charging, trucks, grid, optimization

1 Introduction

Large potential for greenhouse gas abatement in transport lies in electrification. For road vehicles, the possible zero emission technologies, battery electric vehicles and hydrogen fuel cell electric vehicles, will result in increased demand for electricity and for regional and local grid capacity. The penetration of battery electric passenger vehicles in the Norwegian fleet is significant as well as the development of infrastructure serving it. While commercial vehicles, and especially trucks, are still in a very early phase.

The need of the infrastructure for zero-emission trucks (ZET) is currently exposed for technical pull as both battery electric trucks (BET) and fuel cell electric trucks (FCET) are in rapid development with first serial produced vehicles available [1] and in need for appropriate infrastructure. From the other side, policy push is expected with initiatives such as EU's Alternative Fuels Infrastructure Regulation (AFIR) [2].

The technical development of the infrastructure serving ZET is still immature as for example standards for recharging trucks with high power chargers are still in development as well as no refuelling standard is yet in place adapted for rapid large volume refueling of FCET [3, 4].

Fast charging of heavy duty vehicles has been identified as demanding to accommodate in the existing grid [5, 6], which sometimes is presented as a significant barrier [7]. While others argue that utilisation rate is more important than power outtake [8].

The work presented in [5] shows significant variation in power demand considering no queuing and modelling the charging station with temporal resolution of 1 minute. Their findings show significant intra-hour variation for charging. On the other hand, hydrogen production will preferably be operated at relatively constant pace to assure high utilization rate to recover the high investment costs of electrolyzer over large quantity of hydrogen produced [9].

Work has been done to estimate the charging infrastructure in Europe as a whole as an intent to quantify the impact of AFIR regarding charging station sizing [10]. The identification of optimal charging locations has been made for various countries to different extent [11, 12] as well as for hydrogen refuelling [13].

There has been made previous studies on sizing charging and hydrogen stations in Norway for selected locations [5, 14-16] and made the first nationwide estimations of the infrastructure costs [17]. In general, the previous work has been made on either rough assumption of the demand development, driving patterns, location choice and/or the system design of the energy station.

This works main aim is to understand better the demand for the infrastructure serving ZET in Norwegian transport corridors by combining three unique contributions: Developing a novel methodology to estimate demand with help of combining forecasted annual trips, including start and end location, with nearby located traffic counters with hourly resolution. Extrapolate the demand forecast for energy stations towards 2050 and lastly suggesting an optimal energy station layout using energy system modelling framework of TIMES.

In chapter 2 are outlined chosen methodology and key assumptions, while in chapter 3 are presented the results which are complemented with a sensitivity analysis. The main findings and shortcomings of the analysis as well as suggested further work is presented in chapter 5. Finally, acknowledgments are given in chapter 6.

2 Methodology and assumptions

The analysis was made in three steps as shown in Figure 1. As a starting point, some initial assumptions are needed (0a and 0b). The different scenarios in the analysis are based on different technical and market assumptions which changes over time from 2030 to 2050. The technical assumptions diverse into either a full electric future (BET only) or a case where both electric and hydrogen trucks are used (FCET+BET).

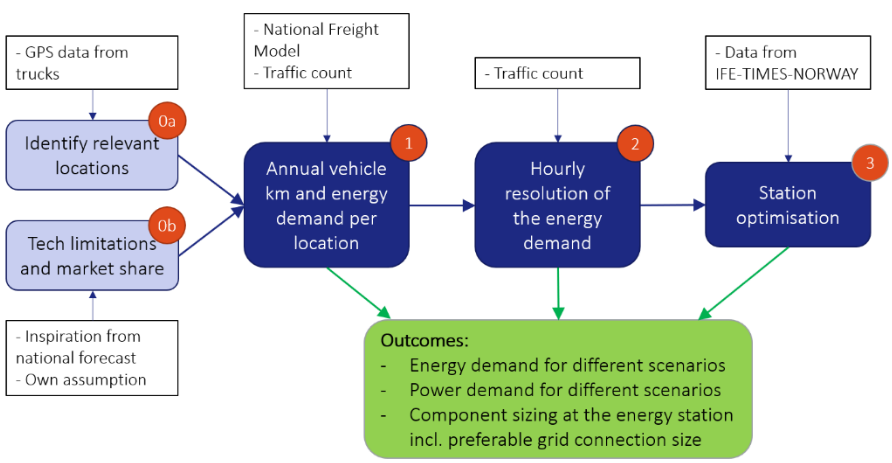

Figure 1 Workflow chart of local analysis

The details of selecting locations as well as the assumed technology limitations and market shares are described in detail in sub-chapter 2.1 and 2.2. In sub-chapter 2.3 more details are provided about traffic counts, while in sub-chapter 2.4 a rough estimation of grid capacities is presented.

To deduct the annual energy demand in each of the chosen locations, projections of traffic volumes in vehicle kilometers (vkm) made by the Norwegian Freight Model (NFM) for the Norwegian Transport Plan 2022-2033 are used as input in this work [18]. NFM is operated by The Institute of Transport Economics (TØI, by its

Norwegian initials). This model optimises modal choice for annual freight flows between Norwegian municipalities including imports and exports, choosing between truck, train and ships as freight options. In addition, the model selects optimal size and frequency for transport.

The NFM can also provide the composition of the origin and destination for the freight flow at any given point on the Norwegian road network, which has been used as input in this work. The important information extracted from this dataset has been following; how long are the trips by trucks passing chosen points in the transport corridor and how far has they driven from the start of the trip until arriving to the selected locations. As well as the total volume of trips made.

As a step to make quality assurance of the data from the NFM, the model output for the selected locations in 2018 has been compared with the annual traffic counts provided by the Norwegian Public Roads Administration (NPRA). After the quality assurance and based on the technology limitations and assumed market shares, described in sub-chapter 2.2, an annual energy demand was retrieved for the FCET+BET and BET only scenarios for 2030 and 2050.

To understand better the energy demand effect on the grid, the annual energy demand was disaggregated into an hourly resolution with help of the traffic count (described more in detail in sub-chapter 2.3) for vehicles longer than 16 m [19]. The annual energy demand was distributed equally over each counted truck during the reference year, from which an hourly profile was made based on number of trucks passing each hour. It can be seen as an average demand throughout the hour, while the intra-hour demand peak could either be much higher if all trucks arrive simultaneously or that queuing is present in the intra-hourly timeslot providing a constant demand over the entire hour. As current demand patterns from the traffic count are used, it induces large variability with few hours with very large traffic counts. It results in few hours with very high hourly peaks and gives most of the time a significant spare capacity at an hourly level. Due to this methodology choice, it is reasonable to assume that only limited queuing is expected at traffic flows equal to today. Another particularity of this approach is that now assumptions are required about the charging or refueling speed of an individual truck.

With this hourly demand profile and cost data taken from IFE-TIMES-Norway [20] corresponding to year 2030, an optimised energy station was identified considering the costs of grid connection, local hydrogen production and local battery by using a local optimisation model based on TIMES model framework and VEDA 2.0 user interface with high temporal resolution (hourly). The model was set up according to the illustration in Figure 2. The electricity prices for Oslo region from 2018 were used and a grid connection fee of 2000 NOK/kW was set.

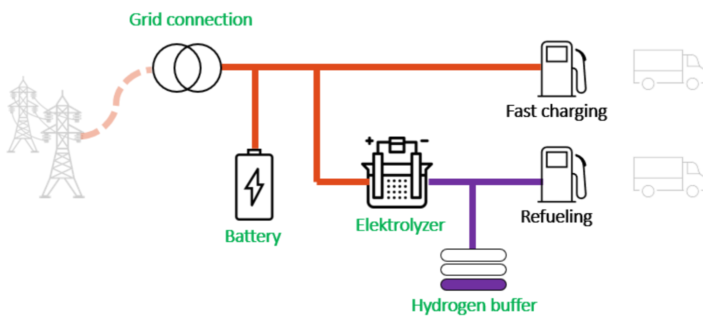

Figure 2 The scheme of modelling local energy station, where the system components in green text were optimized based on fixed demand of charging and refuelling.

2.1 Location

The aim of this study has been to assess the expected impact ZET might have on some of the important road freight corridors in Norway, where focus has been on corridors north and west from Oslo.

Truck drivers are according to EU legislation obliged for at least 45 min break when have driven for 4,5 hours. A natural location for recharging or refueling the future ZET would be locations where trucks are stopping already today to take their obligatory brake. As decision material for location selection was used data gathered by TØI of vehicle driving patterns, including breaks [21]. The final decision of locations was taken after a qualitative assessment. Common locations for trucker to have break in southern Norway as well as chosen locations for this analysis are shown in Figure 3.

For the corridor Oslo – Bergen, the main locations of stops of long-distance drivers (>4h) from GPS data were Gol, Lærdal and nearby Vøringsfossen in Hardangervidda. The traffic from all three points is most probably passing Gol, where a notable number of drivers stops. Thereby this location was chosen as suitable for the transport corridor Oslo-Bergen.

For the corridor Oslo – Trondheim, there are substantial flow of road freight both in the E6 through Gudbrandsdalen and Rv3 through Østerdalen. The main flow between south-east Norway and Trondheim as well as destinations further north will prefer Rv3 as it is the fastest route, while E6 is used in larger extent for freight transport to/from northern parts of Western Norway (Ålesund, Molde, Florø, etc.) and within Gudbrandsdalen. To assess both these freight streams Hanestad on Rv3 and Otta on E6 were selected. Even if GPS data does not show many stops in Otta, it is assumed to be a relevant location as some of the freight volumes diverges here on Rv15 towards Stryn and it takes approx. 4h to arrive to Otta from Oslo, which suits relatively well for a break.

Figure 3 Heat map of where trucks stop for more than 30 min after been driving at least 4 hours [21]. The map is alternated by adding location which are subject for this analysis.

2.2 Tech limitations and market share

Recent national forecast of road transport electrification consisting of fast decarbonization pathway with high carbon pricing shows that ZET could stand for 12-50% of vkm in 2030 and 93-100% vkm by 2050 [22, 23]. These are however national scenarios, where local deviation will occur.

As BET seems to be a more economical, but with challenges to reach large distances, they are assumed to conquest short distance trips, while FCET expand in replacing heavy duty vehicles used for long distance trips. The technology of BET and its market share is assumed to advance relatively rapidly towards 2030. Due to FCET currently lagging development relative to BET, they are assumed to have a lower market penetration in 2030.

Considering the limitation in range for zero-emission technologies when compared to diesel, it is highly probable that efforts will be made to limit the range anxiety. Slow charging at depots of battery electric trucks becomes a great opportunity to reduce the range limitations at the same time being probably the cheapest charging alternative. This aspect is included in the analysis by assuming that all BET start their trip fully charged and that no fast charging is done for trips which are well within the range of the BET, as they will be charging at the end destination of the trip. It is assumed that BET stopping for charging will only charge the energy spend from start of the trip to the energy station, while stopping the charging when battery has reached 90% state of charge.

On the other hand, hydrogen refueling station are more expensive to install, but can efficiently refuel large energy quantities. This particularity is included in the analysis by assuming that trucks departing from larger logistic hubs (Oslo, Bergen and Trondheim) will be fully fuelled up and will not need refueling in the middle of the studied transport corridors. While the rest of the FCET will be interested in refueling corresponding their trip length and that they have as a minimum always 20% of their range capacity left when they enter the refuelling station.

In Table 1 &

Table 2 are summarized the assumptions and thresholds described above to estimate energy demand at the selected locations. Of all trips suitable for BET, based on a trip length, it is assumed that BET will be used in 35% of the cases in 2030. The corresponding share for trips assumed suitable for hydrogen is 10%. By 2050, both BET and FCET are assumed to stand for 100% of the trips within their assigned trip lengths.

Table 1 Assumption regarding which trips and how much BET and FCET will be charged/refueled in 2030 and 2050 in FCET+BET scenario

Year	Trip length	Energy carrier	Driving distance refuelled at station
2030	>300 km	H2	= Trip length, but max 500 km
	100-300 km	Battery	= Distance from the start of trip, but max 90% SoC
	<100 km		Excluded as only depot charging assumed
2050	>500 km	H2	= Trip length, but max 800 km
	200-500 km	Battery	= Distance from the start of trip
	<200 km		Excluded as only depot charging assumed

Table 2 Assumption on for which trips and how much BET will be charged in the battery only scenario in 2030 and 2050

Year	Trip length	Energy carrier	Driving distance refuelled at station
2030	>500 km	Not covered	
	100-500 km	Battery	= Distance from the start of trip, but max 90% SoC
	<100 km		Excluded as only depot charging assumed
2050	>200 km	Battery	= Distance from the start of trip, but max 90% SoC
	<200 km		Excluded as only depot charging assumed

The energy efficiency from tank to wheel is assumed to be in average 1.75 kWh/km for BET and 2.9 kWh/km for FCET. With an assumed a range of 400 and 600 km for BET in year 2030 and 2050 respectively, the battery size grows from 700 kWh in 2030 to 1050 kWh in 2050. These sizes exclude any additional buffer to account for battery degradation over the vehicle's lifetime. On the other hand, the ranges for FCET are set to 600 and 1000 km for the same two reference years. Such range can be translated to a storage capacity of 52 kg in 2030, which grows to 87 kg in 2050.

2.3 Traffic count

To transform the annual energy demand into an hourly resolution, the nearest site for vehicle counting was selected based on available and satisfying data quality. The selected sites are listed in Table 3. For Otta and Gol, where several roads are joining, a station which is located slightly to the south of such joint is selected considering the concentration of traffic flow towards Oslo region and for traffic towards Europe, passing by Oslo.

The most recent complete traffic count year was selected prior 2020, excluding possible Covid pandemic effects from 2020 and 2021.

Table 3 Shows which vehicle counting sites were used and year of time series

Location	Name of vehicle counting site	Year
Hanestad	Hanekampen	2017
Otta	Sjoa Bomstasjon	2019
Gol	Flå Syd	2019

The available data from traffic counts are divided into different length categories. The shortcoming of dividing the traffic counts based on the length is that trucks without trailer can easily be mixed with other vehicle types, such as passenger vehicles with trailer, motor homes or smaller busses. Thereby only counts representing trucks with trailer is considered, as they are the dominant vehicle type on the roads longer than 16 m.

In Figure 4 is shown how the distribution of counts are occurring when seen with a weekly resolution. The pattern is relatively consistent at this resolution with lowest traffic during Saturday and with clear increase in traffic during Sunday afternoon. In Figure 4 is presented data for Otta, but very similar patterns where also found for Hanestad and Gol.

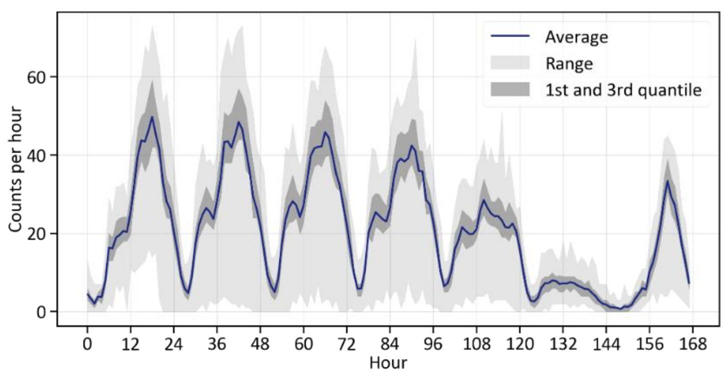

Figure 4 Average and the variation in the traffic flow over a week at Otta for vehicles 16-24 m long during 2019. Authors summary of data from [19]

2.4 Capacity in the power grid

The capacity of the power grid to deliver a certain amount of power output will depend on various factors. The fixed variables are the voltage level of power lines, the size of the lines and capacity of other equipment such as breakers and/or transformer stations. A variable factor for overhead lines is the weather, as power lines develop heat due to resistance, the cooling of the lines will be affected by temperature and wind. Another important consideration is that the national power grid serves a lot of different loads, so the capacity of power outtake from a given line for a charging station will depend on available spare capacity in existing line. To what extent there is a spare capacity will depend a lot on the specific location and vary between hours, weekdays, and seasons.

A simplified assessment made by authors of capacity available from grid at different voltage levels and for different shares of spare capacity is shown in Table 4. The representative cable type has been chosen by author based on discussion with The Norwegian Water Resources and Energy Directorate (NVE) of typical cross section diameters/resistance. The current ratings for selected cables are based on worst case scenario by assuming ambient temperature of 30°C according to technical standard developed by Statnett [24]. Thus, significantly higher current ratings at the same voltage level can be achieved at lower temperatures and when a cable with larger diameter is used.

Table 4 Rough estimation of possible capacities at different grid voltages for representative overhead lines

kV	Representative cable type	Current rating (A)	Capacity at various utilization rates (MW)			
			100%	50%	30%	10%
24	80-AL1/13-ST1A	303	11,3	5,7	3,4	1,1
66	151-AL1/25-ST1A	506	52	26	16	5
132	402-AL1/52-ST1A	908	187	93	56	19
145	402-AL1/52-ST1A	908	205	103	62	21
300	806-AL1/102-ST1A	1394	652	326	196	65

3 Results

In this chapter will firstly be briefly described adjustment of received data from NFM relative to traffic counts, in the next part will be presented the volume of traffic passing through the selected locations. Further on, the energy demand for the different scenarios is presented based on the methodology and assumptions regarding market penetration and technological parameters. As next step the results from the local energy system modelling is presented, together with a sensitivity analysis. As a final step, the modelled grid connection is compared to available grid in the region.

When considering only the trucks with trailer (>16 m), the trips provided by the NFM for the selected locations was 2.2 to 3.8 times higher than counts made at selected locations in 2018. However, a significant part of trucks is operating without a trailer and therefore, following assumption was added: that 75% of all vehicles counted within a length between 7.6 and 16 m are also trucks. With this assumption the number of trips in the data from NFM is 1.6 to 1.9 times higher than assumed trucks passing based on vehicle counts. The forecast of trips passing selected locations where downscaled for 2030 and 2050 accordingly, while the distribution of where trips start, and stop are remained constant.

When considering the estimated origin and destinations of all the vehicles passing selected locations in 2018 and summing up their vkm, through Hanestad would pass 9% of all national vkm. The share for Otta would be 7% and Gol 4%. Which means that 19% of the vkm nationally would be made on trips passing these three locations.

In Figure 5 is shown the calculated annual electricity demand including efficiency losses of electrolyzer. In FCET+BET scenario the energy demand is notably larger than in BET only scenario, as direct electrification of the trucks is more energy efficient and because battery electric trucks are assumed to use depot charging extensively.

By converting the annual energy demand to an hourly demand profile and running the optimisation model for energy station, the different component sizes were identified for the different scenarios as shown in Table 5 and Table 6. For a hybrid station, hydrogen storage is used as a buffer, while in BET only scenario batteries are used for energy storage while they have significantly smaller storage capacity in comparison with hydrogen storage.

To identify the most important design parameters and the rigorously of the results from the energy system modelling, a sensitivity analysis was performed. Due to the model and demand similarity of the three chosen locations, the sensitivity analysis was only made for Otta.

The sensitivity analysis consisted of 5 alternations of the results: 1) increase the cost of grid connection fivefold to reach 10 000 NOK/kW, 2) double the hourly power prices, 3) increase the variation in the power prices, 4) assume a slower scale up in the demand and 5) use a more volatile demand profile based and vehicle count of passenger vehicles which has few high peaks corresponding to increased travelling during holidays.

The sensitivity analysis of both FCET+BET and BET only scenario shows relatively small changes except when the demand profile becomes much more volatile throughout the year, see Figure 6 and Figure 7. It strongly effects the price per energy unit delivered, but not as much as the doubling of the power prices.

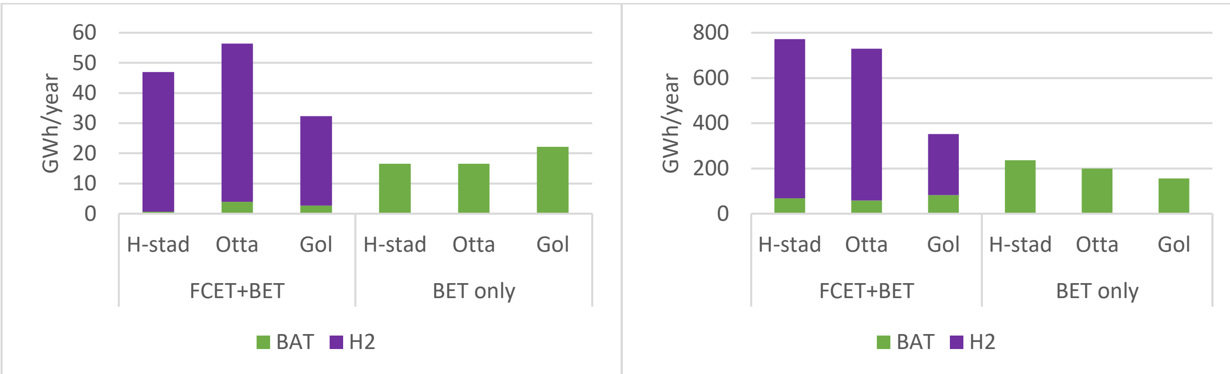

Figure 5 Annual electricity demand for refueling and recharging trucks in year 2030 (left) and 2050 (right) divided per location and scenario. Assumed efficiency of electrolyzer is 64% relative to hydrogens lower heating value. Observe different scales of y-axis. (H-stad = Hanestad)

Table 5 The component sizing for different locations and years in FCET+BET scenario

		2030			2050		
		Hanestad	**Otta**	**Gol**	**Hanestad**	**Otta**	**Gol**
Electrolyzer	MW	3.8	4.2	2.3	58	54	22
H2 storage	MWh	68	77	51	1038	993	483
	ton	2.0	2.3	1.5	31	30	14
Battery	MWh	0	0	0	0	0	0
Grid connection	MW	6.2	7.7	4.6	114	101	59
Mean energy cost	NOK/kWh	1.3	1.2	1.2	1.2	1.2	1.1

Table 6 The component sizing for different locations and years in BET only scenario

		2030			2050		
		Hanestad	**Otta**	**Gol**	**Hanestad**	**Otta**	**Gol**
Battery	MWh	0.6	1.5	1.9	7.9	18	13
Grid connection	MW	5.9	5.9	9.1	85	71	64
Mean energy cost	NOK/kWh	0.67	0.70	0.73	0.67	0.70	0.73

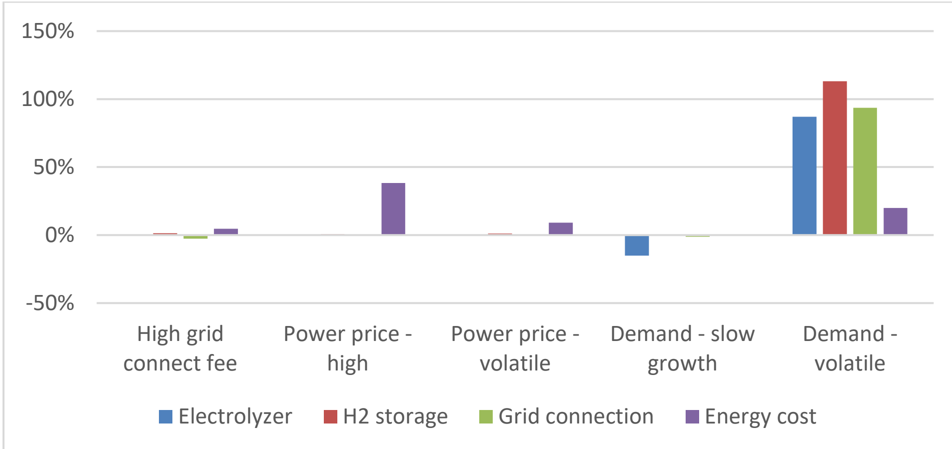

Figure 6 Changes in component size relative to default run in the FCET+BET scenario when altering different input parameters.

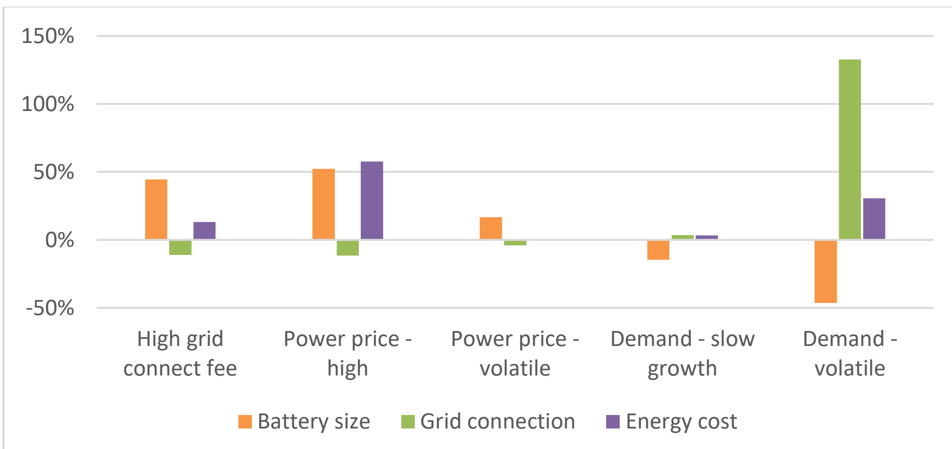

Figure 7 Changes in component size relative to default run in the BET only scenario when altering different input parameters.

The grid connection according to the modelling results could be expected to be between 4.6-9.1 MW by 2030. Such power demand can according to estimates presented in Table 4 be covered by distribution grid at 22 kV, but more probably 66 kV line will be needed to accommodate also other loads served by the power grid in addition to the charging station.

The resulting need for grid connection by 2050 increases to a range between 59-114 MW. Such power levels can be provided at 132/145 kV level, however it would occupy a significant share of the power lines capacity (approx. 30-50%). It might require power line upgrade to accommodate this demand at such voltage levels or consider power outtake from nearby 300 kV central grid. With such a high demand for charging, it might also be natural to divide this demand over several separate locations and with distinct access points to the grid.

Mapping the locations for energy stations and available grid infrastructure [25] showed that in Hanestad only 22 kV grid is available, while the closest feasible connection point to voltages up to 300 kV would be at Rendalen power plant, requiring the crossing a mountain for a distance of 13 km. Stronger grid connection along the road can be found 40 km south (300 kV line), nearby Koppang or 40 km north (145 kV line), nearby Alvdal. The next location studied, Otta, have a 73 kV power line serving the village and local industry. This line is connected to 300 kV level 26 km north-west at Vågåmå and 30 km south along the road. At last, when looking at Gol it shows that it is very well connected to the grid with both power lines and transformer stations handling 300 kV.

4 Conclusion and discussion

This work estimates the energy demand for fast charging and refuelling at the selected locations to be in the range of 17-57 GWh in 2030 and increasing to 156 to 772 GWh in 2050 as the vehicle fleet transitions to 100% ZET. In FCET+BET scenario the energy demand is notably larger than in BET only scenario. The difference in energy demand can be explained by BET being more energy efficient and due to the assumption of BET's extended use of depot charging.

The grid would be exposed to 4.6-9.1 MW peak demand from a charging/refuelling station in 2030, which increases to 59-114 MW by 2050. The results are relatively similar for the BET+H2 and the BET only scenario. Similar peak demand while lower energy demand in the BET only scenario implies that power demand in this scenario is much more volatile.

When comparing the optimal grid connection size with existing grid at the chosen locations, the challenges could arise already in 2030 at Hanestad as only 22 kV distribution grid is available. The demands forecasted for Otta towards 2050 also imply a challenging situation. On the other hand, strong grid is available at Gol. This shows the need to consider available grid together with good match with logistic scheduling of the trucks, including the mandatory breaks for truck drivers.

These energy and power demand should be seen in context that all national trips passing by selected locations collect in total 19% of national annual vehicle km driven. Which displays that energy stations in chosen locations would serve a significant share of the total road freight.

The core of this analysis is based on combining data from existing models and available data sets in a novel matter. However, each of the models and data sets has its own shortcomings and represents only a partial picture of challenges and possible solutions. For example, the hourly demand profile is based on traffic counts for trucks with trailer (length >16 m). However, trucks without trailer might alternate the demand profile significantly. Another area of improvement was identified in the NFM, which heavily overestimated the number of trips passing selected locations. Which indicates that for certain trips other transportation modes might be more feasible or that trip frequency should be different.

With the selected methodology, including hourly time resolution, the impact of queuing was not considered. However, it would be of value to assess how queuing and/or inclusion of active scheduling of charging time slots would affect the system sizing and costs for charging. The role of vehicle scheduling should also be seen in the light of the limited grid access, where it would be important to understand better the tradeoffs between a station optimal location in the grid versus the most convenient locations for truck operators.

5 Acknowledgments

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6 References

[1] D.R. Pinchasik, et al., *Grønn lastebiltransport? - Teknologistatus, kostnader og brukererfaringer*, Institute of Transport Economics, 2021, TØI-rapport 1855/ 2021,

[2] European Commission, *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU of the European Parliament and of the Council*, 2021, Document 52021PC0559

[3] CharIN, *Megawatt Charging System (MCS)*. n.d. https://www.charin.global/technology/mcs, accessed on 2022/05/09/

[4] ITF, *Regulations and standards for clean trucks and buses: on the right track?*, OECD, 2020, No. 77, https://www.itf-oecd.org/regulations-and-standards-clean-trucks-and-buses

[5] K.K. Fjær, et al., *Heavy-duty electric vehicle charging profile generation method for grid impact analysis*, in *2021 International Conference on Smart Energy Systems and Technologies (SEST),* 2021. IEEE.

[6] X. Zhu, B. Mather, and P. Mishra, *Grid impact analysis of heavy-duty electric vehicle charging stations*, in *2020 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT),* 2020. IEEE.

[7] The Loadstar, *Daimler enters further agreement to drive hydrogen-fuelled trucking in Europe*. 2021 https://theloadstar.com/daimler-enters-further-agreement-to-drive-hydrogen-fuelled-trucking-in-europe/?fbclid=IwAR0EjLLUW-QLgLQ-c2-Pi1m3Gtcq2VxPdcpDkOA5M5P5W3TY4KTuvHpn2S4, accessed on 2021/11/10/

[8] A. Grauers, *How Costs and the User Preferences will shape the Charging Infrastructure*. 2021, Swedish Electromobility Center & Swedish vehicular engineering association: Infrastructure for the charging of electrical vehicles [digital seminar].

[9] IEA, *Renewable energy for industry*, International Energy Agency, 2017,

[10] V. Sauter, et al., *A charging infrastructure network for battery electric trucks in Europe*, Fraunhofer-Institut für System- und Innovationsforschung ISI, 2021, No. S02/2021,

[11] J. Whitehead, et al., *Exploring public charging infrastructure requirements for short-haul electric trucks,* International Journal of Sustainable Transportation, 2021: p. 1-17.

[12] D. Speth, et al., *Public fast charging infrastructure for battery electric trucks–a model-based network for Germany,* Environmental Research: Infrastructure and Sustainability, 2022.

[13] P.K. Rose and F. Neumann, *Hydrogen refueling station networks for heavy-duty vehicles in future power systems,* Transportation Research Part D: Transport and Environment, 2020. **83**: p. 102358.

[14] A. Danese, et al., *Electrical infrastructure design methodology of dynamic and static charging for heavy and light duty electric vehicles,* Energies, 2021. **14**(12): p. 3362.

[15] J. Danebergs, *Techno-economic Study of Hydrogen as a Heavy-duty Truck Fuel: A Case Study on the Transport Corridor Oslo–Trondheim* [MSc thesis], DiVA, KTH, 2019

[16] J. Fagerström, et al., *Hybrid PV-systems for electrification and sector coupling of road transport sector in Norway,* Solar RRL, 2021.

[17] THEMA Consulting Group, *Infrastrukturkostnader for etablering av et nettverk av energistasjoner til tungtransport*, 2022, https://www.nho.no/samarbeid/gront-landtransportprogram/artikler/thema-rapport-infrastrukturkostnader-for-etablering-av-et-nettverk-av-energistasjoner-for-tungstransport/

[18] A. Madslien and I.B. Hovi, *Projections for freight transport 2018-2050*, 2021, TØI rapport 1825/2021,

[19] The Norwegian Public Roads Administration, *Trafikkdata*. n.d. https://www.vegvesen.no/trafikkdata/start/om-trafikkdata, accessed on 2021/04/07/

[20] J. Danebergs, et al., *Documentation of IFE-TIMES-Norway v2*, Institute for Energy Technology, 2022, IFE/E-2021/005,

[21] I.B. Hovi, et al., *Logistikk, miljø og kostnader - Kjøretøydata som grunnlag for forskning, transportplanlegging og forbedringsarbeid*, Institute of Transport Economics, 2021, TØI-rapport 1861/2021,

[22] Lasse Fridstrøm and Vegard Østli, *Forsering eller hvileskjær? Om utsiktene til klimagasskutt i veitransporten*, The Institute of Transport Economics, 2021, ISBN 978-82-480-1399-0, https://www.toi.no/samfunnsokonomiske-analyser/klimagasskuttene-i-veitransport-kommer-ikke-av-seg-selv-article37112-1648.html

[23] J. Danebergs, E. Rosenberg, and K.A. Espegren, *Impact of zero emission heavy-duty transport on the energy system*, Institute for Energy Technology, 2022, IFE/E-2021/002,

[24] Statnett, *Teknisk standard - Beregning av termisk grenselast på kraftledninger*. 2021.

[25] NVE, *NVE Temakart - Kraftsystem Nettanlegg*. n.d. https://temakart.nve.no/tema/nettanlegg, accessed on 2021/12/17/

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