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Analysis of long haul battery electric trucks in EU

Marketplace and technology, economic, environmental, and policy perspectives.

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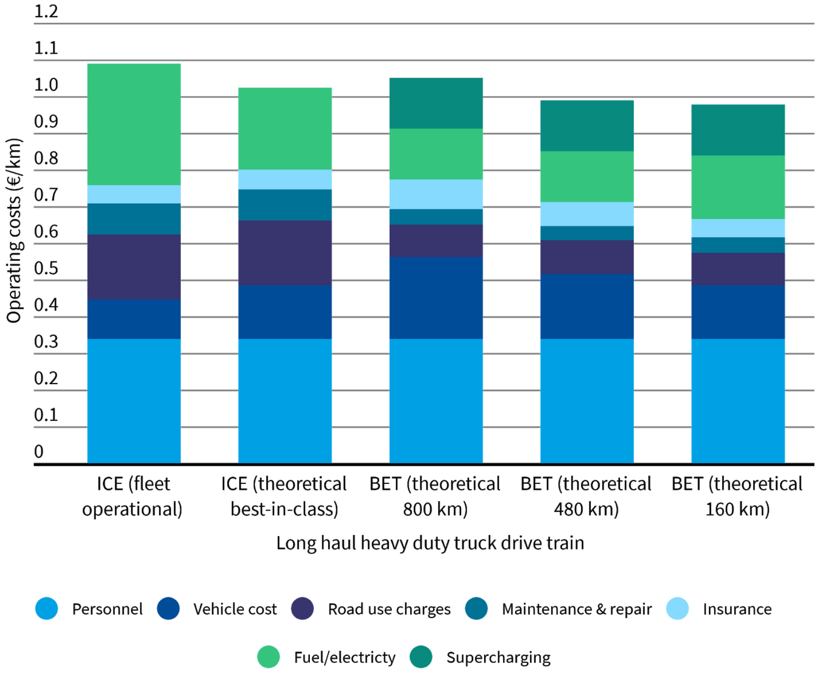
Abstract

The EU has to decarbonise by 2050 to achieve the goals of the Paris Agreement. To meet these long term targets, trucks will need to become zero-emission. One technology that could deliver this is the battery electric truck. This paper looks at the potential of battery electric heavy duty trucking in the EU, in particular for the more difficult long haul segment, by analyzing the technical feasibility, regulatory and market enablers and inhibitors, together with environmental impacts.

We provide an overview of the electric truck markets, which show more heavy duty trucks with longer ranges being announced. In the European market, sales and series production have been announced by MAN, Volvo, Mercedes and others. Tesla in the US will release its long range Semi in 2019. To test the technical feasibility of these trucks and to compare them with their diesel counterparts, the paper uses technical data and a simplified road load equation to compute the energy requirements for these vehicles, and the battery required to achieve the ranges claimed by manufacturers. The paper analyses charging strategies and potential solutions to overcome the significant power requirements on the grid from fast charging. In terms of total electricity generation, a European fleet of battery electric vehicles could require around 10% of present day generation.

The technical analysis enabled a total cost of ownership comparison between diesel and battery electric trucks, considering wages, maintenance, insurance, fuel and electricity prices, and road charging. The results show that the biggest sensitivity to cost competitiveness is the electricity price, and to a lesser extent the road charging discount that may be applied to zero emission trucks on motorways. This finding is contrary to some of the scepticism about both the technical and economic feasibility of battery electric heavy duty trucks.



Finally, this paper lays down the necessary policy recommendations to facilitate and expedite electric trucking uptake are suggested, namely: CO_2 standards for trucks and trailers; a zero emission vehicle (ZEV) mandate for trucks; electricity pricing; road charges, tolls, and fuel taxes; zero-emission freight strategies for cities; infrastructure; the reform of the weights and dimensions directive, including payload allowance, and battery manufacturing.

1. Introduction

The greenhouse gas emitted from trucks moving freight in Europe is responsible for around 20% of road transport emissions [1]. In accordance with the Paris Agreement, the European Union has regulations in place to ensure that all sectors of the economy contribute to decarbonisation. By 2030, non-ETS sectors such as transport will need to cut emissions by 30% compared to 2005. In the longer term, the emission reduction target for all sectors in 2050 is in the range of 80% to 95% compared to 1990 levels - transport should achieve 94% [2]. As some sectors in transport are more difficult to completely decarbonise (such as aviation), in order to meet these reductions, it is imperative that all road vehicles combusting fossil fuels be replaced by zero-emission vehicles.

Electric trains offer the greenest and one of the most energy efficient means of transporting goods. While Europe has an extensive network of railway infrastructure, passenger trains generally enjoy priority over freight, leading to lower punctuality for freight trains on busy routes. The EU has identified dedicated freight corridors to be improved under the TEN-T framework[1] and, with very robust investment and reform, it may be possible for rail to increase its current market share of 18% of surface freight to 23% [3]. Owing to the flexibility of trucks, their speed, cost advantage, and the overhaul needed in the rail sector to realise its maximum potential, road transport is likely to maintain a market share not greatly dissimilar from its 75% level today [4][2]. For these reasons, this paper focuses on the solutions available to decarbonise the trucking sector.

The European Commission's Reference Scenario [5] predicts increasing transport demand; considering marginal fuel efficiency improvements of new trucks, this will result in increasing GHG emissions as observed historically[3]. To curb these emissions from their current upward trajectory, the European Commission will table truck standards in May 2018. These standards will not only help meet Europe's climate targets, but are expected to boost emission-reduction technological improvements, such as more fuel efficient engines, aerodynamics, and high performance tyres. This of course all depends on the stringency of the standard. When combined with other current measures, including reduced road charges for zero emissions vehicles, the upcoming package of measures should incentivise new, zero emissions drivetrains. Although more efficient trucks are a step in the right direction, trucks running on fossil fuel will continue to produce GHG emissions.

One report [6] on decarbonising road freight found that direct electric trucks are the most energy efficient solution for decarbonisation. E-highway[4] technology being developed by Scania and Siemens is an example of how to decarbonise long haul freight. E-highways are an intriguing proposition and may be more cost effective than BETs for long haul trucking (including infrastructure building), as indicated by [7] - the ongoing trials in Sweden and Germany show that they are already technically feasible. Other zero emission technologies, namely hydrogen fuel cells and power to liquid 'drop-in' fuels for internal

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[1] https://ec.europa.eu/inea/en/ten-t/ten-t-projects

[2] http://lowcarbonfreight.eu/

[3] https://www.eea.europa.eu/data-and-maps/indicators/freight-transport-demand-version-2/assessment-7

[4] www.siemens.com/global/en/home/products/mobility/road-solutions/electromobility/ehighway.html

combustion engines, would require 3 to 5 times more electricity than a pure electric drivetrain. In the simplest terms, this would result in an equivalent cost increase factor for the energy/fuel. The report's addendum considered the impact of using BETs for long-distance transport (rather than e-highways), arriving at the key conclusion that current trip lengths in the EU mean that the main technical hindrance to battery electric trucking in the EU would be a charging network. Before the unveiling of the Tesla Semi, [8] carried out an analysis that rather dampened the expectations of BETs for long haul, showing that with current technology, batteries would be too heavy and too costly for long range trucks.

In recent years BETs have become viable, zero tailpipe emission alternatives to diesel fuelled trucks. As a result, an increasing number of models have been announced accompanied with the release of technical specifications, such as range and air drag coefficient, and importantly their prices. These data enable a comparison between diesel trucks on the roads today to be carried out, and the following sections essentially compare BET and diesel trucks from technological and economic standpoints.

This report aims to understand the economic and logistic business cases for battery electric trucks, to see whether BET is a technology that Europe should be promoting as a solution to decarbonise the road freight sector. To begin with, an overview of the current truck market is provided. Following that, a comprehensive comparison between a battery electric truck with a diesel ICE truck in long haul operation is undertaken. Consideration will be given to the technical, economic, and regulatory enablers for heavy duty trucks in a European context. We aim to find if there is a market case for battery electric trucks, and to identify the policies that will tip the scales in favour of zero emissions heavy duty trucks in the EU. Finally, the environmental benefits of electric trucks will be investigated.

2. BETs in the marketplace

The conditions for battery electric trucks (BETs) have drastically changed since 2010, a year when lithium-ion battery prices were around $US 750-1000/kWh [9] with energy densities of around 110 Wh/kg[5]. Compared to 2018, prices have come down by around a factor of four, and densities have more than doubled. In simple terms, batteries are cheap and dense enough to be considered as viable for powering trucks. These trends in the reduction in cost and improvement in specific density has lead to (and conversely been driven by) a rapid increase in both passenger electric vehicles (surpassing 2 million sales globally [10]), electric urban buses, and the emergence of heavy duty trucks.

Perhaps the first BETs to come to market in large scale were garbage trucks - ideal candidates for electrification owing to their predictable routes and stop-start operation (which is where internal combustion engines, ICEs, are particularly inefficient and noisy). A notable example of the deployment of electric garbage trucks occured in preparation for the Beijing Olympics in 2008, where 3000 garbage trucks were replaced with battery electric variants to reduce noise and pollution. China has also been at the forefront of electrifying its urban bus fleets, notably in Shenzhen, where the entire fleet of over 16 000 buses was electrified with batteries[6]. With this investment, BYD and the city clearly see the viability and benefit of battery electric heavy duty vehicles.

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[5] batteryuniversity.com/learn/archive/the_high_power_lithium_ion

[6] qz.com/1169690/shenzhen-in-china-has-16359-electric-buses-more-than-americas-biggest-citiess-conventional-bus-fleet/

In continental Europe, the battery electric Emoss began converting diesel trucks to BETs in the Netherlands in 2012 for a number of Dutch companies. In Switzerland in 2014, an 18t E-Force One truck began operations for the supermarket chain Coop[7]. More recently traditional truck makers also made announcements to enter the market. In early 2018 both MAN and Mercedes[8] placed pilot e-trucks with customers. Volvo[9,10], with the 16t *FL Electric*, and Renault have announced that they will start selling electric trucks by 2019. In the case of the Volvo, there is a claimed range of 300 km. VDL has partnered with MAN to develop a 37 t truck, however the range is mainly targeted for deliveries, at 100 km. In short, current announcements in Europe tend to be for urban deliveries and often smaller payloads.

The long haul and larger segment sectors are technically more challenging than the urban delivery truck segment. Trucks are driven further between towns and cities, and they also tend to require a larger payload capacity. To accommodate these higher demands, Nikola Motors has announced a BET with hydrogen fuel cell range extender[11] and Toyota a hydrogen fuel cell truck[12]. However, other manufacturers see the potential of BETs in the long haul sector too. Notably, US company Tesla unveiled its battery powered class 8 truck[13] in late 2017 and Chinese manufacturer BYD[14] added long haul trucks to its increasing offering of electric trucks in 2016.

3. Technical comparison[15]

The main aim of this section is to determine how much energy a heavy duty BET will need to transport cargo across the continent, and how this compares with its diesel counterpart. Independent of powertrain or range, we define a tractor trailer truck in this analysis as having a gross vehicle weight (GVW) of 40 tonnes and a frontal area of 10 m^2 (from a width, $W = 2.5$ m and a height, $H = 4$ m). We define two ICE diesel trucks, one that represents the performance of the fleet, and a best-in-class truck that will more directly be compared to the BET. Likewise, two class 8 BETs will be considered, namely the Tesla Semi and the BYD Q3M.

The fleet average fuel consumption of recently-manufactured (i.e. circa 2015) long-distance 40 t trucks in the EU is 33 L/100km [11]. This number not only encompasses all driving conditions, from the extreme cases of flat, straight-line driving in the Netherlands, mountainous driving in countries such as Austria, to stop-start driving in cities, but also the varying mass of freight being transported by the trucks, which run empty almost a quarter of the time, on average [12]. Modelling this fuel consumption would require a range of real-world speed and inclination profiles and engine maps. In lieu of this, we define the second

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[7] www.20min.ch/finance/news/story/Detailhaendler-setzen-auf-Elektro-Lastwagen-23057287

[8] www.daimler.com/products/trucks/mercedes-benz/eactros.html

[9] www.volvogroup.com/en-en/news/2018/jan/news-2796722.html

[10] www.thedrive.com/tech/20089/volvo-debuts-its-first-electric-truck-the-fl-electric?iid=sr-link5

[11] nikolamotor.com/one

[12] corporatenews.pressroom.toyota.com/releases/toyota+zero+emission+heavyduty+trucking+concept.htm

[13] www.tesla.com/semi/

[14] en.byd.com/usa/wp-content/uploads/2017/06/t9-final.pdf

[15] This section takes inspiration and uses values from [11] and this piece of analysis from Chris Stelter (http://selenianboondocks.com/2017/11/tesla-semi-part-1/)

ICE, that has a performance which is best in class and thus has a known maximum efficiency that is possible to analyse analytically, as will be shown below.

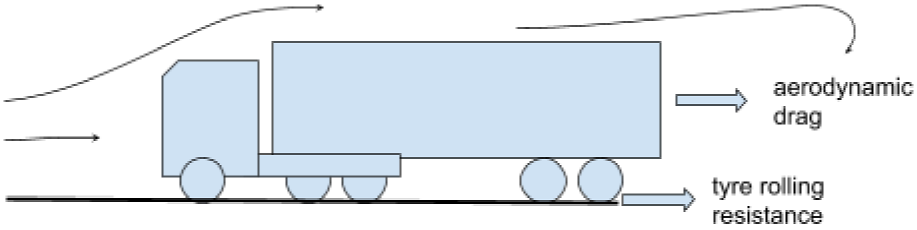

Figure 1: Main resistive forces to forward motion from the simplified road load equation

The two main forces working against the truck's forward motion, namely the aerodynamic drag and the rolling resistance of the tyres, are collectively known as the "road load" and we denote them as F_{RL}. To perform the analytical comparison between the best in class ICE and BET, we use a simplified version of the road load equation which assumes a constant speed, a flat road, no road surface deformation, and no tyre slip[16]:

$$F_{RL} = 1/2\rho V^2 HWC_D + mgC_{RR}$$

where $\rho = 1.2$ kg/m^3 is the density of air, $V = 25$ m/s (equal to 90 km/h) is the truck speed chosen as it is the legal maximum permissible speed in the EU, m is the GVW in kg, and $g = 9.81$ m/s^2 is the acceleration due to gravity. The term C_{RR} is the rolling resistance, and that is a factor determined by the choice of tyre; we choose C-rated tyres with $C_{RR} = 0.0055$. The drag coefficient C_D is a measure of how aerodynamic the truck is. The current fleet average in the EU is $C_D = 0.6$. By visual inspection, the BYD Q3M appears to have no obvious modifications to its cab design compared to a standard EU cab over engine tractor design, thus we assume it has the same aerodynamic efficiency as the fleet average. On the other hand, we assume that a new best in class ICE could attain the same aerodynamic efficiency as the Tesla BET, so $C_D = 0.36$ is assigned to those vehicles. These assumptions are in a similar range as [8], although the C_D is lower than the 0.45 minimum assumed in that paper. It's important to note that to obtain a C_D of 0.36 would require a reduction in the length of the trailer (and thus the volume of goods that can be carried), as the tractors in the US can be longer than in EU, permitting greater aerodynamics. This would be the case even if additional length was given to tractors under the Weights and Dimensions directive, discussed later in this report.

With these assumptions, we find that the more aerodynamic trucks require 0.98 kWh/km compared to 1.23 kWh/km to overcome the road load on a flat road to maintain a constant highway speed. To convert that into fuel (or electricity) consumption, the energy efficiency of the power trains must be considered. The full list of assumptions is set out in the Table 1. For the ICE engines, a best in class peak diesel engine maximum brake thermal efficiency is 46% (assuming that in this scenario the engine can be kept in its 'sweet-spot', i.e. at high efficiency) was was chosen from the ICCT [11], whereas for the average truck it was back calculated to be 39% from the 33 L/100km average consumption.

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[16] Note: The total resistance is a force which has the unit of Newtons (N), so to convert to kWh/km requires a division by 3600.

For the BET powertrain, charging and running an electric truck would typically require drawing AC electricity from the grid, rectify it to DC to charge the battery, and then inverting it to run the truck's AC induction motors. Fast charging from DC directly would remove this first inversion step. There are greater losses in the ICE transmission that has up to 12 gears, clutch, a drive shaft with universal joints and a differential, compared to the BET that will have a motor for each driven wheel and single gear reduction at each wheel. Other sources that draw energy, such as auxiliaries including lights, cab climate control are not considered in this analysis (for both diesel trucks and BETs). These driveline assumptions are also inline with those from [8].

Table 1: Drivetrain efficiencies used in the simplified road load equation.
*Not considered in road load equation, but used in calculation of electricity cost.

Efficiency	**Diesel ICE**	**BETs**
AC/DC rectification*	-	95%
Battery charging/running	-	95%
DC/AC inversion	-	95%
Engine operation (fleet; best in class)	39%; 46%	95%
Transmission	95%	99%
Total drivetrain	**40%**	**85%**

Dividing the energy required to overcome the drag and rolling resistance by the powertrain efficiencies results in 1.15 kWh/km for the aerodynamic BET, 1.44 kWh/km for the non-optimised (cab-over-engine) BET, 2.2 kWh/km for the best-in-class ICE, and 3.3 kWh/km for the average ICE. The conversion into fuel consumption results in the best-in-class diesel truck consuming 22 L/100km. If this truck had a drag coefficient of 0.6 (comparable to the EU fleet today), its fuel consumption would be 28 L/100km. This clearly shows the importance of aerodynamics for truck fuel efficiency at highway speeds. Importantly, it also shows that a BEV reduces energy consumption by a factor between 1.5 and 2.9 times.

It should be noted here that this comparison is biased in favour of the ICE, as typical operation involves slowing down, accelerating, as well as going up and down hills that would reduce the engine efficiency, whereas the BET has approximately constant engine efficiency across driving profiles. Moreover, the BET can recuperate significant energy on descents and deceleration to charge the batteries, whereas current ICE technology would be converting that energy to heat by braking, thus operating at suboptimal efficiency.

The battery size in terms of mass and volume will influence the payload capacity of the truck. To determine how big the Tesla Semi battery would need to be for its officially stated 800 km range (unofficially 960 km range[17]), the battery utilisation rate must be considered. A battery can't be run completely flat, as it may cause permanent damage to the cells. The US DOE[18] typically uses a utilisation rate of 85% to 90%[19]. We assume a utilisation rate of 90%; 800 km at 1.15 kWh/km and a utilisation rate of 90% implies a battery capacity of approximately 1000 kWh. BYD on the other hand advertises its battery capacity at 207 kWh. Based on our assumptions, we calculate a required battery size of 250 kWh for a minimum range of 160 km, a difference that suggests that BYD use a driving cycle with lower speeds, a higher utilisation rate, better performing tyres, and/or is more aerodynamic than assumed.

To determine the weight of the batteries, the lithium cobalt oxide (LCO) battery cell density of the Tesla Model S of 250 Wh/kg[20] is used as a proxy for the Tesla truck. With the same technology, the truck would need 4.1 t of battery cells, or just over 10% of the GVW; the 480 km range version would require 2.5 t of battery cells. A rougher comparison could be to take the pack density of a Tesla Model S of 540 kg[21] as 85 kWh; this would imply that the battery pack for the Tesla Semi could be in the order of 6.4 t. An important note on battery pack density (which includes control management, cooling, electronics, housing) compared to cell density: Pack density is an inexact measure, as the housing for the batteries could be incorporated into the chassis as a structural element. For the BYD, the battery chemistry is lithium iron phosphate (LFP), which assuming a similar technological level as the LCO batteries, would have an energy density of approximately 165 Wh/kg [13]. Using the officially stated 207 kWh battery capacity, this implies a battery cell weight of 1.25 t.

These battery masses are significant in terms of payload and GVW. In addition, the BETs would typically have four electric AC induction motors, inverter electronics, and transmission, that could be in the order of 400 kg[22]. However, a BET no longer requires a large and heavy diesel engine, transmission and differentials[23], nor the fuel system and exhaust hardware that collectively weigh in the order of 3 t [14] [24]. The available payload will be a significant factor for hauliers, as this will dictate the maximum amount and thus value of goods that they can transport with a single truck, even if the typical payload is reported to be significantly less than the maximum [11]. Without data on the weight of the Tesla Semi glider, no speculation on the change in payload capacity can be assumed, which will be vital for hauliers in assessing the economic benefits of the truck. For this analysis, all trucks are assumed to have the same gross vehicle weight.

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[17] electrek.co/2018/05/02/tesla-semi-production-version-range-increase-elon-musk/

[18] energy.gov/eere/vehicles/batteries

[19] From person communication

[20] electrek.co/2016/11/02/tesla-panasonic-2170-battery-cell-highest-energy-density-cell-world-cheapest-elon-musk/

[21] uk.businessinsider.com/raw-materials-used-in-teslas-model-s-2016-3?r=US&IR=T

[22] For example a Bosch eAxle (www.bosch-mobility-solutions.com/en/products-and-services/passenger-cars-and-light-commercial-vehicles/powertrain-systems/electric-drive/eaxle/)

[23] Which with the axles and driveshafts can be several hundred kg, as shown for example in the MAN website (www.engines.man.eu/global/en/components/axles-and-transfer-cases/product-range/Product-Range.html)

[24] energy.gov/eere/vehicles/fact-620-april-26-2010-class-8-truck-tractor-weight-component

4. Charging requirements and its impact on the grid and electricity generation

Total energy demand

The total energy demand of a fleet of BETs in the EU is an important metric for anticipating generation requirements. As will be discussed in this section, it will depend on charging strategies that are employed by the haulier. As a point of comparison, the average annual electricity consumption of a household in the EU is 3.5 MWh[25], implying a single truck charge of 1 MWh would be the equivalent to under a third of the annual consumption of an average house, or for the BYD truck, around 6% of an average houses. In terms of power, 3.5 MWh spread over the year is 0.4 kW; assuming fast charging with a 1 MW connection, the battery electric truck would draw as much power as 2500 houses. This can be compared to a recent article from the Financial Times[26] that reported a long-haul electric truck requiring the electricity of 3000 to 4000 average UK houses per truck charge.

With a full fleet of electric vehicles on the road, the question often arises as to whether or not the EU grid and generation capacity could cope with the new demand. To get an order of magnitude appreciation of the total electricity required to charge a European fleet of long haul BETs, the energy consumption per truck (1.44 kWh/km, noting that this from the less aerodynamic heavy duty truck travelling at 90 km/h) can be combined with the number of trucks in the EU (4.5 million) with calculated average mileage (50 000 km/year, covering all truck sizes and ages [15]). This would equate to 324 TWh, or just over 10% of EU generation in 2015 which was 3000 TWh[27]. For comparison Bitcoin estimated global annual energy consumption is 45 TWh as of end of January, or 0.2% of world consumption[28].

Overnight charging

A common charging scenario for BETs could be charging at night in the depot. In this scenario, the BET will rely on this time for the majority of its charging. In a few years, BETs like the Tesla Semi might become common in the fleet mix of operators. A fleet of 10 Tesla Semi (1 MWh battery) could easily need about 800 kWh to recharge overnight. The same calculation as above show that a 80kW charger[29] per truck is sufficient and a 1 MW connection would probably be necessary. This strategy implies a necessity to have a connection to the medium voltage grid. Two crucial considerations are the capital costs when scaling up the transformer and the cost of connection to the medium voltage grid, that scales with distance to the infrastructure. When charging at the depot is not an option, the driver is obliged to spend the night in the truck or a hotel. Safe and secure places for trucks to park overnight will need to be built across Europe's primary road network equipped with charging facilities for trucks while they're parked. These facilities will require high power connections in order to charge potentially many trucks at a time.

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[25] Eurostat: 770 TWh total electricity used in households in EU28 across 220 million private dwellings.

[26] www.ft.com/content/f5593480-d29a-11e7-8c9a-d9c0a5c8d5c9

[27] ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_production,_consumption_and_market_overview

[28] digiconomist.net/bitcoin-energy-consumption

[29] 80 kW AC chargers are used today for some trucks and buses and are a good compromise for slow charging of large vehicles

Opportunity charging

Opportunity charging occurs when loading and unloading goods or during the driver's rest time[30]. This strategy could allow the vehicle to carry a smaller battery thus enabling the truck to carry more goods. These batteries would ideally be power-optimised (e.g. LTO batteries) meaning they can charge in a very limited time period but are more expensive. In the case of opportunity charging, the need for smart management of charging will be essential as the fleet operator would probably look for a trade-off when building fast charging infrastructures. This will include selecting the right number and power rating of chargers versus the appropriate battery size. The battery size, timetables, dwell times and fleet operations must be optimized closely to avoid the need to charge a large number of vehicles at the same time. Long haul trucks will typically require higher power in order to recharge to an sufficient capacity to complete the next leg of its journey.

Uncontrolled charging

During uncontrolled charging, the vehicle is plugged into a fast charger when the battery is exhausted, regardless of the prevailing demand or energy price. Although this type of flexibility (charge-on-demand) may be required and highly desirable for hauliers, it is not necessarily the case that it will be adopted on a wide scale as this type of operation requires over-investment in infrastructure and typically results in higher electricity prices. Fast charging poses a different strain on the grid, as the infrastructure itself can limit the amount of power that can be transferred. For example, in a future scenario of a full fleet of BETs, fast charging anywhere between 5-50 trucks at a roadside charging point could draw 1.5 MW to 20 MW. to limit impacts on the grid, several solution could be employed, as described below.

Stationary onsite storage

One solution to the considerable power requirements of charging (particularly fast charging) is on-site storage, not dissimilar to the system currently used for e-ferries in Norway[31]. On-site large stationary batteries[32] that can charge while electricity is cheaper and demand is low (typically at night, although we note that in a renewable mix dominated by photovoltaics, the cost of electricity may be cheaper during the day, as is the case in California[33]). These large batteries can rapidly charge trucks during the day when they need it without overly impacting the grid. An advantage of these systems can be realised when similar systems are deployed in larger numbers enabling them to deliver flexible storage capacity to the whole energy grid as well. This will stabilize the grid and support the integration of more renewable sources into the energy system. The battery acts as a buffer and an advantageous cost trade-off could be found between the capital cost of the battery and the capital cost gain from having a lower power grid connection and the operational cost gain from buying cheap (renewable) electricity from the grid at any time and providing peak shaving services to the grid, as is the case in South Australia[34].

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[30] In the EU, drivers have to stop for a 45 minute break at least every 4.5 hours

[31] www.siemens.com/innovation/en/home/pictures-of-the-future/mobility-and-motors/electromobility-electric-ferries

[32] www.bloomberg.com/news/articles/2017-11-24/tesla-s-newest-promises-break-the-laws-of-batteries

[33] eia.gov/todayinenergy/detail.php?id=30692

[34] reneweconomy.com.au/tesla-big-battery-officially-switched-on-in-south-australia-55285/

Demand side management (DSM)

A secondary strategy to reduce high power requirements of charging is through DSM strategies. By necessity, DSM will be widely employed to varying degrees of sophistication. DSM can also be considered to be smart charging based on network optimised charging times and power levels to reduce peak demand. Smart charging management plans can help provide additional flexibility to the grid and ensure smooth operations without creating capacity that exceeds demand. Another element of DSM is vehicle-to-grid (V2G) [16], where the electric vehicle is essentially considered as a battery on wheels, capable of bidirectional exchanges with the grid. In principle, the vehicle supplies electricity into the network in response to variability to renewable energy production and prices. By doing this the vehicle provides services for the power grid or for the home and achieves income on a day-to-day basis. V2G has a good potential to relieve peak demand by day and by night, to manage overloads, voltage levels and frequency, while absorbing the surplus energy produced from renewables. However, as e-trucks and e-buses have a higher utilization rate than passenger cars, the benefit from V2G will be limited. Trucks will need a longer time to charge, and when that charging occurs at night, there are less opportunities to contribute to peak shaving. This is especially true of long-haul trucks.

Electricity grid

The electricity grid is divided into several distribution voltage levels. The medium voltage grid (primary utility distribution) is usually around 10-11 kV in Europe while the low voltage grid (secondary distribution) is divided into 480 V and 240 V ratings for buildings and distribution panels respectively. Charge station operators can choose the voltage subscription they desire, where according to a [17] a 400 V subscription can be considered for power demands below 1 MW and a 10 kV subscription for power demands above 1 MW.

Connecting charging stations to the medium voltage grid can offset the effect on local distribution infrastructure and enable the station power it be scaled up in line with the future take-off of electric vehicles. Stations with megawatt connections are well within the limit of the capacity of the medium voltage grid and already exist for e-bus depots in cities. According to some experts this is not such a big problem for the grid, especially for most big cities. The negative impact of charging on the grid might intensify in the future with fast chargers becoming more and more powerful. The next generation of ultra-fast chargers planned will deliver up to 350 kW per charge point. Therefore coordinating closely with the utility and having fast chargers and large stations near adequate high-capacity electrical infrastructure should be the best practice to prevent negative effects on the grid, especially as the fast charging market continues to grow argues ICCT [18].

Adapting the network

So far and in the short term future, charging stations will be sized according to the needs. Rapid stations will be built on the motorway network and fleet operators will rely on relatively low levels of power within their facilities. Future development is likely to start with the sites where sufficient capacity is available. This capacity will not be sufficient in the future for two reasons, namely: technological progress will likely bring to market batteries able to withstand higher charging power, and; BEVs will likely accelerate when there is wider uptake of EVs beyond a niche. The necessity to upgrade the available power to charge more cars and charge them faster (high speed) will lead to a significant step change in capital costs.

Cost implications

The cost of infrastructure and who ultimately bears this cost is now considered. Table 2 shows cost estimates from [19]. For the initial stage site, and assumed to be suitable for a maximum of two BETs, the cost of the infrastructure is one and a half to double the price of the trucks themselves. The mature site assumptions indicates that there is a reduction in price per charger or installed kW of power. Considering a fleet of 12 BETs with 100 kW chargers, the total cost of the infrastructure would approach €1.5 million, or approximately 60% of the purchase price of the trucks. However the depreciation time for the infrastructure would be considerably longer than for the trucks.

Table 2: Costs of electric charging infrastructure, extract from [19].

Item	Initial Stage Site	Mature Site
Civils	€64,000	€82,000
50kW chargers	€60,000 (for two)	€120,000 (for four)
100kW chargers	-	€240,000 (for four)
Charger installation	€10,000 (for two)	€40,000 (for eight)
Grid connection	€10,000	€345,000
Brownfield total	**€144,000**	**€827,000**
Access roads	€50,000	€50,000
Earthworks, Fencing, Surfacing, Drainage, Other Works	€100,000	€100,000
Additional professional fees	€33,000	€33,000
Grid Connection (cost saving)	-€5,000	-€5,000
Greenfield total	**€322,000**	**€1,005,000**

These costs clearly show that the upfront costs of infrastructure, if borne solely by the hauliers, would amount to a significant increase in upfront costs. These costs are not considered in the TCO of ownership calculations owing to the uncertainty around subsidies and discount rates as there technologies become more widespread. As a comparison, e-highways and hydrogen powered trucks would require a pan-European coordinated roll-out of infrastructure, that would be borne by the hauliers through the price of the electricity or fuel.

5. Total cost of ownership

Before undertaking the total cost of ownership analysis, it is worth considering the implied battery price from the details that we have. Indeed, a large uncertainty when analysing the economic viability of EVs (whether cars, vans, trucks, or buses) is the price per kWh of battery. Allocating the entire upfront cost of the Tesla Semi to cover *only* the cost for the ~1000 kW battery, would find a battery cost of €150/kWh, aligning with battery pack cost predictions made for 2020 [9][20][35]. Of course, this price is a gross overestimate, ignoring the cost of the remainder of the truck and any profit margin. Alternatively, we can

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[35] bloomberg.com/news/articles/2017-11-28/electric-cars-need-cheaper-batteries-before-taking-over-the-road

consider the price difference between the two available models under the assumption that the price difference is attributable only to the battery size. Thus, comparing the 300 mile versus the $US 30k more expensive 500 mile variant (i.e. 320 km range difference for €25k), would result in a battery price around €70/kWh - a price that betters optimistic 2030 battery projections. The real price is somewhere within this range, and probably around €100/kWh. This implies Tesla will have to make up for the longer range cost somehow - perhaps by selling fast charging electricity. For the BYD BET, there is no available information on the price of their batteries.

The 800 km version of the Tesla semi is $US 180 000, but as that is likely to exclude optional extras desirable for EU hauliers. We assume that the final price is $US 200 000, or €170 000 at today's exchange rate (this is equivalent to the price of the highest specification variant of the Tesla Model X). We assume assembly takes place in Tesla's Dutch-based plant, avoiding the EU's 22% import tariff[36]. The best in class truck in the EU with similar add-ons would cost in the order of €110 000 [21]. We assume that the fleet average truck is €80 000. No information about the BYD was available, so a price of €110 000 has been assumed.

A haulage business looking to buy a new truck would likely want to use the truck as much as possible, so we assume an annual mileage of 150 000 km. This compares to the EU fleet average of around 110 000 km, and corresponds with the ICCT [22] analysis on the first 5 years of long haul adjusted mileage based on analysis of [15]. The total cost of the vehicle is assumed to be recuperated over a 5 year period, as per the IEA [23], without any resale value, as a simplifying assumption.

The personnel wages for the driver are the same irrespective of the powertrain, and amount to a cost of around €50 000 per year. After taxes and other costs such as pension fund contributions, the driver would likely see around half of that. We take maintenance and repair costs from the impact assessment [24] from the European Commission. They equate to €12 500 per year for the ICE, and we estimate one half of that for the BET, owing to the much simpler drivetrain, less wear and tear on the brakes due to regenerative braking, and lack of gearbox (tyre use however, is assumed to be the same). This is inline with BEUC [25], who use half with the caveat that there is a large variation of reported maintenance costs. Other examples include page 53 of the EEA report, Electric vehicles in Europe [26], which claims 'significantly less maintenance costs', compared to the ICCT [20] assumption of very similar costs ($0.11/km for an ICE vs $0.12/km for a BET). Importantly, we assume that there is no battery replacement cost in the first 5 years of life. Insurance is also taken from the impact assessment, and assumed to be proportional to the upfront cost of the vehicle, which was scaled accordingly.

The fuel cost is a sensitive parameter in the cost breakdown. On the one hand, the current diesel cost of €1/litre [27] applicable to hauliers is known with high confidence. This comes from €0.55/litre for the fuel itself [28], a sales weighted average of €0.45/litre in excise duty, (taking into account the diesel fuel rebate offered in an increasing number of Member States), and business exemption of VAT. The electricity cost that will eventually be charged is more uncertain. This stems from businesses with high electricity usage being able to negotiate prices with the suppliers. Today, the EU average industry rate is

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[36] Commission Implementing Regulation (EU) 2015/1754 of 6 October 2015 amending Annex I to Council Regulation (EEC) No 2658/87 on the tariff and statistical nomenclature and on the Common Customs Tariff, OJ L 285, 30.10.2015

€0.12/kWh[37] whereas Tesla superchargers for cars are currently €0.24/kWh[38]. This should be put in the context of the Shell supercharger charging €0.55/kWh[39] and Tesla promising (US customers at least) €0.06/kWh, a range covering a ten-fold difference. When assessing these costs, we consider both the EU industry average with the option of supercharging. As can be seen, the cost of electricity will make or break the cost competitiveness of BETs in the EU.

Finally, the infrastructure access cost (road charging) is legislated under the current Eurovignette legislation and is currently being revised[40]. There is potential for a 75% reduction of zero emission vehicles compared to the equivalent worst in class. The proposal essentially equates to a 50% reduction compared to the best in class, something that the German Federal Transport Minister has proposed[41] The EU average weighted by km driven for the best in class semi is 0.18€/km[42], so for the BET it would be €0.09/km, assuming that the Commission's proposal is passed as law. Following from the analysis above, it is evident that there are a several factors that will either enable (or hinder) battery electric trucking in Europe, and these are not dominated by technical limitations.

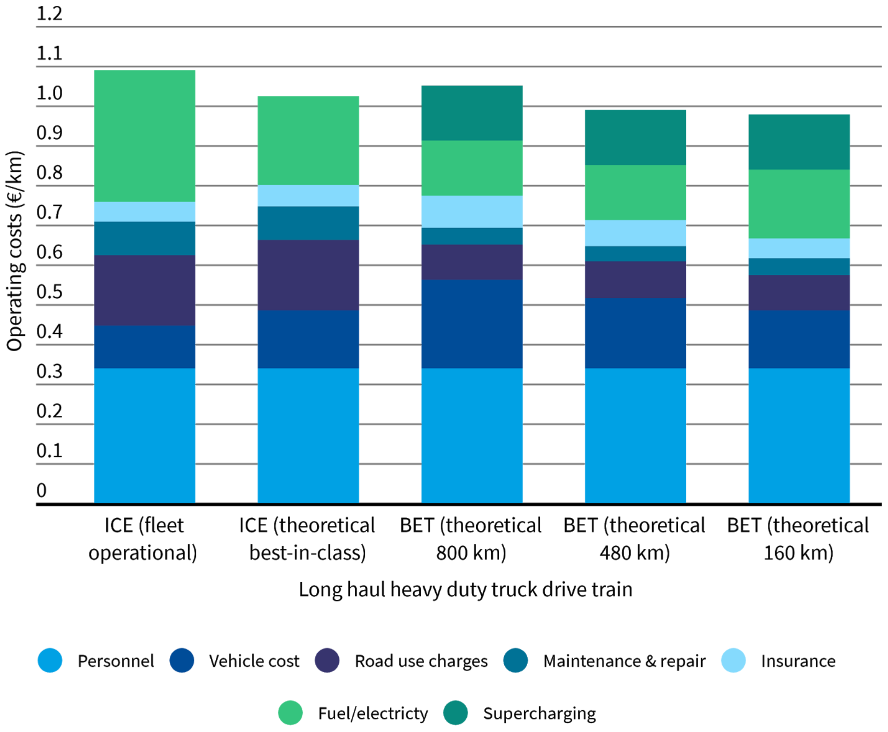

Figure 2: Total cost of ownership (5 years) analysis of diesel ICE long haul trucks versus battery electric (BET).

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[37] http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics (Accessed January 2018)

[38] www.tesla.com/fr_BE/supercharger?redirect=no

[39] support.shell.com/hc/en-gb/articles/115002988472-How-much-does-Shell-Recharge-cost-

[40] eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52017PC0275

[41] www.spiegel.de/auto/aktuell/lkw-maut-e-lastwagen-sollen-befreit-werden-a-1202492.html

[42] From T&E analysis. For comparison, the German Maut for Euro 6 HDTs is €0.135/km, whereas the autoroute in France going from Paris-Strasbourg is €0.24/km

6. Environmental impacts, from well-to-wheel

We have shown the technical and economic feasibility of BETs in Europe. In this section we consider the climate implications of electrifying the heavy duty truck fleet. A full life-cycle analysis (LCA) of a truck would account for the energy required to (and associated emissions) of the fuel or battery and all manufactured components; this analyse would be an extensive study in itself. It has been shown in several studies that for cars [29] the LCA of EVs is far better than for fossil fuel powered vehicles, even in relatively dirty electricity grids. Therefore, in this report we consider only the emissions in a well-to-wheel closed system; that is, the CO_2 emissions associated with producing and transporting the fuel to its final utilisation in the engine. Pollutants such as NOx, SOx, and PM for BETs are zero from a powertrain perspective, and are significantly improved from brake pad wear. Although these are not considered further in this analysis, they are important considerations for local air pollution.

The average EU electricity emissions per kWh of energy produced was 276 gCO_2/kWh[43] in 2014, and on a downward trajectory. Diesel fuel is not only a fossil fuel, but has a mix of biofuel content derived from sources such as palm oil[30] and rapeseed oil that can incur higher emissions due to land use change [31]. Fossil based diesel can also come from traditional wells to oil sands, the later having significant associated production emissions. To keep the analysis simple (and in doing so being generous to the ICE powertrain), we consider a diesel truck powered only with conventional fossil diesel extracted from a well. The well-to-tank emissions are 55 gCO_2/kWh [32], and the combustion of the diesel in the engine 263 gCO_2/kWh[44], giving a total of 318 gC02/kWh. Converting to a per km basis based on the calculated efficiencies, we find 351 gCO_2/km for the long range and 441 gCO_2/km for the short range electric truck. These figures take into account the additional 95% rectification efficiency from Table 1 and an assumed 95% transmission efficiency over the electrical grid. Otherwise, we find 709 g CO_2/km for the constant speed ICE truck and 1051 gCO_2/km for the standard operation truck.

This translates to long range BETs being between 51% to 67% cleaner than equivalent fossil fuel powered trucks. In the case of Poland, as a high carbon intensity example with 671 gCO_2/kWh, an electric truck would still have 19% less emissions than a fleet average diesel ICE, albeit 20% worse than the optimum performance of a best-in-class model; in France with 35 gCO_2/kWh, it would be 94% to 96% cleaner. This well-to-wheel gap is on a trajectory to reach 100% as the electricity grid decarbonises under the EU ETS. Figure 3 shows these results on a per km basis, with the BETs running on an EU average grid.

7. Policy recommendations

This paper shows that BET faces technological and economical barriers before widespread uptake can commence. In terms of the environment, BETs have the potential to significantly reduce CO_2 emissions measured from a well-to-wheel perspective. This paper proposes several key policy recommendations in order to ensure rapid and sustainable deployment of BETs in Europe.

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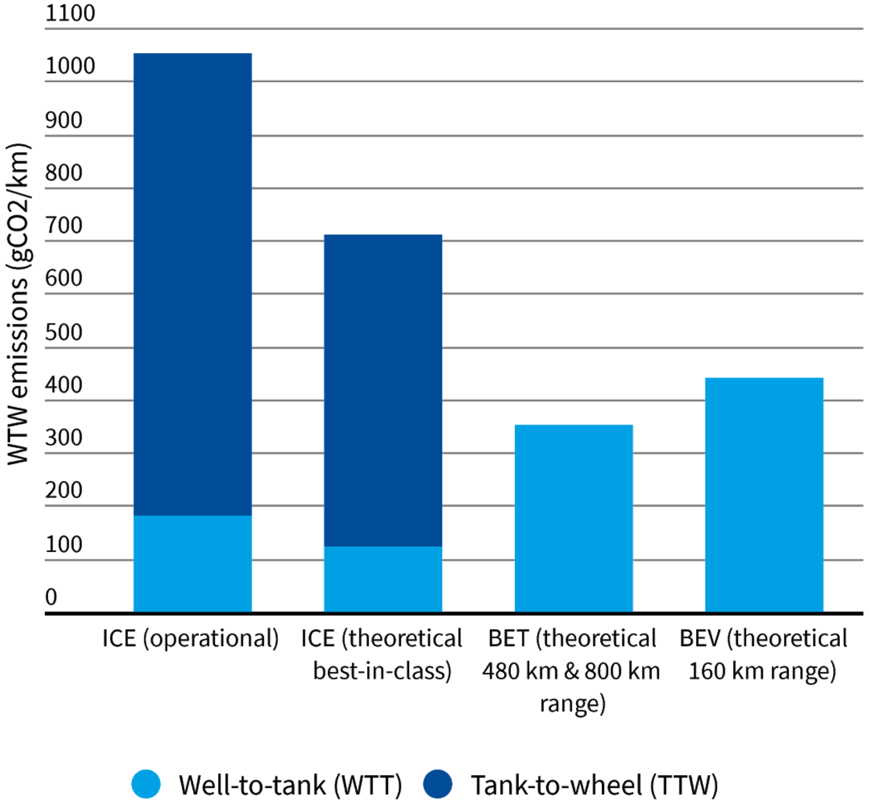
[43] www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-2/assessment

[44] Idem. Table 3-1, page 12.



Notes: Based on EU average carbon intensity of electricity production in 2014 (276 gCO2/kWh). The 160 km range BET is less efficient based on an assumption of being less aerodynamic. EU grid efficiency and AC/DC rectification efficiency for charging both assumed to be 95%. Theoretical indicates flat, constant speed highway driving

Figure 3: Well-to-wheel CO_2 emissions of diesel and battery electric long haul trucks

CO_2 standards for trucks and trailers.

Standards governing CO_2 or fuel efficiency provide manufacturers and suppliers with long term planning and investment certainty. The Commission will propose a first CO_2 standard for the four categories accounting for 80% of truck emissions in May 2018. This will need to be complemented by more aggressive standards for all trucks and trailers for 2030. Standards should exhaust the cost-effective technology potential (30-50% reductions in emissions / fuel)) and push hybrid technology for trucks with a high share of start and stop driving. Standards will facilitate and expedite the shift towards e-trucks and give the regulatory underpinning that makes BETs more attractive for manufacturers.

A zero emission vehicle (ZEV) mandate for trucks

On top of stringent standards, Europe should introduce a mandate or well-designed benchmark with a bonus/malus system for zero emission trucks of 5-10% by 2025 and 25-35% by 2030. This benchmark is a sales target for zero emission trucks that truck makers will need to meet. It goes hand in hand with the CO_2 standard: If a manufacturer overachieves the 5% by 2025, they will have to do less on CO_2. On the contrary, manufacturers who are not meeting the 5% zero emission sales target, will need to do more on CO_2. This benchmark system will increase the supply of zero emission trucks, reduce prices and create a market for electromobility.

Electricity pricing

The price paid for electricity can make or break the economic case for BETs. Applying today's supercharging rates charged for cars to trucks quickly renders the business case less attractive, particularly for the longer range option truck. The EU could consider guiding Member States to reduce rates for electricity for transport in the short term to help enable the uptake of BETs. While the EU can issue such recommendations, it is likely that action on electricity pricing will remain predominantly a Member State matter (typically handled by national regulators).

Road charges, tolls, and fuel taxes

The EU will propose an amendment to its tolling directive (Eurovignette) in 2017. National governments should introduce, expand and redesign tolls so as to accelerate the market take-up of zero or low carbon trucks. A 75% reduction compared to the worst in class (equivalent to a 50% reduction on the best in class) would be a key enabler. National governments should consider gradually increasing diesel tax, ideally in bigger groupings of countries (to avoid fuel tax tourism). Revenues could be used to fund the transition of the sector. More expensive diesel that better covers its environmental and health impacts can also help the economic case for strong electrification.

Zero-emission freight strategies for cities

Cities across Europe have significant potential to push investment to electric trucks. Currently the Netherlands is one of the few countries that explicitly aims to phase out combustion engine trucks and buses from cities in between 2020 and 2030. This bottom-up pressure will further incentivise vehicle makers to invest in zero emission trucks and buses, as a coalition of cities can constitute the majority of the population on the continent.

Infrastructure

Electrifying trucks, whether it be by battery electric, e-highway, or hydrogen, all require infrastructure to operate. The EU should use its post 2020 transport budget lines to co-finance such projects. Further, to harmonise charging technology for e-trucks, the EU should rapidly adopt a common specification for fast HDV charge points. At present this is not the case, as heavy duty vehicles are not mentioned in the Implementing Decision and the standardisation procedure has already taken three years. A timeframe of "end 2019" is now signalled. However, standardisation needs to pre-date the adoption of BETs to avoid a patchwork of OEM or Member State standards[45]. The roll out should offer consistency not only for trucks, but also buses. This should be coupled with rules governing fair access.

Onsite storage systems can help with grid balancing with a large uptake of renewables; this should be considered when procuring this infrastructure, as it could benefit both the energy and transport sector.

Weights and dimensions directive, and payload allowance

The Weights & Dimensions Directive (96/53/EC) allows an additional one tonne of legally permissible weight for trucks up to 26 tonnes that are powered by "alternative fuels", including electric powertrains. The legislation establishes that the extra weight that results from such "alternative" technologies should not be counted as part of the effective load of the vehicle, since this would penalise the road transport sector in economic terms. However, the extra weight cannot increase the load capacity either.

The issue with this allowance is that it only applies to rigid trucks and tractors only but not to vehicle combinations (i.e. articulated or "tractor trailer" trucks). The limitation regarding truck type comes as a result of the belief at the time of drafting the Directive that such alternatively powered trucks would not be possible beyond short-distance transport. This law needs to change so that all trucks can benefit from additional tonnage to account for the alternative technology. Such additional weight should not jeopardise the freight tonnage able to be transported as that could reduce the competitiveness of such trucks with internal combustion engine vehicles.

The Commission is also expected to progress the implementation of rounder, more aerodynamic truck cabs during 2018. This reform, agreed in outline under the 2015 reform of the Weights & Dimension, recently won backing from vehicle-makers through its representative body ACEA[33]. The new designs to be permitted are projected to deliver both safety and emissions benefits.

In practice, reducing the drag coefficient would require an extension of the cab nose to allow it to have a rounded rather than a boxed front. This will be a benefit to both BETs and to the new best in class ICEs. As the batteries can range from 1t to 4t, the EU may consider a small increase in GVW to accommodate these technologies so there is no or reduced penalty on the payload.

Battery manufacturing

Europe's exposure here may be reduced if agreement is reached on Commission Vice President Maroš Šefčovič's initiative for a European battery-maker modelled on Airbus. VP Šefčovič needs to draw the heavy duty sector in more on this important initiative.

The Commission should consider the creation of a joint undertaking for the research and development of battery technologies. Such a joint venture could be half funded by the EU budget and half funded by industry stakeholders similar to how the Shift 2 Rail and Fuel Cells and Hydrogen Joint Undertakings are

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[45] M/533 - Commission Implementing Decision C(2015)1330) on the implementation of the AFI directive 2014/94/EU

managed today. The EU could then use such a body to improve the European market for battery technologies while also researching how to reduce the environmental impact of the supply chain, as well as the best means to integrate electromobility into smart electricity grids.

8. Conclusion

The success of battery electric trucks in the EU is technically feasible, owing to improvements to battery density, the efficiency of electric power trains, and improvements to aerodynamics and tyre rolling resistance. This analysis was demonstrated with a simplified road load equation for a fleet average diesel ICE, a best in class diesel ICE, and three battery electrics trucks. Owing to the efficiency of electric motors, and in case of the Tesla Semi, drastically improved aerodynamic drag, the energy consumption was up to three times less than the diesel trucks.

An analysis of the different methods of charging was carried out. Uncontrolled and opportunity charging would require large power demand, as would overnight charging, albeit at a lesser extent. Two solutions to reduce the peak power demands were discussed, including onsite stationary storage and demand side management charging strategies. A total cost of ownership analysis was undertaken, taking into account wages, fuel use, insurance, road charging, and electricity costs. The main price sensitivity is the electricity price, which can be reduced with logistic planning to avoid uncontrolled charging as much as possible. The environmental benefits of battery electric trucks was highlighted.

Finally, a number of enabling policies at the EU (and some at local) level were analysed, namely: CO_2 standards for trucks and trailers; a zero emission vehicle (ZEV) mandate for trucks; electricity pricing; road charges, tolls, and fuel taxes; zero-emission freight strategies for cities; infrastructure; the reform of the weights and dimensions directive, including payload allowance, and battery manufacturing. These policies will not only help the market case for BET, but ensure truck makers are incentivised and required to increase their repertoire of BETs.

On paper, a battery electric truck like the Tesla Semi stacks up. We note that some of the data used in this study have been manufacturer's claims, which should always be considered with scepticism. Whether these prices and promises can be delivered is yet to be seen. The case is increasingly clear for short haul heavy duty trucks, with many more offerings being announced. This analysis shows that long haul trucking is feasible, significantly reduces GHG emissions, and would make sense for rational economic decision makers such as hauliers in a TCO sense.

9. References

1. UNCC National Inventory Submissions 2018 [Internet]. Apr 2018 [cited Apr 2018]. Available: https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/national-inventory-submissions-2018
2. Graichen J. Targets for the non-ETS sectors in 2040 and 2050. Öko-Institut e.V; 2016.
3. D. Sutter, M. Maibach, D. Bertschmann, L. Ickert, M. Peter, C. Doll, A. Kühn. Finanzierung einer

nachhaltigen Güterverkehrsinfrastruktur. INFRAS, Fraunhofer, Umwelt Bundesamt; 2016. Report No.: FKZ 3713 45 101.

4. EU Transport in Figures - Statistical Pocketbook. Directorate General for Mobility and Transport; 2017. Report No.: Table 2.2.2.

5. De Vita N. Tasios P. Siskos M. Kannavou A. Petropoulos S. Evangelopoulou M. Zampara D. Papadopoulos Ch. Nakos L. Paroussos K. Fragiadakis S.Tsani P. Karkatsoulis et al. P. Fragkos N. Kouvaritakis L. Höglund-Isaksson W. Winiwarter P. Purohit A. Gomez-Sanabria S. Frank N. Forsell M. Gusti P. Havlík M. Obersteiner H. P. Witzke Monika Kesting PCA. EU Reference Scenario 2016 Energy, transport and GHG emissions Trends to 2050. European Commission; 2016 Jul.

6. Calvo Ambel C, Earl T, Kenny S, Cornelis S, Sihvonen J. Roadmap to climate-friendly land freight and buses in Europe [Internet]. Transport & Environment; 2017 Jun. Available: https://www.transportenvironment.org/publications/roadmap-climate-friendly-land-freight-and-buses-europe

7. Nicolaides D, Cebon D, Miles J. Prospects for Electrification of Road Freight. IEEE Syst J. 2017;1937: 1–12.

8. Sripad S, Viswanathan V. Performance Metrics Required of Next- Generation Batteries to Make a Practical Electric Semi Truck. ACS Energy Letters. 2017;2: 1669−1673.

9. Wolfram P, Lutsey N. Electric vehicles: Literature review of technology costs and carbon emissions. The ICCT; 2016 Jul. Report No.: WORKING PAPER 2016-14.

10. Cazzola P, Gorner M, Munuera L, Schuitmaker R, Maroney E. Global EV Outlook 2017 - Two million and counting. International Energy Agency; 2017.

11. Delgado O, Rodríguez F, Muncrief AR. Fuel Efficiency Technology in European Heavy-Duty Vehicles: Baseline and Potential for the 2020–2030 Time Frame. The ICCT; 2017.

12. REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL on the State of the Union Road Transport Market. European Commission; 2014. Report No.: COM(2014) 222 final.

13. Nitta N, Wu F, Lee JT, Yushin G. Li-ion battery materials: present and future. Mater Today. 2015;18: 252–264.

14. den Boer E, Aarnink S, Kleiner F, Pagenkopf J. Zero emissions trucks An overview of state-of-the-art technologies and their potential. CE Delft; 2013. Report No.: 13.4841.21.

15. Papadimitriou G, Ntziachristos L, Wuetrich P, Notter B, Keller M, Fridell E, et al. TRACCS - Transport data collection supporting the quantitative analysis of measures relating to transport and climate change [Internet]. EMISIA; 2013. Report No.: 13.RE.025.V1. Available: http://traccs.emisia.com

16. Marie Chéron, Abrial Gilbert-d'Halluin, Aurélien Schuller, Esther Bailleul, Joseph Beretta, Marie Castelli, Adrien Bouteille, Jean-Baptiste Crohas, Béatrice Lacout, Lorelei Limousin, François Marie, Hervé Mignon, Emanuele Colombo, Maxime Pasquier, Philippe Osset, Cécile Beaudard, Dephine

Bauchot, Céline Cluzel, Jérôme Payet, Hélène Teulon. From cradle to grave: e-mobility and the French energy transition [Internet]. European Climate Foundation (ECF) and Fondation Pour La Nature Et L'homme (FNH) ; 2017. Available: https://europeanclimate.org/wp-content/uploads/2018/01/Electric_vehicles_ENG_AW_WEB.pdf

17. Olsson O, Grauers A, Pettersson S. Method to analyze cost effectiveness of different electric bus systems. Viktoria Swedish ICT and Chalmers University of Technology; 2016. p. 12.

18. Hall D, Lutsey N. Emerging Best Practices For Electric Vehicle Charging Infrastructure. The ICCT; 2017.

19. Wainwright S, Peters J. Clean Power for Transport Infrastructure Deployment. Steer Davies Gleave; 2017.

20. Moultak M, Lutsey N. Transitioning To Zero-Emission Heavy-Duty Freight Vehicles [Internet]. The ICCT; 2017 Sep. Available: www.theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf

21. Todts W. Truck CO2 – why market forces alone cannot deliver the goods [Internet]. Transport & Environment; 2016 May. Available: www.transportenvironment.org/publications/truck-co2-%E2%80%93-why-market-forces-alone-cannot-deliver-goods

22. Meszler D, Delgado O, Rodríguez F, Muncrief R. European Heavy-Duty Vehicles: Cost-effectiveness of Fuel-Efficiency Technologies For Long-Haul Tractor‑Trailers in the 2025–2030 Timeframe [Internet]. Meszler Engineering Services and the ICCT ; 2018 Jan. Available: www.theicct.org/sites/default/files/publications/ICCT_EU-HDV-tech-2025-30_20180116.pdf

23. Teter J, Cazzola P. The Future of Trucks - Implications for energy and the environment. Internation Energy Agency; 2017.

24. Markus Maibach MP, Sutter D. Analysis of operating cost in the EU and the US. Annex 1 to Final Report of COMPETE Analysis of the contribution of transport policies to the competitiveness of the EU economy and comparison with the United States. Infras, TIS, EE; 2006 Jul.

25. Stewart A, Dodson T. Low carbon cars in the 2020s: Consumer impacts and EU policy implications Final report [Internet]. BEUC and Element Energy; 2016 Nov. Available: www.beuc.eu/publications/beuc-x-2016-121_low_carbon_cars_in_the_2020s-report.pdf

26. Jóźwicka M. Electric vehicles in Europe [Internet]. European Environment Agency; 2016 Nov. Available: www.eea.europa.eu/publications/electric-vehicles-in-europe/download

27. Calvo Ambel C. Europe's tax deals for diesel [Internet]. Transport & Environment; 2015 Oct. Available: www.transportenvironment.org/publications/europes-tax-deals-diesel

28. European Commission. Weekly oil Bulletin [Internet]. 2018. Available: https://ec.europa.eu/energy/en/data-analysis/weekly-oil-bulletin

29. Messagie M. Life Cycle Analysis of the Climate Impact of Electric Vehicles [Internet]. Vrije

Universiteit Brussel; 2017 Oct. Available: https://www.transportenvironment.org/sites/te/files/publications/TE%20-%20draft%20report%20v04.pdf

30. Sihvonen J. Europe keeps burning more palm oil in its diesel cars and trucks [Internet]. Transport & Environment; 2016 Nov. Available: www.transportenvironment.org/sites/te/files/publications/2016_11_Briefing_Palm_oil_use_continues_to_grow.pdf

31. Valin H, Peters D, van den Berg M, Frank S, Havlik P, Forsell N, et al. The land use change impact of biofuels consumed in the EU - Quantification of area and greenhouse gas impacts [Internet]. ECOFYS, IASA, E4 Tech; 2015 Aug. Report No.: Ref. Ares(2015)4173087 - 08/10/2015. Available: https://ec.europa.eu/energy/sites/ener/files/documents/Final%20Report_GLOBIOM_publication.pdf

32. Edwards R, Larivé J-F, Rickeard D, Weindorf W. WELL-TO-TANK Summary of energy and GHG balance of individual pathways [Internet]. Joint Research Centre Institute for Energy and Transport ; 2014. Report No.: Appendix 2 - Version 4a. doi:10.2790/95629

33. ACEA. Future CO_2 standards for heavy-duty vehicles. ACEA; 2018 Apr.