Cost Structures of Fossil Free Alternatives for Long Haulage Road Freight Transport

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Abstract. This study compares cost structures for different fossil free propulsion systems for heavy duty, long haulage trucks. The compared alternatives include biofuels, biogas, battery electric vehicles, electric road systems and fuel cell electric vehicles. A relative mobility cost [EUR/vehicle-km] is estimated for each combination of propulsion system and alternative fuel/energy carrier, including vehicle costs (investment, service, and repair) and energy costs (fuel production and distribution, investment, and maintenance of infrastructure for fuel distribution). The estimates show that by 2030, battery electric vehicles have lower than or similar relative mobility costs as the diesel reference. Some alternatives have slightly higher costs (4-7%) than the diesel reference (e.g., DME, methanol, rail electric roads ED95 and CBG (anaerobic digestion)). Electrofuels have substantially higher costs than the diesel reference. The infrastructure costs for electric road systems are high compared to infrastructure costs for the other renewable energy alternatives and the relative mobility cost is sensitive to assumptions regarding investment cost and number of vehicles using the electric roads. The results can be used as a basis for politicians, decision makers and industry by showing where investments and policy instruments are needed to mitigate the transport sectors greenhouse gas emissions.

1. Background

An increased share of renewable energy is needed to decrease greenhouse gas emissions from the transport sector. In the long haulage heavy road transport segment, several different alternative systems for replacing fossil fuels are being discussed. While some alternatives (drop-in biofuels) are compatible with today's vehicles and fuel infrastructure, others require an extensive expansion of fuel infrastructure as well as continued development of vehicles (e.g. BEVs, electric roads and fuel cell electric vehicles). A transformation of the road freight transport sector towards fossil free propulsion systems, will come with high costs in for example infrastructure investments and technical development. To design policy instruments which can accelerate this transformation it is important to investigate the costs of different fossil free propulsion systems and how these costs are distributed between stakeholders and different parts of the system (vehicle – energy carrier – energy distribution system). This study compares several different renewable energy alternatives (see Table 1) for long haulage heavy trucks in terms of their cost structures. The study is relevant as its results can constitute a basis for politicians, decision makers and industry by showing where investments and policy instruments are needed to mitigate the transport sectors greenhouse gas emissions.

Table 1 – Fuel and powertrain combinations included.

Fuel	Description
Diesel	Fossil diesel. Internal Combustion Engine (ICE) vehicle.
DME	Dimethyl Ether from gasification or electrofuel. ICE vehicle.
MeOH	Methanol from gasification or electrofuel. ICE vehicle.
ED95	Ethanol from straw or sugar cane. ICE vehicle.
FAME (RME)	Fatty Acid Methyl Esther from rapeseed. ICE vehicle.
HVO	Hydrogenated Vegetable Oil from tall oil. ICE vehicle.
Fischer Tropsch (FT) -diesel	Synthetic diesel from gasification or electrofuel. ICE vehicle.
BEV	Battery electric vehicles with a range of 430 or 720 km. Electricity from depot or fast charging

Fuel	Description
ERS cat, ERS ind, ERS rail	Electric road system (ERS) vehicle with overhead catenary (cat), inductive (ind) or rail conductive (rail) technology. electric roads. Range of 250 km outside of the electric road.
H_2-FCEV	Fuel cell electric vehicles with energy from hydrogen (H_2).
LBG/LNG SI or HPDI CI	Liquefied biogas (LBG) or natural gas (LNG) in vehicle with spark ignited (SI) engines or with high-pressure direct injection system (HPDI CI) in compression ignited engines.
CBG/CNG SI	Compressed biogas or natural gas (fossil) in vehicle with spark ignited systems.

2. Data and methodology

A relative mobility cost [EUR/vehicle-km] is estimated for each of the fossil free alternatives (and fossil references) in this study. The relative mobility cost is estimated according to Eq1:

$$\boldsymbol{rm} = vi \;+\; s\&r + en \qquad (1)$$

Where **rm** is the relative mobility cost [EUR/vehicle-km], ***vi*** is the vehicle investment cost, s&r is service and repair cost for the vehicle, and en is the energy cost. The vehicle investment cost [EUR/vehicle-km] is calculated according to Eq2:

$$\mathbf{vi}= \frac{[(pp - rv\ \times pv) * a]}{vkm} \qquad (2)$$

Where *pp* is the vehicle purchase price, *rv* is the vehicles retail value after 7 years, *pv* is a present value factor, *a* is an annuity factor and *vkm* is the number of annual vehicle-kilometres for the vehicle. Energy cost, ***en*** [EUR/vehicle-km] is calculated according to Eq3:

$$\boldsymbol{en} = en[EUR/kWh] \times en[kWh/Vkm] \qquad (3)$$

Where *en[EUR/kWh]* is the energy carrier (fuel or electricity) costs and *en[kWh/Vkm]* is the vehicles energy consumption. The energy carrier cost is calculated according to Eq4:

$$\boldsymbol{en}[\boldsymbol{EUR/kWh}] = p + d + i + o\&m \qquad (4)$$

Where *p* is production costs of the energy carrier, *d* is the distribution costs, *i* is the investment costs in distribution infrastructure (fuel stations, electric roads etc.), and *o&m* is operation and maintenance costs of distribution infrastructure.

The relative mobility cost does not include costs that are independent of fuel/powertrain or where differences are not well documented and estimated to be small compared to the other costs. These costs include driver wages, tyres, and insurance costs.

The costs are estimated for a heavy-duty truck with a maximum permissible weight of 40 tonnes mainly performing long haulage missions in Sweden, for the year 2030. The cost estimates are based on data from literature and from industry contacts. Updates to EUR_{2020} have been made and cost reductions until 2030 have been adjusted based on updated knowledge of e.g., cost levels and learning curves. All costs are expressed in EUR_{2020}/vehicle km, excluding taxes.

2.1 Vehicle investment and S&R costs

Vehicle investment- and S&R costs are based on data from [1–4], with some adjustments based on values from industry. Battery costs are adjusted based on assumptions from BloombergNEF [5]. ICE vehicle costs are assumed to increase slightly between 2020 and 2030 due to stricter emission standards. Costs for batteries, electric motors, grid connections (to the electric roads), fuel cells, hydrogen tanks and natural gas tanks are expected to decrease between 2020 and 2030, based on learning curve models of these technologies. Assumptions regarding annual vehicle-kilometres, retail value, present value and annuity are based on data from [6].

2.2 Energy carrier costs

Costs for production and distribution of energy is based on values and assumptions from [7,8]. Production costs for electricity, fossil gas and diesel are assumed to be constant over the time period. Production costs for 1st generation biofuel only decrease slightly (approximately 2%) between 2020 and 2030, while 2nd generation biofuel decrease more over time due to process development and learning effects.

Infrastructure investment costs for electric roads are based on data from, among others [4,9–11] and are calculated for a scenario where they cover 1% of the Swedish public roads (985km) with an optimistic assumption that this will reach 25 % of the heavy truck traffic (vehicle kilometres).

2.3 Energy consumption

Energy consumption is based on values from [12]. Annual energy efficiency improvements for diesel, gas and biofuels are assumed to be 1.5 % during 2017-2030 based on estimates for 2017-2045 by [13]. For BEV:s, electric roads and FCEV:s the yearly energy efficiency improvements are assumed to be 1,8 to 2 % based on [12].

3. Results

Figure 1 presents results regarding the relative mobility cost 2030. All costs are given without taxes in EUR_{2020}. The results show that the only alternatives with lower relative mobility costs than the diesel reference are the BEV alternatives (except for the large battery with fast charging) and the CNG (fossil) vehicles. Other alternatives, such as DME and methanol (gasification), ERS-rail, ED95 and CBG (anaerobic digestion) have slightly higher costs (4 - 7%) than the diesel reference, while the rest of the alternatives are more expensive. Electrofuels have substantially higher costs than the diesel reference, especially when combined with gas vehicles (about 50 % higher costs).

When it comes to the vehicle costs (investment and S&R) LNG HPDI vehicles come with the highest costs followed by FCEVs and BEVs with a ranger of 720 km. A smaller gas tank for the LNG HPDI vehicle would shorten the range but also make the vehicle cheaper. By 2030 BEVs with smaller battery, as well as the ERS vehicles come with lower costs than the diesel reference due to lower S&R costs of the vehicles.

The infrastructure costs for ERS are high compared to the other systems. The analysis of the ERS shows that the total costs are very sensitive to the traffic intensity of the electrified stretch, the number of vehicles that will use the road (carry the cost) and the investment cost per road km. In this study it is assumed that only heavy trucks will use the electric roads. For the ERS-cat. technology, this is a more reasonable assumption than for the ERS-rail and ERS-ind. technologies, which can also be used by other vehicles. The results are based on a Swedish context, where distances are long and traffic intensity is low compared to several other European countries. Therefore, infrastructure costs per vehicle-km might vary between countries.

As can be seen in the figure, production costs are high for electrofuels compared to the other alternatives. Production cost for electricity is very low compared to all other energy options, which is one of the main advantages for electric vehicles.

The distribution costs of H_2 for FCEVs and fast charging for BEVs are high compared to the other alternatives. In this study, it is assumed that H_2 is distributed by truck and not by pipe.

The results show that there are several alternatives that can compete with the diesel reference already in 2030. However, to enter the market or to reach a higher market share for these alternatives, investments will be needed in for example distribution infrastructure and policy instruments will be needed to target costs in several parts of the alternative systems.

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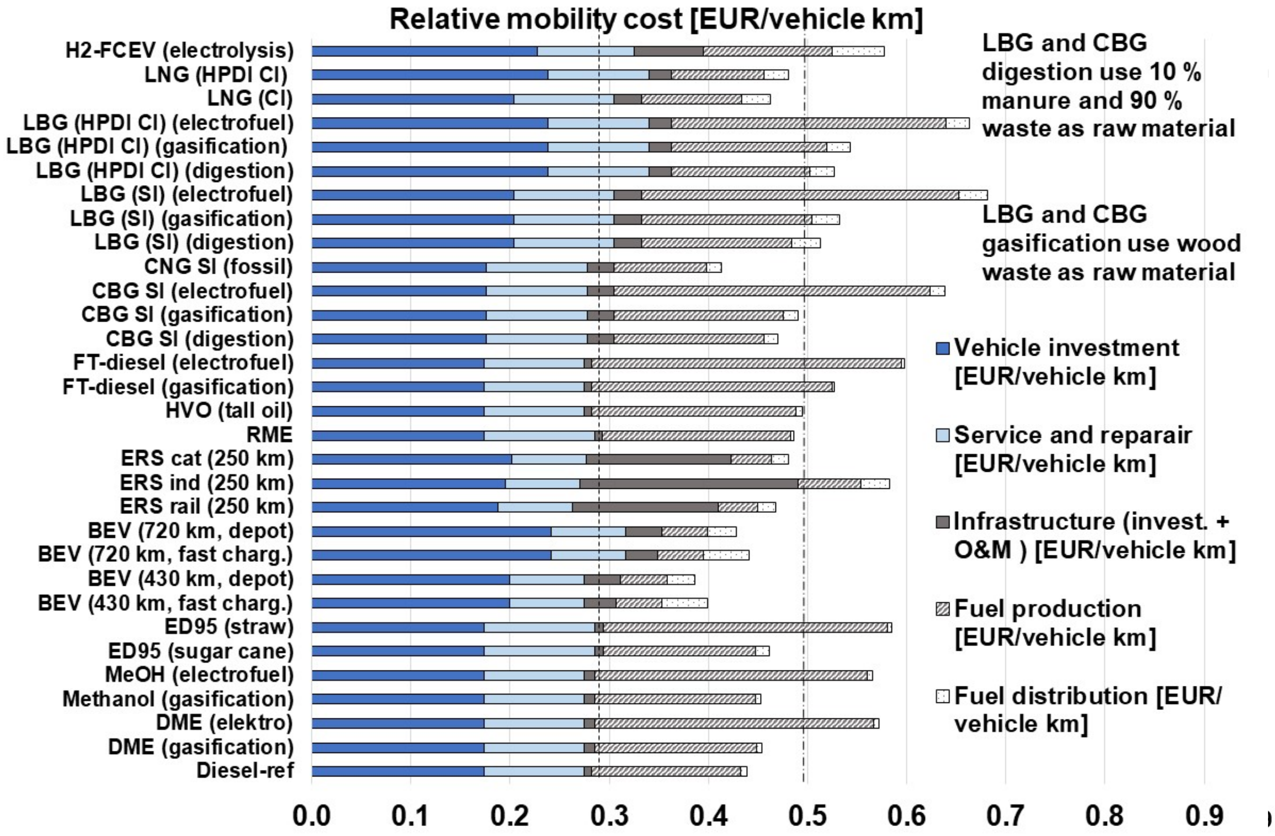

Figure 1 - Relative mobility cost for HGV40 (heavy duty vehicle with total weight of 40 tonnes) in 2030.

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