Future Measures for Fuel Savings of Heavy-Duty Vehicles

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Introduction

For the German Federal Environmental Agency UBA (Umweltbundesamt) an evaluation of fuel saving measures for heavy duty vehicles (HDV) in terms of reduction potential and profitability was conducted by ifeu Heidelberg and TU Graz. It covers actual available components and technological measures, which will be available with high probability in near future [Dünnebeil 2014].

The saving potentials were simulated with the program VECTO, which is part of the upcoming European CO2 certification procedure for HDV. The study is based on three generic vehicles, a tractor-trailer 40 t, a delivery truck 12 t and a city bus 18 t. The analysed options include amongst others energy recovery like exhaust heat power generation and brake power recuperation by electrical hybrids, gas engines, aerodynamic add-ons, low rolling resistance tyres and electrical vehicles.

In addition, the implementation costs for these technologies have been analysed systematically. Standardized fuel saving potentials and implementation costs were combined to a cost - benefit matrix. This allows the comparison of the cost-effectiveness for single technologies as well as for technology bundles.

In this paper the results for the tractor-trailer vehicle on the long haul cycle are presented, because they have ca. 50 % share in the European HDV's CO2 emissions [Hausberger 2012 p. 175]. The results for the other vehicles can be found in the final report [Dünnebeil 2014].

Methodology

VECTO will be used in the future certification of CO2 emissions from HDV in the European Union. The whole procedure shall become mandatory in 2017 and provide for each HDV its fuel consumption and CO2 emission value per kilometre for representative test cycles. The development of this method is coordinated by TU Graz and is performed in close cooperation with ACEA and the supply industry. It consists of physical tests of vehicle components and a simulation of the fuel consumption (FC) of the entire vehicle, based on the component data. The simulation uses vehicle longitudinal dynamics and a driver model to compute engine torque and engine speed over the cycle from the measured aerodynamic drag coefficient, the rolling resistance coefficients, the transmission losses and the generic power demand of auxiliary consumers. The vehicles follow in the simulation predefined "CO2-testcycles", which are target speed cycles for different mission profiles ("urban delivery" up to "long haul"). The FC is then interpolated from an engine map. This approach showed good accuracy in a “proof of concept phase” [Fontaras 2014] and is described in [Luz 2014]. Nevertheless from 2014 to 2017 several details of the procedure shall be further elaborated.

For the investigated HDV classes the input data for VECTO was collected from literature research, own measurements and standard data of average components from the industry. Most of the FC-reducing measures could be simulated directly with VECTO, in the cases of exhaust heat power generation with an organic rankine cycle, hybrid drivetrains and battery electric vehicles a manual post processing in Microsoft Excel became necessary.

The long haul cycle is shown in **Figure 1**.

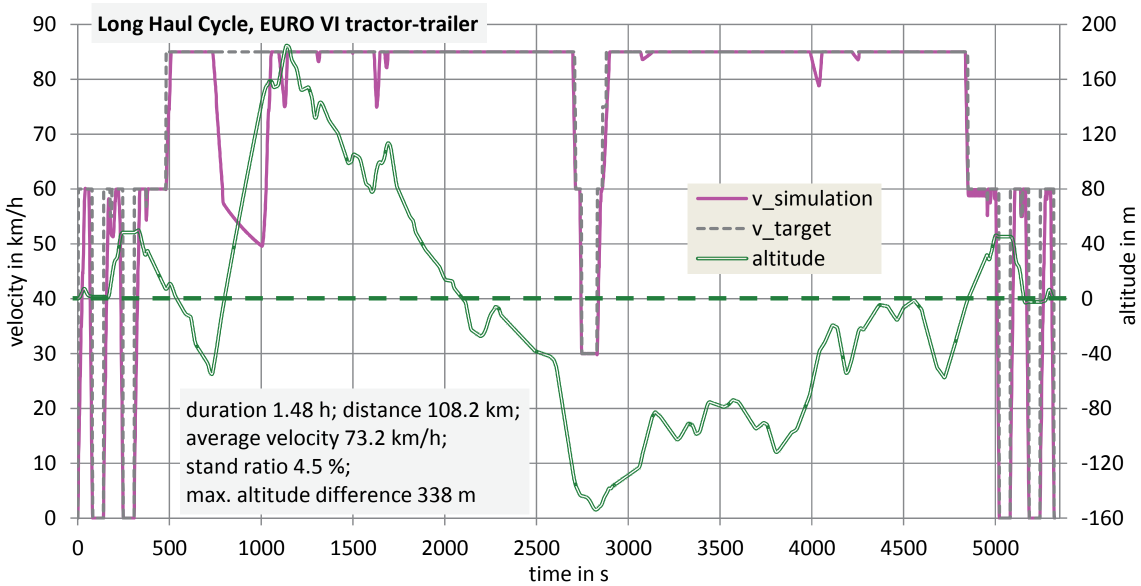

Figure 1: Long haul cycle, simulated with a the EURO VI tractor-trailer

For assessing of cost-effectiveness of the analysed FC-reducing measures, additional investment costs for these measures and further relevant cost changes were investigated:

- Today's investment costs for the single measures were determined from price lists, journals and requests at manufacturers. Market launch prices for not yet available technologies were estimated from reports, e. g. [Baker 2009] [Hill 2011] [Schroten 2012]. As the cost research revealed a considerable bandwidth of possible investment costs for the individual measures, plausible average values for current investment costs were estimated.

- Cost changes of FC-reducing measures can also affect running vehicle costs, e. g. vehicle maintenance, urea demand or tire- and oil changes. Hence, relevant changes of running costs were estimated for concerned measures as well.

Based on the simulated fuel consumption, fuel cost reduction potentials of each measure were calculated for different time periods.

The results of the simulation and the cost research were used to calculate the payback period of single FC-saving measures and of packs of measures. In addition the CO2 abatement cost and marginal abatement cost curves for combinations of components were figured up.

At the end of the project the preliminary results for FC-saving and investment cost were discussed with HDV engineers from two OEMs, where corrections and suggestions for some vehicle configurations were made.

Results - Tractor-trailer on the long haul cycle

To give an impression of actual possible saving measures, a tractor-trailer with improved aero-dynamics is shown in **Figure 2**.

Figure 2: Tractor-trailer with improved aerodynamics

With exception of the round front extension and the rear view cameras all shown aerodynamic measures are already permitted: panels between tractor-cabin and trailer, side- and underbody panels at the trailer and a short boat-tail of 0.5 m. These comparatively cheap components allow ca. 4 % energy saving on the long haul cycle, see measure "5) Aero package 1, trailer" in **Figure 3**.

The results for the calculated saving potentials of energy and fuel cost are given in **Figure 3**.

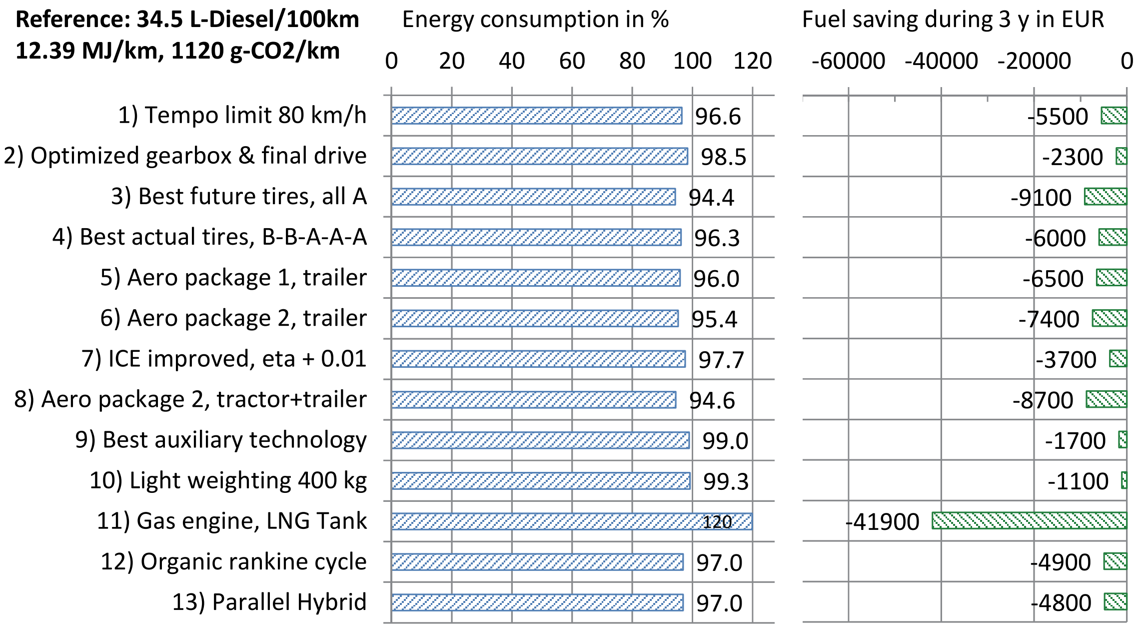

Figure 3: Saving potentials for energy and fuel cost. Tractor-trailer on long haul cycle[1]

It is obvious, that only with three simple measures, namely 1) tempo limit 80 km/h, 4) best actual tires and 5) aero package 1, a sum saving of ca. 10 %[2] is possible, what leads to a financial saving of ca. 16'100 EUR during three years of operation. This is communicated by the industry to be a typical demanded payback period for the first HDV operator.

[1] **Reference vehicle:** Diesel engine 350 kW, tires B-C-B-B-B (RRC-classes EC 1222/2009), RRC_{avrg} = 5.4 N/kN, $C_d \cdot A_{cr}$ = 5.3 m², $P_{auxiliaries,avrg}$ = 4.6 kW, 12 gear AMT, $m_{veh,total}$ = 33.7 t
Fuel saving measures: 2) losses reduced by 25 % 3) RRC_{avrg} = 4.1 N/kN 4) RRC_{avrg} = 4.6 N/kN 5) trailer: side panel, underbody panel, boat-tail 0.5 m, $C_d \cdot A_{cr}$ = 4.51 m² 6) like no. 5 + boat-tail 1 m, $C_d \cdot A_{cr}$ = 4.40 m² 7) no EGR, SCR-only, variable water- and oil-pump, low-friction lubricant 8) like no. 6 + rear view cameras, $C_d \cdot A_{cr}$ = 4.24 m² 9) compressor w. clutch, variable steering pump, LED headlights, $P_{auxiliaries,avrg}$ = 3.1 kW 12) steam power process, driven by exhaust heat 13) electrical machine 75 kW at gearbox input, battery 12 kWh, SOC 20 to 40 %
Assumptions: annual kilometrage 130000 km/y, Diesel: 1.20 €/L 35.9 MJ/L, Natural Gas: 0.93 €/kg 46.8 MJ/kg
[2] Multiplication of the single consumption factors: 0.966 * 0.963 * 0.960 = 0.893 ≈ - 10 %

The results for the investment cost and the CO2 abatement cost are shown in **Figure 4**.

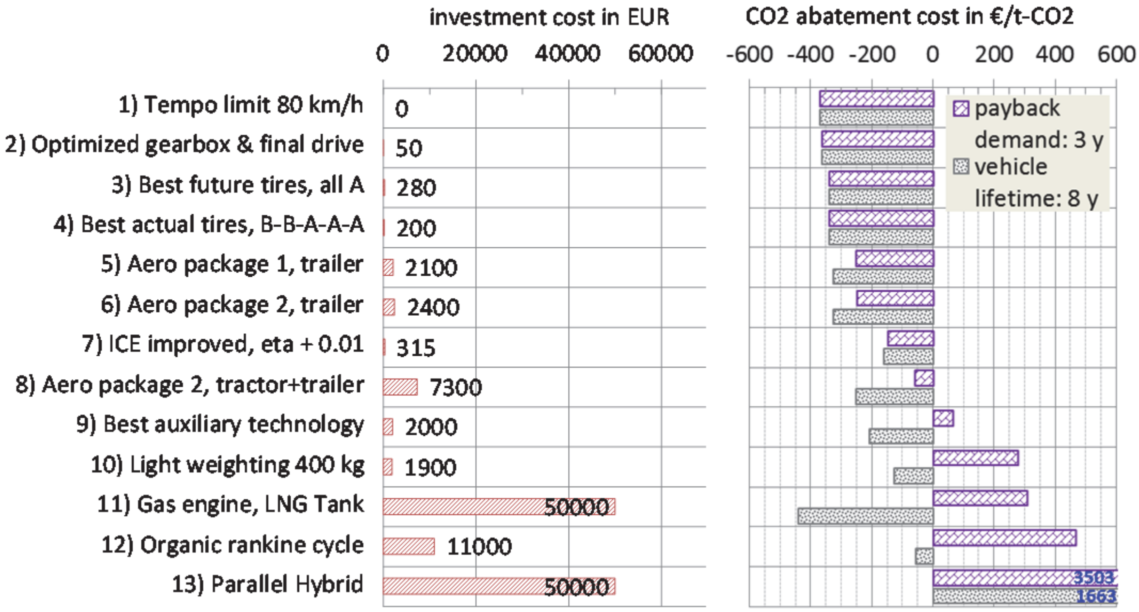

Figure 4: Investment cost and CO2 abatement cost[3]

The proposed three saving measures would cause an additional investment of ca. 2'300 €, what results, less the 16'100 € fuel cost, in a net benefit of ca. 13'800 € for the original purchaser during the first three years. The CO2 abatement cost of the combined measures is ca. - 320 €/t.

So this investment would be very attractive for the owner and for the environment, but there are also reasons against these measures, the obstacles. The use of the HDV is constrained, because the maximum velocity is limited to 80 km/h and the rear boat-tail needs to be folded every time when driving backwards to the terminal. Also the side panels can be damaged during the robust loading with a forklift. These are practical obstacles, but there are also financial ones. Often, the trailer is owned by another company than the tractor. So when the trailer-owner invests in saving measures like better tires and aerodynamic panels, the benefit will be on the tractor-side, where the fuel is paid. Therefore, an incentive system, e. g. subsidies or tax-reduction for effective saving measures, would be helpful to motivate the different stakeholders to make the investments. The obstacles and possible political countermeasures are discussed in detail in the final report [Dünnebeil 2014].

In addition it is obvious that a demanded payback period of 3 years is too short to exploit high fuel saving potentials. Only the measures 1) to 8) reach the payback and negative CO2 abatement cost. When the period is extended to the average vehicle lifetime 8 years, measures 1) to 12) get profitable with negative CO2 abatement cost. Only the hybrid tractor does not reach the payback. To solve the problem, that a saving measure is profitable over vehicle lifetime but not for the first owner, who demands a payback period of 3 years, also an incentive system could be a solution.

Summary

In this contribution future fuel saving measures for tractor-trailers on a typical long haul cycle were assessed in terms of reduction potential and profitability. The saving potential was simulated with VECTO, the future standard program for the upcoming CO2 certification of new HDV in the European Union. The cost for the measures were researched from publicly available sources and requests at manufacturers. The result is a ranking of saving measures in terms of cost and of payback period. E. g. with the three comparatively cheap and immediately realizable measures tempo limit 80 km/h, tires with reduced rolling resistance and a trailer with aerodynamic add-ons, a saving of ca. 10 % is possible. The payback period is less than a half year. But also obstacles for the application of the saving measures are explained, e. g. a lower transport velocity or a bigger effort when handling the trailer with aerodynamic panels and a boat-tail. In addition to these practical obstacles, the task is depicted to share the benefit from saving measures between the different stakeholders of the haulage means "tractor-trailer". Tractor and trailer belong often to different owners, and the party with a higher investment for the additional components does not necessarily profit from the reduced fuel cost. In addition the payback period of three years is too short for many measures to become profitable, but typically demanded from the first owner. When the given period is extended to the average vehicle

[3] €/t-CO2 $=(€_{invest} - €_{FC\text{-}saving,accum}) / m_{CO2,accum}$, well-to-wheel: Diesel 90.4 g-CO2/MJ, Gas 68.1, DIN EN 16258

lifetime of 8 years, also other components like exhaust heat power generation systems or controllable engine auxiliaries become lucrative. The practical and financial obstacles can be overcome by political measures like changes in regulations and incentives for the use of saving measures, to make the investment more attractive.

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