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TNO report

Potential CO_2 reduction from optimal engine sizing for light commercial vehicles

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Contents

Summary

The average performance of light commercial vehicles has increased during the last decades. Due to this enhanced performance, the achieved levels of fuel consumption and CO_2 emission reductions are smaller than the engine efficiency improvements realized in the same period. A possible way to realize this full potential is by modification of engine characteristics to historic power levels. With modern engine technology, performance levels of the previous decade can be met with more compact engines. This can result in a CO_2 emissions reduction of 6% to 16%, based on the type approval test cycle.

Additionally, these vans with more compact and more efficient engines can have economically interesting consequences for both purchase and operation costs. Besides smaller and therefore cheaper produced engines, vans consume less fuel and may be eligible for tax reductions. Cumulatively, these measures can lower total cost of ownership by 1%-12 %.

Introduction

The efficiency of internal combustion engines for road vehicles has increased significantly during the past decades. In the light commercial vehicle (LCV) industry this development has to a large extent been used to achieve higher power-to-weight ratios rather than fuel consumption and CO_2 emission reduction. A possible way to recapture this considerable reduction potential is by optimal engine sizing to power levels as used in the previous decade. Herein, optimal engine sizing is characterized as a combination of optimal power rating and downsizing of the engine.

Throughout this report the following terminology is used:

"optimal engine sizing" =	the sum of "optimal power rating" and "engine downsizing"
with:	
"optimal power rating" =	adjusting the engine power by reducing engine displacement to go back to performance levels of 10 years ago
"engine downsizing"=	reducing engine displacement while maintaining performance through application of turbo charging

On 28 October 2009 the European Commission published a proposal for a regulation of CO_2 emissions for light commercial vehicles[1]. The reduction potential provided by optimal power rating LCV engines is additional to the potential of CO_2 emission reduction by technical measures to engines and vehicles as calculated for the European Commission by TNO and partners[2]. In these support studies performance levels in future target years are assumed equal to reference vehicles of 2007.

In order to get insight into the potential for CO_2 emission reduction by optimal engine sizing of light commercial vehicles to levels common in the past decade, TNO has performed a study of which the main conclusions are summarized in this document.

[1] COM(2009)593, REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - Setting emission performance standards for new light commercial vehicles as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles

[2] See European Commission website: http://ec.europa.eu/environment/air/transport/co2/co2_home.htm: reports http://ec.europa.eu/environment/air/transport/co2/pdf/final_report_lcv_co2_250209.pdf and http://ec.europa.eu/environment/air/transport/co2/pdf/Report%20LT%20targets.pdf

1 Potential CO_2 reduction of engine optimal engine sizing for light commercial vehicles

Between 1997 and 2009 the power-to-weight ratios and power-to-fuel consumption ratios of the least powerful model LCV versions type-approved within the EU increased. Assuming the five best sold LCV types are representative for LCV fleet, increases where respectively 9% and 38% (fig. 1 & 2). In this period the average fuel consumption reduction of these models was only 11%. It can therefore be concluded that part of the technological development has resulted in enhanced performance rather than in fuel consumption reduction.

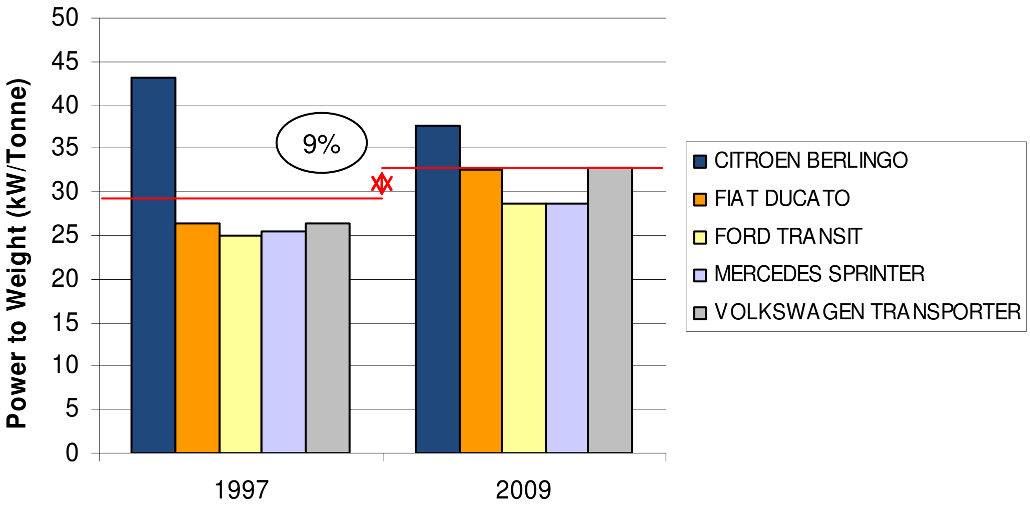

Fig 1: Power-to-weight increased 9% between 1997 and 2009 (Source: Kraftfahrt-Bundesamt[3])

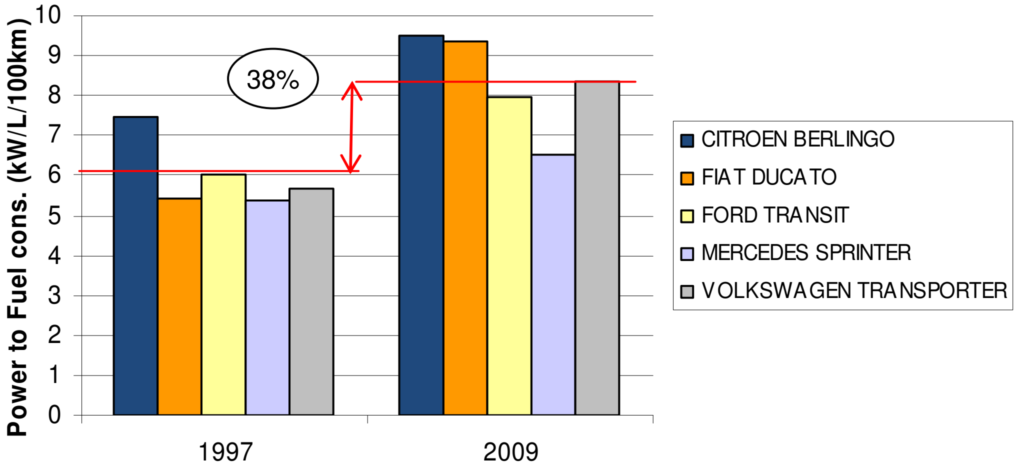

Fig 2: "Efficiency" increased 38% between 1997 and 2009 (Source: Kraftfahrt-Bundesamt[3])

1.1 Method for assessment of potential CO_2 reduction

In order to get an overview of trends in the performance of LCVs, the following method was applied:

1. The five best sold LCV models from 2007, assumed to be representative for the LCV fleet, were selected for further investigation. From these five models the 'base' models, being the ones with lowest power-to-weight ratios, were selected.
2. The power-to-weight ratios of these five 'base' models were analyzed for 1997 and 2009[3] new type-approved versions.
3. Assuming the power-to-weight ratios of 1997 were sufficient, the potential optimal power rating was calculated by multiplying current weights with 1997 power-to-weight ratios (or 2009 power-to-weight ratios in case these were lower than the 1997 values).
4. The potential downsizing was hereafter determined by dividing the power of the optimally power rated engines by the power-to-displacement ratios of the 2009 engines.
5. Four LCV weight categories were created (i.e. 1200 kg – 1500 kg, 1500 kg – 1800 kg, 1800 – 2100 kg and 2100 – 2300 kg). In these categories models with comparable aerodynamic characteristics were selected. From these models the (type approval) fuel consumption and displacement were plot. A linear relation per weight category was determined by applying the method of least squares to the plotted data.
6. Depending on the current weight of the five selected best sold LCV model types, one of these relations was selected to calculate the potential fuel consumption for the optimally power rated and downsized engines.

Numbers representative for the total van fleet were calculated by weighing the five selected LCV model types over 2007 European sales.

1.2 Potential for CO_2 reduction due to optimal power rating

Given the current van weights and 1997 power-to-weight ratios (approximately 29 kW/tonne), modern vans could do with 13% less power than they have now. Given that the specific power outputs of the 2009 versions of the selected models are about 33 kW/dm^3, average displacement could be reduced by 13% (figure 3).

As a result of this smaller power and displacement, fuel consumption can be reduced. This can be concluded from the fitted relations between displacement and fuel consumption (from the type approval driving cycle), for various weight categories shown in the figures in appendix B. Based on these fitted relationships, the average potential fuel consumption decrease is approximately 6% (figure 4). This also means a potential CO_2 reduction of 6% for these van types.

[3] *Fuel Consumption and Emissions Type Approval Values for Motor Vehicles with a National or EC Whole Vehicle Type Approval,* Kraftfahrt-Bundesamt

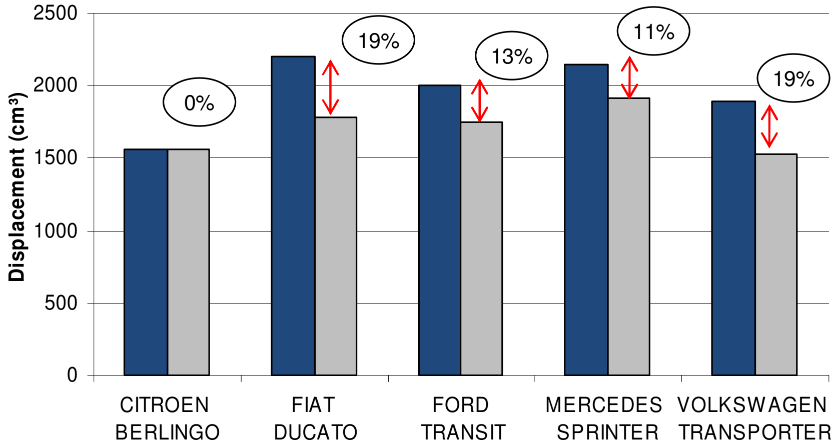

Fig 3: Average possible displacement reduction is 13% assuming current power-to-displacement values (Source: Kraftfahrt-Bundesamt[3])

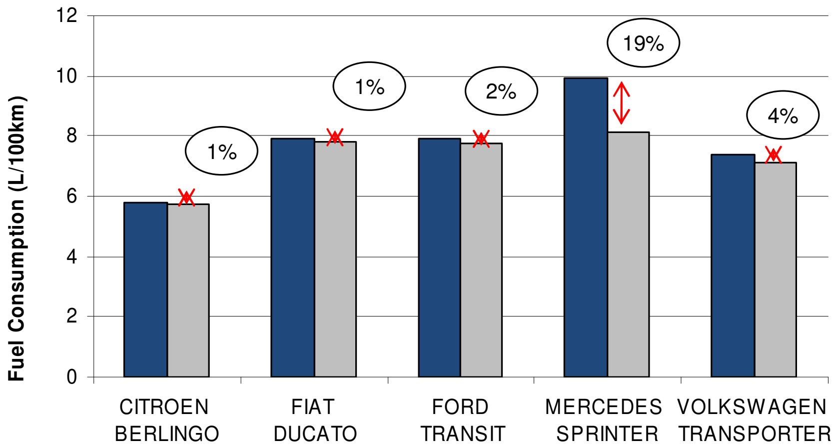

Fig 4: Average potential reduction in fuel consumption as a result of smaller power and displacement is 6% assuming current power-to-displacement values (Source: Kraftfahrt-Bundesamt[3])

1.3 Potential for CO_2 reduction including downsizing to current state-of-the-art

Taking modern efficiency improvements into account, e.g. turbo charging, CO_2 reduction can be increased even more, without the use of technology other than that is already available. For example a modern 1.6 liter diesel Peugeot Expert with 66 kW and torque of 180 nm, has a specific power of 41.3 kW/dm^3. Applying this in our calculation (in stead of the specific power output of the five selected LCV versions), engines could be downsized 31% (figure 5). The CO_2 reduction potential then increases to 16% (figure 6).

Modern combustion engines[4] can even have specific power outputs up to 75 kW/dm^3. However optimal engine sizing, using these specific power outputs, results in very small displacements. These engines cannot be realized with current technology and efficiency gain is expected to be much less.

[4] Verbeek, R. et al. (2008), *Impact on Bio-fuels on air pollutant emissions from road vehicles*, TNO report nr. MON-RPT-033-DTS-2008-01737

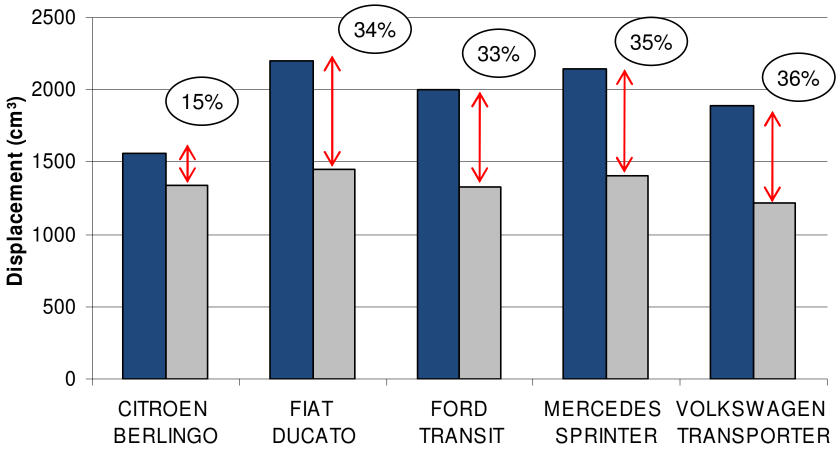

Fig 5: Average possible displacement reduction is 31% assuming power-to-displacement of 41.3 kW/dm³ (Source: Kraftfahrt-Bundesamt[3])

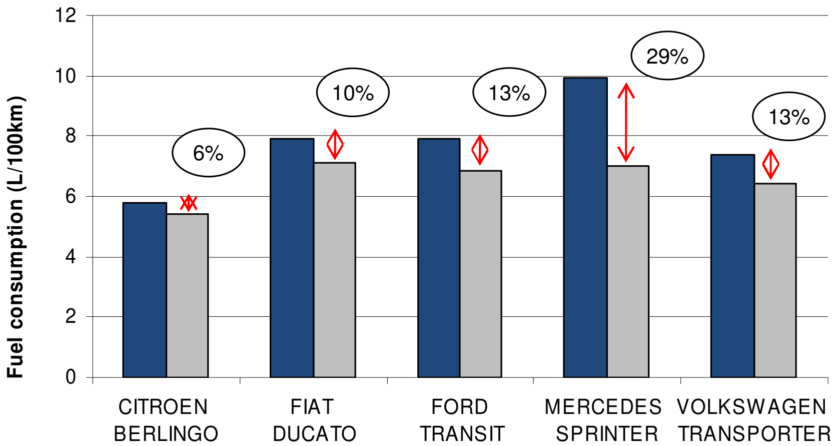

Fig 6: Average potential reduction in fuel consumption as a result of smaller power and displacement is 16% assuming power-to-displacement of 41.3 kW/dm³ (Source: Kraftfahrt-Bundesamt[3])

Generating sufficient torque on the wheels with small displacements is possible from a technological point of view with the proper transmission/gear-ratios. Up to now European van makers have not brought to market such technology.
However, since most OEMs co-develop van types and/or drive trains to maximize economies of scale, the introduction of new torque optimized small displacement engines (including gear-box) by multiple van manufacturers should be feasible at acceptable cost intensity.

1.4 Conclusions

Analyzing the base models of the five best sold LCV models of 2007, power-to-weight ratios have increased over 9% between 1997 and 2009. Combining the current specific power outputs (averaged approximately 33 kW/dm³) and average 1997 power-to-weight ratios, today's engine displacements could be decreased by 13%. As a result of this smaller power and displacement, fuel consumption and CO_2 emissions can be reduced by approximately 6%. This corresponds to findings by MAHLE[5], taking into account that, in contrast to the MAHLE study, also the power is lowered.

[5] MAHLE (2009), *The future is in downsizing*, MAHLE, press release, Shanghai 2009

Moreover, increasing the specific power output to levels that are being achieved already, even more CO_2 can be reduced. For instance, with a specific power output of 41.3 kW/dm^3, engines could be downsized approximately 31%, resulting in 16% CO_2 reduction.
This potential is estimated to be equal for the best sold versions of the LCVs, which have higher power and more displacement than the analyzed base models. On one hand these higher performing engines have higher specific power outputs, lowering the potential of downsizing; on the other hand the higher displacements increase the downsizing potential.
Given that urban traffic is relatively heavily weighted in the type approval cycle, the real world fuel consumption reduction can deviate from what is calculated in paragraph 1.2 and 1.3. Since smaller engines have higher reduction potential urbanely than rurally or on motorways, real world reduction potential could be somewhat lower than calculated in this study. Since not enough data is available, this is not quantified.
Expectations are that there is a substantial demand for vans with these downsized engines, since the 2007 European sales share of the smallest engine is highest in four of the five analyzed LCV types (appendix C).

2 Impact on cost of ownership

The fuel consumption reduction resulting from optimal engine power rating leads to a reduction in total cost of ownership. Further cost reductions could be expected from lower engine production costs, lower costs of other components that can be optimally power rated and possibly of insurance costs.

The cost of ownership can be broken down into fixed and variable costs, they can be further broken down (roughly according to the structure of the Harmonised Index of Consumer Prices – HICP[6]) into those items listed in table 1. The impact of optimal power rating on the cost of ownership is summarised, in this same table. The percentages are indicative and will be discussed below.

Cost type	Origin of cost	impact	
		Low estimate	High estimate
Fixed	Purchase of vehicles	-/-1%	-/-10%
	Registration tax[7]	+0%	-/-15%
Variable	Spare parts and accessories	+0%	
	Fuel and lubricants[8]	-/-6%	-/-16%
	Maintenance and repair	+10%	+0%
	Insurance	+0%	
	Circulation taxes	+0%	-/-15%

Table 1: Summary of impacts on costs

2.1 Purchase of vehicles

The strength and weight of various LCV components, e.g. brakes, axis and suspension are in principle scalable with the power/performance of the vehicle. Optimal power rating would then result in cost savings on these components. However, since LCVs are dimensioned on gross vehicle weight (GVW) rather than on power, this is found not the case for LCVs.

Peripheral elements that specifically have been looked into are the suspension and the brakes. It has been found that those elements do not strongly benefit from optimal power rating. Suspension requirements relate to the gross vehicle weight, which does not change much as a result of optimal power rating. Brakes are designed to dissipate the brake energy. Brake energy scales linearly with vehicle mass and quadratically with initial vehicle velocity. Type approval testing, however, requires vehicles to pass braking tests while fully laden, which mostly negates the limited weight effect of optimal power rating. Braking of N1 vehicles, furthermore, is tested at 80% of the maximum speed but with a maximum velocity of 120 km/h. A top speed higher than

[6] http://circa.europa.eu/Public/irc/dsis/hiocp/library?l=/public/compendium_reference/compendium_reference/_EN_1.0_&a=d; accessed April 28, 2010

[7] For those countries that have a CO_2 performance related registration tax.

[8] Real world fuel related cost savings are derived from the fuel savings as estimated in the previous section. This implies that real world fuel consumption savings can be equated with those savings as can be measured on the type approval cycle (for which the estimate was derived). This is not necessarily true.

150 km/h, therefore, has no consequence in the type approval test[9]. From this, it is not to be expected that optimal power rating will have a significant (cost) effect on brakes. This is further illustrated by the retail prices of the brake discs (being the most expensive single part of the brake system and, therefore, serving as proxy for the brake costs) that are found to be invariant when compared, within a van type, for varying levels of engine power (table 3).

brand	type	engine displacement (cm³)	power (kW)	fuel type	price brake discs (€)
Ford	Transit connect 1.8 tdci s		55	diesel	95
Ford	Transit connect 1.8 tdci l		66	diesel	95
Ford	Transit connect 1.8 tdci l		81	diesel	95
Mercedes-Benz	Sprinter 3-t bus 211 CDI		80	diesel	90
Mercedes-Benz	Sprinter 3-t bus 215 CDI		110	diesel	90
Mercedes-Benz	Sprinter 3-t bus 224		190	petrol	90
Mercedes-Benz	Sprinter 5-t bestelwagen 509 CDI		65	diesel	95
Mercedes-Benz	Sprinter 5-t bestelwagen 511 CDI		80	diesel	95
Mercedes-Benz	Sprinter 5-t bestelwagen 515 CDI		110	diesel	95
Citroën	Berlingo 1.6 hdi 9ht	1560	55	diesel	60
Citroën	Berlingo 1.6 hdi 9hx	1560	66	diesel	60
Citroën	berlingo 1.6 hdi 9hz	1560	80	diesel	60
Volkswagen	Transporter 1.9 tdi	1896	62	diesel	130
Volkswagen	Transporter 2.5 tdi	2461	96	diesel	130
Volkswagen	Transporter 2.5 tdi	2461	128	diesel	130
Fiat	Ducato 35 2.2 jtd		74	diesel	90
Fiat	Ducato 35 2.3 jtd		88	diesel	90
Fiat	Ducato 35 3.0 jtd		115	diesel	90

Table 3: Brake discs retail prices are invariant when compared, within a van type, for varying levels of engine power

An area of manufacturing cost that is expected to be affected by optimal power rating is the powertrain itself (engine and transmission). Costs thereof are however strategic information and notoriously hard to come by. As mentioned above, they can not be derived from variations in the retail price of the vehicle. Very indicatively, using a relationship from a non-disclosed TNO study, a 10% power decrease translates roughly to an 8% cost decrease for the transmission and a 5% cost decrease for the engine[10]. These components represent approximately 1% and 10% of the total vehicle costs respectively and therefore optimal power rating is expected to affect only approximately 1% of the total vehicle manufacture costs.

The vehicle purchase price is composed of the manufacturing costs plus a mark-up for manufacturer and dealer plus taxes. The manufacturer mark-up is determined by the OEM to fit its particular marketing strategy. Vehicle purchase costs to owners are not necessarily directly related to the manufacturing costs and, therefore, do not necessarily reflect the vehicle's technical makeup.[11] This is illustrated by a comparison of the retail price of equivalent vehicles of the same brand but with different power ratings. For different brands, the cost difference expressed for an almost identical power difference can vary an order of magnitude (table 2).

From the above the cost effect of optimal power rating may be estimated between 1% and 10%. The upper estimate, however, implies that a manufacturer is, in effect, subsidising the vehicle. This is not likely to be a sustainable practice when optimal

[9] Directive 31/320/EEC Annex II sections 1.1.3.1; 1.2.1.2.1; 1.2.1.2.2 and 1.3.
[10] For the five best selling van types of 2007.
[11] In some cases it can even be expedient for OEMs to sell their vehicles at a loss (e.g. when trying to break into a new market).

power rated vehicles increasingly take the place of today's lowest rated vehicles, which make up the largest share on the LCV market.

brand	type	version	engine displacement (dm³)	power (kW)	price (€ incl. BTW/BPM)	price difference (%)
FIAT	DUCATO	33 MH1	2.3	88	36131	8.7%
FIAT	DUCATO	33 MH1	3.0	115	39265	
FIAT	DUCATO	30 KH1	2.3	88	32841	9.5%
FIAT	DUCATO	30 KH1	3.0	115	35975	
FORD	TRANSIT	350M AMBIENTE	2.4	104	45311	0.7%
FORD	TRANSIT	350M AMBIENTE	3.2	149	45625	
FORD	TRANSIT	460L JUMBO DL AMBIENTE	2.4	104	49229	0.6%
FORD	TRANSIT	460L JUMBO DL AMBIENTE	3.2	149	49542	

Table 2: The price difference between identical vehicles with different engine displacement and power, compared for 4 models with similar available differences in power, can vary by an order of magnitude between brands.

2.2 Spare parts and accessories

The category of spare parts and accessories consists of such elements as tyres, inner tubes, spark plugs, batteries, shock absorbers, filters, pumps, fire extinguishers for transport equipment and products specifically for the cleaning and maintenance of transport equipment such as paints, chrome cleaners, sealing compounds and bodywork polishes.[12] Those are marginally affected, with the possible exception of tyres and shock absorbers. The cost effect of optimal power rating on shock absorbers, as was the case for the suspension, is thought to be limited owing to the relatively unaffected GVW.

Tyres are sold for different load capacities and in different speed ratings (i.e. the maximum speed for which a tyre is rated) and vehicles are required to be fitted with tyres with a rating that matches at least their maximum speed (table 4). The load capacity refers to GVW, which is largely unaffected by optimal power rating.

Speed Rating	Mile/Hour	Kilometers/Hour		Speed Rating	Miles/Hour	Kilometers/Hour
N	87	140		**U**	124	200
P	93	150		**H**	130	210
Q	99	160		**V**	149	240
R	106	170		**Z**	150+	240+
S	112	180		**W**	168	270
T	118	190		**Y**	186	300

Table 4: Tyre speed rating codes

For the five best sold models of 2007, it is found that optimal power rating causes the speed rating to drop by, at most, one degree (Table 5), also because their maximum speed, even in 2009, falls within the category of the lowest rating degree (i.e. 'N'). In practice, however, the lower speed ratings are not available and LCVs are typically fitted with R, S and T rated tyres.[13] From this it follows that optimal power rating is expected to have none, or limited effect on the purchase cost of spare parts and

[12] http://www.acea.be/images/uploads/files/20091215_ER_0911_2009_III_Q1-3.pdf, page 28.
[13] Telephonic consultation of Apollo Vredestein B.V.

accessories. However, if the decrease in specific power leads to milder driving behavior, it may be expected that tyre lifetime will increase.

	Top speed 1997	2009
Citroen Berlingo	142 (P)	151 (Q)
Fiat Ducato	123 (N)	135 (N)
Ford Transit	125 (N)	136 (N)
Mercedes Sprinter	135 (N)	139 (N)
Volkswagen Transporter	130 (N)	141 (P)

Table 5: Comparison of top speeds and tyre speed ratings for 1997 and 2009

2.3 Fuels and lubricants
The effect of optimal power rating on fuel consumption is extensively covered in Section 1. The cost of fuel consumption will drop correspondingly by 6%-16%. Compared to this, the absolute cost effect on lubricant use is negligible.[14]

2.4 Maintenance and repair
The category 'maintenance and repair' covers services purchased for the maintenance and repair of personal transport equipment such as fitting of parts and accessories, wheel balancing, technical inspection, breakdown services, oil changes, greasing and washing. It includes the total value of the service (that is both the cost of labour and the cost of materials are covered).[12]

Recent findings indicate that typical maintenance costs over the lifetime of a vehicle (~240,000 km) average about 3ct/km ± 2ct/km(!),[15] in which the large spread emphasizes that overall maintenance costs are strongly dependent on how the driver handles the vehicle. A decrease in the power rating of a vehicle, in principle, has an ameliorating effect on the intensity of accelerations and thereby on the wear of such components as the tyres and the brakes. However, it is to be expected that the lower vehicle performance will be compensated by operating the engine more frequently at full load, which corresponds to increased engine and transmission wear.[16] The latter effect, depending on the driver's disposition, may be expected to dominate the former and, thus, optimal power rating may result in an increase in maintenance costs. Assuming an inversely linear relationship between power and maintenance costs (for similar engines with a relatively small power difference) a 10% decrease in power translates to a 10% increase in maintenance costs.

2.5 Insurances
Whereas it is common that insurance rates at the top of the market are higher for cars with higher top speeds, this can be attributed to both the cost of those high performance cars and components and to the higher risks of accidents and theft.

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[14] Assuming an average yearly kilometrage of 20000 km a fuel efficiency of 7.5L/100km and a diesel price of €1.18 yields savings of 5% * €1770 = €88.5 and 15% * €1770 = €265.
[15] Undisclosed TNO report.
[16] A manufacturer may anticipate this and redesign its engines to maintain their durability. This, however, would imply an additional cost element in the manufacturer costs, which has not been assumed in the discussion above.

Whether faster cars are more accident-prone is not really an issue for the relatively low top speeds of the five best selling vans of 2007 (Table A1), specifically since in most European countries the allowed maximum speed is restricted. The notable exception is Germany, which in stead has a recommended maximum speed of 130 km/h for roads without speed restriction. When in Germany, however, one is involved in an accident while exceeding this recommended speed, the (liability) insurance will not fully cover the damages.[17] For these reasons it is not likely that optimal power rating will lead to significantly lower insurance rates.

2.6 Taxes

Taxes based on CO_2 performance differ throughout Europe. An overview can be found via http://www.acea.be/index.php/news/news_detail/acea_tax_guide_2010/. In some countries an effect can be expected via the registration tax and/or the circulation tax, the former representing a fixed cost and the latter a variable cost. In the countries that have a CO_2 performance related registration tax (registration tax and/or circulation tax), schemes differ from linear to stepped and relate to different baseline emissions or engine displacements. In both schemes, a fuel consumption reduction or engine displacement reduction[18] has a linear relationship with the fleet average taxes. In the case of a stepped scheme, however, the total cost of ownership for a specific vehicle may, or may not, be affected depending on whether optimal engine sizing causes a transition from one step to the next. For the low estimate, therefore, no relation between TCO and taxation is assumed. In the high estimate, however, a tax reduction of up to 16%, corresponding to the full fuel reduction potential of optimal engine sizing, for both the registration as well as the circulation tax may be feasible.

2.7 Conclusion

In conclusion, the total cost of ownership is expected to decrease as a result of optimal power rating. To some extent this will be counteracted by an expected increase in maintenance costs.[19] The vast majority of the cost reduction will be attributable to the fuel consumption reduction (approximately 40% of the total cost of ownership) and the associated lower fuel costs, and the reduction in the costs of purchase (approximately 30% of the total costs of ownership). [20] Also taking into account the effect on the maintenance and on taxes, on the low end of the estimate these cost effects translate to only a 2% decrease in total cost of ownership. On its high end, however, a 12% decrease in total cost of ownership is attainable (figure 7).

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[17] http://kfz-versicherung.suite101.de/article.cfm/die_richtgeschwindigkeit_muss_einhalten_werden; http://www.versicherung.net/news/10-2007-raser-haften-immer-mit.html

[18] Engine displacement reduction, in the context of this paper is the means with which to achieve a fuel consumption reduction.

[19] A 10% increase in maintenance costs, assuming 3ct/km baseline maintenance costs and 20000km/yr yields an increase of €60/yr.

[20] This is assuming the vehicle drives 20,000 km/yr over its lifetime of 12 years.

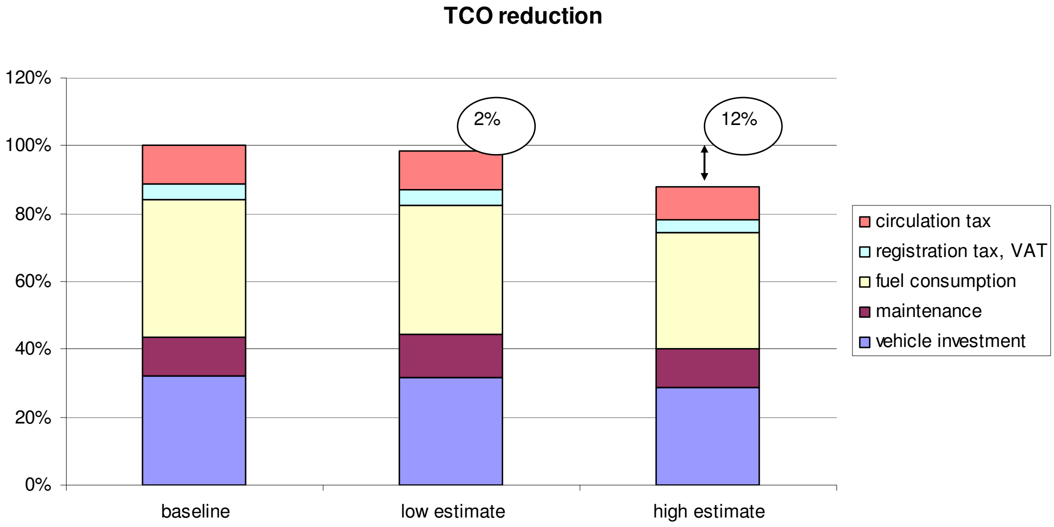

Fig 7: Graphical representation of the estimated reductions in the total cost of ownership.

3 Conclusions

The average performance of light commercial vehicles has increased during the previous decades. Analyzing the five best sold LCV models of 2007, power-to-weight ratios have increased over 9% between 1997 and 2009. Due to this enhanced performance, achieved fuel consumption and CO_2 emission reductions are smaller than technologically possible today. A possible way to realize this potential is by modification of engine characteristics.

Combining the current specific power outputs (averaged approximately 33 kW/dm^3) and average 1997 power-to-weight ratios of the five analyzed LCVs, today's engine displacements could be decreased by 13%. As a result of this smaller power and displacement, fuel consumption and CO_2 emissions can be reduced by approximately 6% (based on type approval data). Moreover, increasing the specific power output to levels that are being achieved already, even more CO_2 can be reduced. For instance, with a specific power output of 41.3 kW/dm^3, approximately 16% CO_2 can be reduced. Concomitant with vehicle optimal engine sizing, it is expected that the total cost of ownership may decrease by up to 12%. This is mainly due to decreased fuel consumption and the possibility of reduced purchase costs.[21]

[21] The maximum expected fuel effect on TCO is 40% x 15% = 6%, whereas the maximum expected effect of purchase cost on TCO is 30% x 10% = 3%. Together they, thus, account for 75% of the maximum feasible total cost of ownership reduction of 12%.

4 Appendices

4.1 Appendix A: LCV characteristics

	Power-to-Weight (kW/tonne)		Power (kW)		Fuel consumption (L/100 km)		Vehicle mass (kg)	
Model	**1997**	**2009**	**1997**	**2009**	**1997**	**2009**	**1997**	**2009**
CITROEN BERLINGO	43.1	37.7	50	55	6.7	5.8	1160	1460
FIAT DUCATO	26.4	32.6	51	74	9.4	7.9	1930	2270
FORD TRANSIT	25.0	28.7	51	63	8.5	7.9	2040	2198
MERCEDES SPRINTER	25.6	28.6	58	65	10.8	9.95	2270	2270
VOLKSWAGEN TRANSPORTER	26.4	32.7	50	62	8.8	7.4	1896	1896
Total weighted over 2007 sales	**29.0**	**31.8**	**51.9**	**63.5**	**8.8**	**7.8**	**1871.0**	**2028.1**

	Displacement (dm^3)		Gross Vehicle Weight (kg)		Top speed (km/h)	
Model	**1997**	**2009**	**1997**	**2009**	**1997**	**2009**
CITROEN BERLINGO	1905	1560	1685	1880	142	151
FIAT DUCATO	1929	2198	2800	3300	123	135
FORD TRANSIT	2496	1998	2650	3000	125	136
MERCEDES SPRINTER	2299	2148	2950	3500	135	139
VOLKSWAGEN TRANSPORTER	1896	1896	2405	2800	130	141
Total weighted over 2007 sales	**2144.8**	**1957.1**	**2502.6**	**2893.2**	**130.7**	**140.2**

Table A1: Various characteristics of the five selected LCV models

4.2 Appendix B: Relation between fuel consumption and displacement

Five models were selected as being representative for the LCV fleet. However, more data was needed to determine the relation between fuel consumption and displacement per weight class. Therefore additional models (table B1) within each weight class were used to determine the relation.

1200 kg < Weight < 1500 kg	1800 kg < Weight < 2100 kg	2100 kg < Weight < 2300 kg
Citroën Berlingo	Volkswagen Transporter	Volkswagen Transporter
Fiat Doblo Cargo	Renault Trafic	Ford Transit
Peugeot Partner	Mercedes Sprinter	Mercedes Sprinter
Ford Tourneo Connect	Fiat Ducato	Fiat Ducato
Volkswagen Caddy	Ford Transit	Renault Master

Table B1: additional models within each weight class used to determine the relation between fuel consumption and displacement

The linear relations between fuel consumption and displacement per vehicle weight class were calculated using the method of least squares.

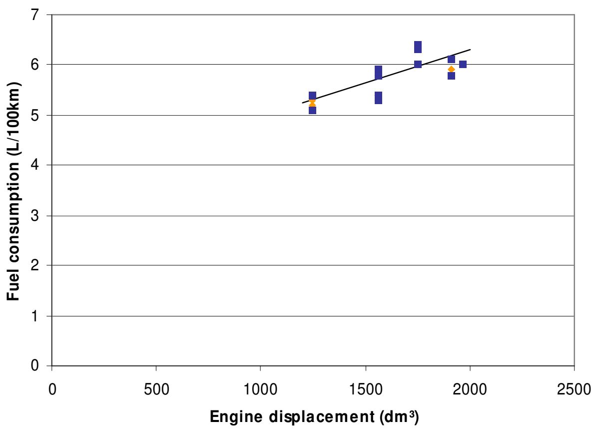

Fig B1: Relation between fuel consumption and displacement for LCVs between 1200 kg and 1500 kg

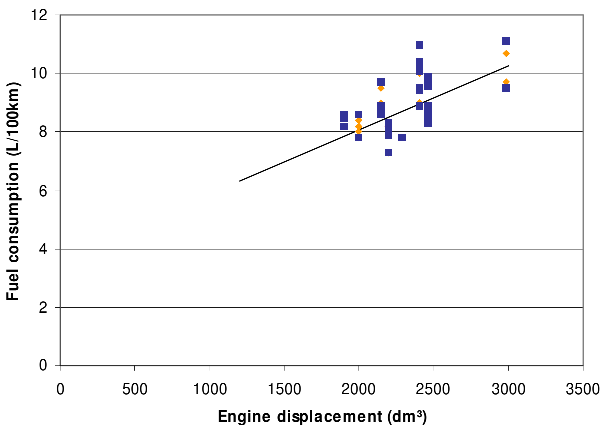

Fig B2: Relation between fuel consumption and displacement for LCVs between 1800 kg and 2100 kg

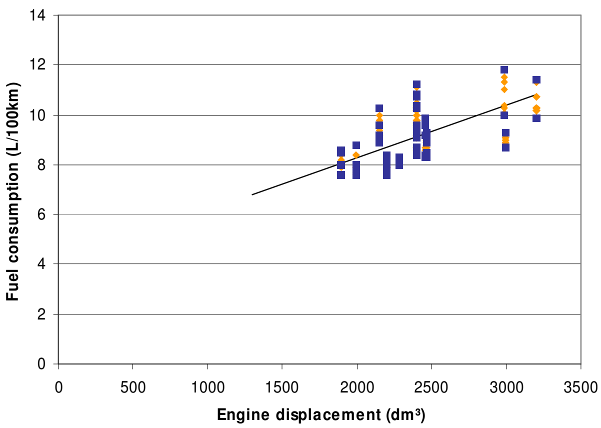

Fig B3: Relation between fuel consumption and displacement for LCVs between 2100 kg and 2300 kg

4.3 Appendix C: Sold LCV types per engine displacement

The five selected LCV models are available with different engine displacements. Sales numbers per displacement are depicted below.

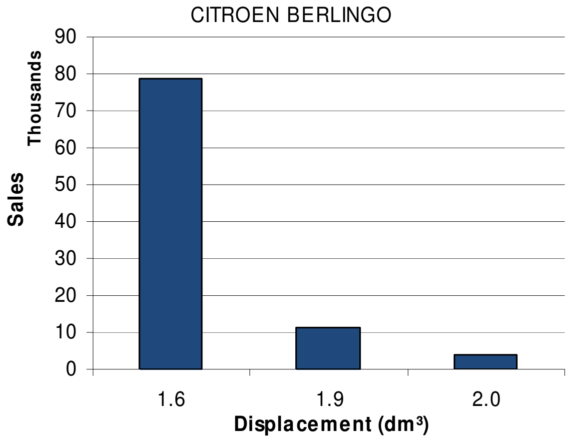

Fig C1: Number of sold Citröen Berlingos in 2007 segmented to engine displacement

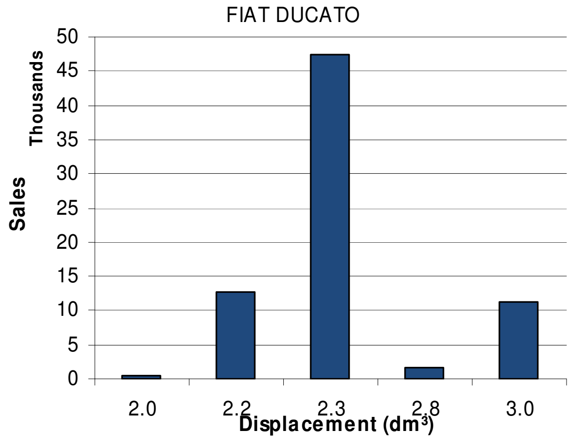

Fig C2: Number of sold Fiat Ducatos in 2007 segmented to engine displacement

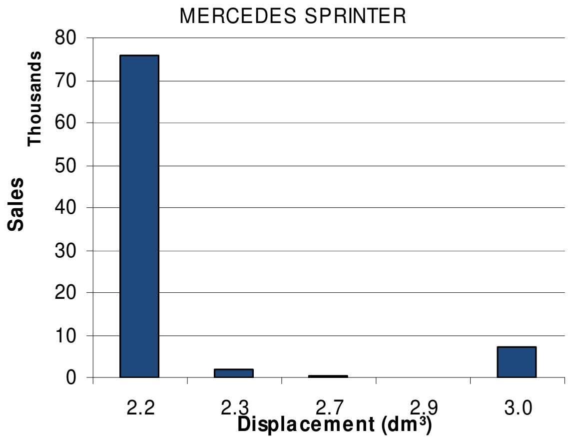

Fig C3: Number of sold Mercedes Sprinters in 2007 segmented to engine displacement

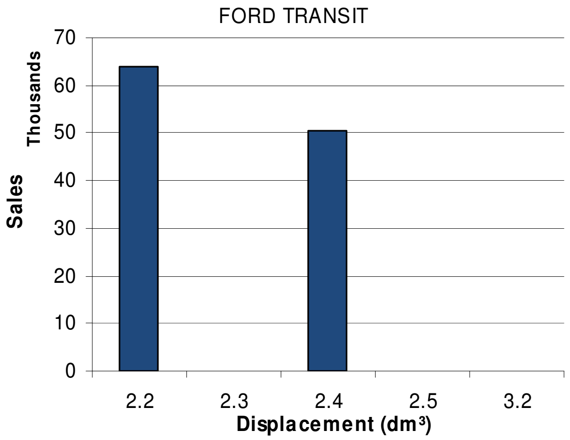

Fig C4: Number of sold Ford Transits in 2007 segmented to engine displacement

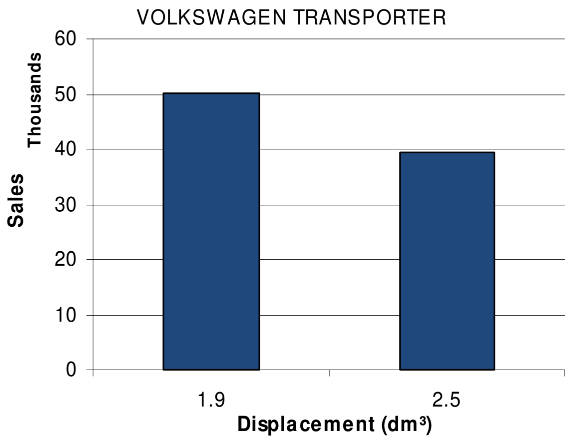

Fig C5: Number of sold Volkswagen Transporters in 2007 segmented to engine displacement