ASSESSMENTS WITH RESPECT TO THE EU HDV CO_2 LEGISLATION

Work in support of the Dutch position on EU regulation on the CO_2 emissions of Heavy-Duty vehicles

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EXECUTIVE SUMMARY

In this report results are presented of work, carried out by TNO, in support of the development of a formal Dutch position on the EU regulation on CO_2 emissions of Heavy-Duty vehicles (HDVs). The assessments include the following elements:

- Indicative estimates of the potential and costs of CO_2 emission reduction measures that can be applied to conventional HDVs, i.e. HDVs with an internal combustion engine;
- Considerations on the required CO_2 reduction at the level of the European HDV fleet in view of the goals of the Paris climate agreement and consequences for the contribution of more fuel efficient ICE-based HDVs and Zero Emission Vehicles (ZEVs);
- Indicative estimates of the technical and economical feasibility of zero-emission (ZE) HDVs;
- Considerations on a number of design elements of the regulation, so-called modalities.

On the CO_2 reduction potential of conventional HDVs

- By 2030 CO_2 emissions from conventional HDVs can be reduced by 28% (excluding trailer-based measures) to 33% relative to 2015 at net negative costs to society and end-user.

On the required contribution from HDVs to meeting overall GHG emission reduction targets

- Meeting an intermediate CO_2 reduction target for the EU road freight sector for 2030, that is consistent with the 1.5˚C goal from the COP21 Paris agreement, is likely to require the combined impacts of:
  - improved logistics to reduce vehicle kilometres;
  - the full available potential for reduced fuel consumption in conventional HDVs together with an increased share of sustainably produced biofuels or other low-CO_2 fuels, plus
  - an additional contribution from employing zero emission vehicles (ZEVs) in the road freight sector.

EXECUTIVE SUMMARY

On the feasibility of zero-emission HDVs

- Battery-electric HDVs may be expected to be technically feasible and close to economically feasible by 2025 for a limited number of market segments. By 2030 battery-electric HDVs are likely to be economically competitive for many types of use.
- The EC should not fix ZE targets for the next 12-17 years based on “old thinking” w.r.t. technical and economical feasibility of technologies, the required speed of the transition and the possible contribution of HDVs to decarbonising the transport sector.

On design options (modalities) for the EU HDV CO_2 Regulation

- For a number of reasons the preferred metric for expressing the target is g/km.
- Relating the target to the transport performance of trucks by using a g/tonne.km or g/m^3.km metric is not an appropriate way to differentiate targets as function of the utility of trucks. Differentiating the target to the size or capacity of vehicles can be adequately done by defining separate target for sufficiently homogeneous vehicle groups or by using utility-based target functions within vehicle groups.
- A number of flexibilities can be introduced to increase the feasibility for OEMs to meet the target, or lower the costs for meeting the target. Appropriate flexibilities also help to reduce the need for a (correct) differentiation of targets as function of the specific characteristics and use of vehicles.

CONTENTS

INTRODUCTION TO THE STUDY

- In this report results are presented of work, carried out by TNO, in support of the development of a formal Dutch position on the EU regulation on CO_2 emissions of Heavy-Duty vehicles (HDVs).
- The study has been commissioned by the Dutch Ministry of Infrastructure and Water management.
- Assessments made with respect to the HDV CO_2 legislation include the following aspects:
  - Indicative estimates of the potential and costs of CO_2 emission reduction measures that can be applied to conventional HDVs, i.e. HDVs with an internal combustion engine;
    - Cost impacts include additional manufacturer costs, fuel cost savings and the resulting impact on Total Cost of Ownership (TCO);
  - Considerations on the required CO_2 reduction at the level of the European HDV fleet in view of the goals of the Paris climate agreement and consequences for the contribution of more fuel efficient ICE-based HDVs and Zero Emission Vehicles (ZEVs);
  - Indicative estimates of the technical and economical feasibility of zero-emission (ZE) HDVs, in particular battery electric trucks, in two different combinations of truck category and logistic application;
  - Considerations on a number of design elements of the regulation, so-called modalities, including the choice of metric and options for creating flexibility.

NOTES TO THE READER

- Conclusions drawn in this report are the responsibility of TNO and do not necessarily reflect the position of the Dutch government on the EU HDV CO_2 Regulation.
- Data used in this study are based on public sources and expert knowledge available at TNO.
  - At the time of writing this report a TNO-led consortium is carrying out a support study* for the European Commission’s DG CLIMA on the same topics. No results of that study for DG CLIMA have been used for the study for the Dutch Ministry of Infrastructure and Water management as presented here. However, the methodological approach and definition of CO_2 reduction measures in this study have been aligned to those in the study for DG CLIMA to an extent that is considered useful for the debate.
- In view of the limited size and scope of this study, results presented here on the potential and costs of various CO_2 reduction measures (including various measures for ICE-based HDVs and battery-electric HDVs) should be considered as indicative estimates only.

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*) Service Request 9: "Heavy Duty Vehicles - support for preparation of impact assessment for CO_2 emissions standards“, carried out under framework contract CLIMA.C.2/FRA/2013/0007 - ”Framework contract for services in the field of energy efficiency and CO_2 emissions from heavy-duty vehicles’ (HDVs): methodology for simulating HDV emissions, certification, analysis and policy development"

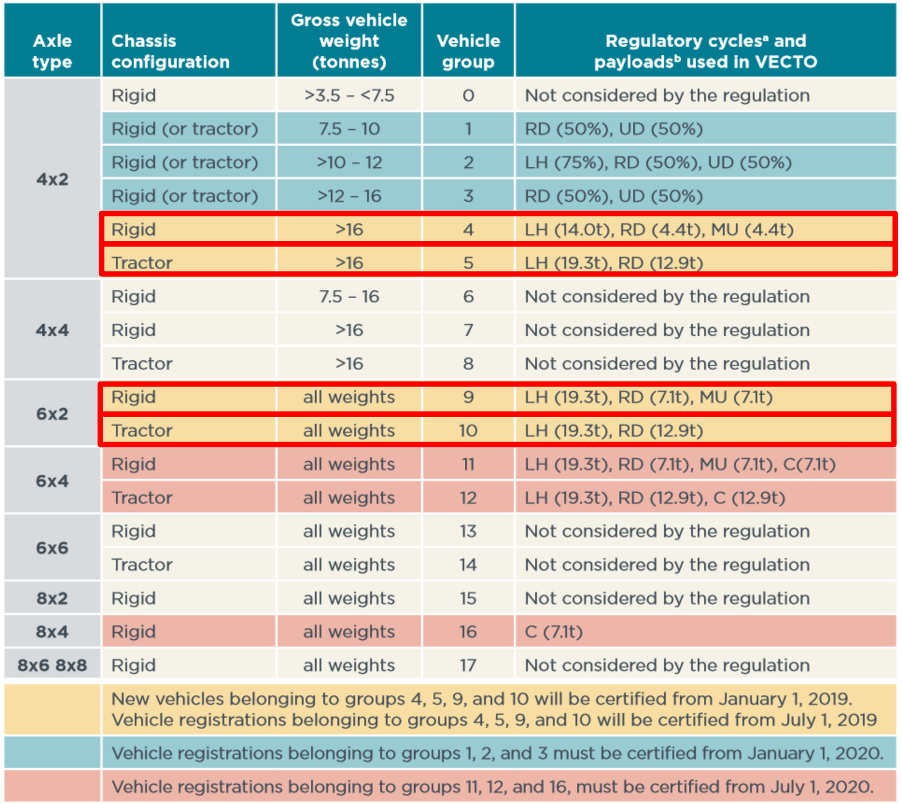
VEHICLE GROUPS

- Regulation (EU) 2017/2400, adopted on 12 December 2017, specifies how and from which date(s) forward certified CO_2 emission and fuel consumption values are to be determined for HDVs. The determination of these values is done with the VECTO simulation tool.
- For this purpose 17 different vehicle groups are defined, specified by the axle configuration and a bandwidth for the maximum technical permissible laden mass (or GVW). For each group a set of representative mission profiles is determined, characterised by speed-time profiles and default values for the average payload.

In this study assessments are carried out for vehicles in groups 4, 5, 9 and 10.

Assumed vehicle configurations for assessments:

- groups 4 and 9: rigid truck without trailer
- groups 5 and 10: tractor + semi-trailer



Axle type	Chassis configuration	Gross vehicle weight (tonnes)	Vehicle group	Regulatory cycles[a] and payloads[b] used in VECTO
4x2	Rigid	>3.5 – <7.5	0	Not considered by the regulation
	Rigid (or tractor)	7.5 – 10	1	RD (50%), UD (50%)
	Rigid (or tractor)	>10 – 12	2	LH (75%), RD (50%), UD (50%)
	Rigid (or tractor)	>12 – 16	3	RD (50%), UD (50%)
	Rigid	>16	4	LH (14.0t), RD (4.4t), MU (4.4t)
	Tractor	>16	5	LH (19.3t), RD (12.9t)
4x4	Rigid	7.5 – 16	6	Not considered by the regulation
	Rigid	>16	7	Not considered by the regulation
	Tractor	>16	8	Not considered by the regulation
6x2	Rigid	all weights	9	LH (19.3t), RD (7.1t), MU (7.1t)
	Tractor	all weights	10	LH (19.3t), RD (12.9t)
6x4	Rigid	all weights	11	LH (19.3t), RD (7.1t), MU (7.1t), C(7.1t)
	Tractor	all weights	12	LH (19.3t), RD (12.9t), C (12.9t)
6x6	Rigid	all weights	13	Not considered by the regulation
	Tractor	all weights	14	Not considered by the regulation
8x2	Rigid	all weights	15	Not considered by the regulation
8x4	Rigid	all weights	16	C (7.1t)
8x6 8x8	Rigid	all weights	17	Not considered by the regulation
🟨	New vehicles belonging to groups 4, 5, 9, and 10 will be certified from January 1, 2019. Vehicle registrations belonging to groups 4, 5, 9, and 10 will be certified from July 1, 2019			
🟦	Vehicle registrations belonging to groups 1, 2, and 3 must be certified from January 1, 2020.			
🟥	Vehicle registrations belonging to groups 11, 12, and 16, must be certified from July 1, 2020.			

LH = long haul
RD = regional delivery
UD = urban delivery
MU = municipal utility
C = construction

Source: ICCT

CONTENTS

INTRODUCTION

- To determine the overall potential and cost-effectiveness of CO_2 reducing technologies for HDVs cost curves have been developed.
  - Manufacturer costs curves describe the additional vehicle costs for applying combinations of CO_2 reduction measures as function of the achieved overall reduction percentage.
  - Combining additional manufacturer costs with the fuel cost savings yield the impact on total cost of ownership (ΔTCO). This is assessed from a societal as well as an end-user perspective.
  - The cost curves are determined for technical CO_2 reduction measures for 4 major HDV groups.
- Estimates for the costs and CO_2 reduction potential of individual measures have been derived from literature sources and in-house expert knowledge.

- This chapter presents:
  - an overview of CO_2 reducing technologies for conventional HDVs as used for the assessment;
  - a table with costs and CO_2 reduction potential per technology/measure;
  - the methodology used for the determination of cost curves;
  - indicative cost impacts for groups 4, 5, 9 and 10 showing additional manufacturer costs, fuel cost reduction and ΔTCO as function of the level of CO_2 emission reduction;
    - Cost impacts are assessed for two cases:
      - based on cost curves containing tractor- / truck-based measures only (consistent with the current approach in VECTO using standard bodies and trailers for the simulation);
      - based on cost curves also including measures applied to (semi-)trailers;
  - sensitivity analyses for variations in diesel price, depreciation period and annual mileage.

NOTES ON REDUCTION POTENTIAL, COSTS & SOURCES

Reduction potential

- CO_2 and reduction potentials are specified relative to 2015 reference vehicles meeting Euro VI pollutant emission standards.
- Individual and combined reduction potentials are calculated with a dynamic vehicle model using vehicle-specific input parameters and operation-specific mission profiles (see [TAP 2016]).

Note: Due to a more limited availability of cost data in public literature, the number of CO_2 reduction options included in this study is smaller than in the SR9 support study for DG CLIMA (see note on page 6). This means that the estimated maximum reduction potentials assessed here are likely to be on the conservative side compared to that study.

Technology costs

- The costs of technologies are estimated for large scale application by 2030. This is consistent with a scenario in which application of these technologies is required to meet the regulatory CO_2 targets.
  - At this scale of production the impact of learning effects and economies of scale on manufacturing costs is saturated.

Sources

- Data used in this study for estimating reduction potentials and costs of technologies are based on public sources and expert knowledge available at TNO.
  - Literature sources include: [AEA-Ricardo 2011], [Cummins 2013], [ICCT 2015], [TIAX 2011], and [TUG 2015].

Assumed **vehicle configurations** for assessments:

groups 4 and 9:	rigid truck without trailer
groups 5 and 10:	tractor + semi-trailer

CO$_2$ REDUCING TECHNOLOGIES

Aerodynamics	
AERO1	Roof spoiler plus side flaps
AERO2	Side and underbody panel at truck chassis
AERO3	Aerodynamic mud flaps
AERO4	Rear/side view cameras instead of mirrors
AERO5	Redesign, longer and rounded vehicle front
AERO6	Side and underbody panels at trailer chassis
AERO7	Boat tail short, additional

Transmission	
TRANS1	Reduced losses (lubricants, design)
TRANS2	Transition from manual to AMT

Mass *	
MASS1	5% Mass reduction (truck/tractor)
MASS1	10% Mass reduction (truck/tractor)

Engine	
ENG1	Improved turbocharging and EGR
ENG2	Friction reduction + improved water and oil pumps
ENG3	Improved lubricants
ENG4	Waste heat recovery
ENG5	Downspeeding (combined with DCT optimization)
ENG6	10% Engine downsizing

Auxiliaries	
AUX1	Electric hydraulic power steering
AUX2	LED lighting
AUX3	Air compressor
AUX4	Cooling fan

Note: grey boxes are measures applied to vehicle build-up or (semi-)trailer

Tyres **	
TYRES1	Low rolling resistance tyres on truck/tractor
TYRES2	Low rolling resistance tyres on truck/tractor + trailer
TYRES3	Tyre pressure monitoring system (TPMS) on truck
TYRES4	Tyre pressure monitoring system (TPMS) on truck and trailer
TYRES5	Automated tyre inflation system (ATIS) on truck
TYRES6	Automated tyre inflation system (ATIS) on truck and trailer
TYRES7	Wide base single tyres

Hybridisation ***	
HYBRID1	48V system with starter/generator
HYBRID2	Full electric hybrid

* MASS1 and MASS2 → never in combination

** TYRES1 and TYRES2; TYRES3 and TYRES4; TYRES3 and TYRES4 → never in combination

*** HYBRID1 and HYBRID2 → never in combination

Costs estimates for large-scale application in 2030

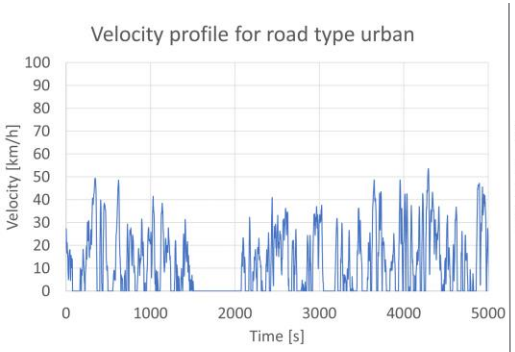
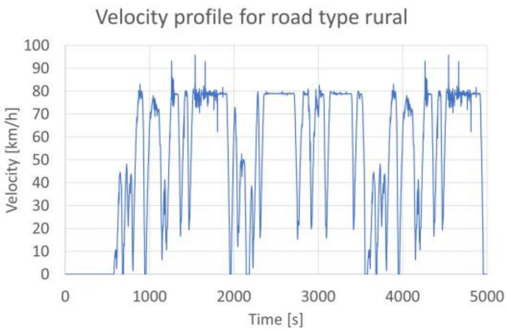
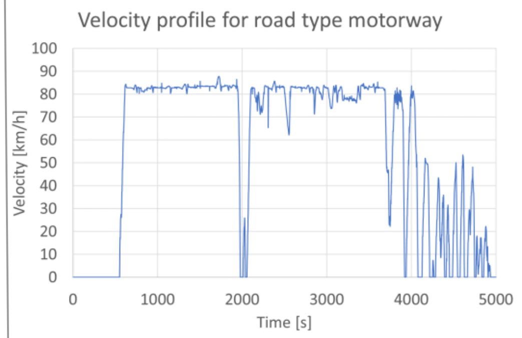
REDUCTION POTENTIAL & ADDITIONAL MANUFACTURER COSTS

	Vehicle group 4		Vehicle group 5		Vehicle group 9		Vehicle group 10	
Measure	CO_2 reduction potential [%]	Additional manufacturing costs [€]	CO_2 reduction potential [%]	Additional manufacturing costs [€]	CO_2 reduction potential [%]	Additional manufacturing costs [€]	CO_2 reduction potential [%]	Additional manufacturing costs [€]
Default	0.0%	€ 0	0.0%	€ 0	0.0%	0	0.0%	€ 0
AERO1	0.0%	€ 2,000	-2.2%	€ 2,000	0.0%	€ 2,000	-2.1%	€ 2,000
AERO2	-1.4%	€ 750	-1.5%	€ 750	-1.1%	€ 750	-1.5%	€ 750
AERO3	-3.0%	€ 1,000	-3.2%	€ 1,000	-2.4%	€ 1,000	-3.2%	€ 1,000
AERO4	-0.8%	€ 3,078	-0.9%	€ 1,539	-0.7%	€ 3,078	-0.9%	€ 1,539
AERO5	-0.8%	€ 40	-0.9%	€ 100	-0.7%	€ 60	-0.9%	€ 120
AERO6	-	-	-1.1%	€ 200	-	-	-1.1%	€ 200
AERO7	-	-	-1.3%	€ 3,000	-	-	-1.3%	€ 3,000
AUX_ALL	-1.0%	€ 915	-1.0%	€ 915	-1.0%	€ 915	-1.0%	€ 915
ENG1	-4.8%	€ 1,050	-4.8%	€ 1,050	-4.8%	€ 1,050	-4.8%	€ 1,050
ENG2	-2.4%	€ 309	-2.4%	€ 309	-2.4%	€ 309	-2.4%	€ 309
ENG3	-1.2%	€ 23	-1.2%	€ 23	-1.2%	€ 23	-1.2%	€ 23
ENG4	-2.4%	€ 5,000	-2.4%	€ 5,000	-2.4%	€ 5,000	-2.4%	€ 5,000
ENG5	-0.2%	€ 1,250	-0.2%	€ 1,250	-0.2%	€ 1,250	-0.2%	€ 1,250
ENG6	-1.0%	€ -400	-1.2%	€ -640	-1.1%	€ -560	-1.3%	€ -700
HYBRID1	-1.7%	€ 4,184	-2.6%	€ 6,694	-2.0%	€ 5,857	-2.8%	€ 7,321
HYBRID2	-2.5%	€ 8,367	-3.7%	€ 13,387	-3.0%	€ 11,714	-4.0%	€ 14,642
MASS1	-2.2%	€ 794	-3.2%	€ 1,416	-2.9%	€ 1,402	-3.3%	€ 1,416
MASS2	-3.3%	€ 1,588	-4.7%	€ 2,831	-4.5%	€ 2,805	-4.8%	€ 2,831
TRANS1	-2.0%	€ 250	-2.6%	€ 250	-2.2%	€ 250	-2.8%	€ 250
TRANS2	-2.9%	€ 2,661	-3.5%	€ 3,288	-3.1%	€ 2,661	-3.6%	€ 3,288
TYRES1	-6.1%	€ 140	-5.1%	€ 350	-6.4%	€ 210	-5.2%	€ 420
TYRES2	-	-	-8.5%	€ 350	-	-	-8.5%	€ 420
TYRES3	-1.2%	€ 140	-1.9%	€ 350	-1.4%	€ 210	-2.0%	€ 420
TYRES4	-	-	-2.0%	€ 350	-	-	-2.1%	€ 420
TYRES5	-1.2%	€ 1,080	-1.9%	€ 1,080	-1.4%	€ 1,080	-2.0%	€ 1,080
TYRES6	-	-	-2.0%	€ 1,350	-	-	-2.1%	€ 1,350
TYRES7	-1.2%	€ -35	-1.9%	€ -70	-1.4%	€ -35	-2.0%	€ -70

Sources: a.o. [AEA-Ricardo 2011], [Cummins 2013], [ICCT 2015], [TIAX 2011], [TUG 2015] and in-house expert knowledge

Note: grey boxes are measures applied to vehicle build-up or (semi-)trailer

MISSION PROFILES

	Urban	Rural	Motorway
			
Regional delivery	27.5%	45.8%	26.7%
Long Haulage	7%	13%	80%

- Mission profiles describe the operational parameters of a trip which are relevant for the road load: velocity, slope/gradient and vehicle weight.
- Figures above show the velocity profiles used for three different road types (urban, rural and motorway), based on measurements of vehicle movements on Dutch motorways and in (between) cities using Weighing-in-Motion systems and license plate recognition camera’s.

Simulations are done for:

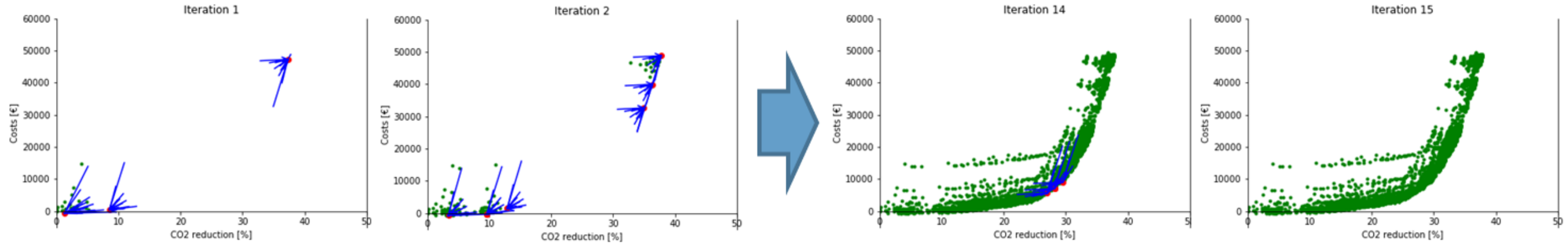
- **Group 4/9** vehicles using a **regional delivery** mission profile and an **annual mileage of 75,000 km**.
- **Group 5/10** vehicles using a **long haul** mission profile and an **annual mileage of 110,000 km**.

METHODS FOR GENERATING ADDITIONAL MANUFACTURER COST CURVES

- Combined reduction potential of packages of measures is determined through vehicle modelling using an in-house model developed by TNO (see [TAP 2016]).
- Additional manufacturer costs are added for all measures in a package.
- Cost curves are based on results for different packages.

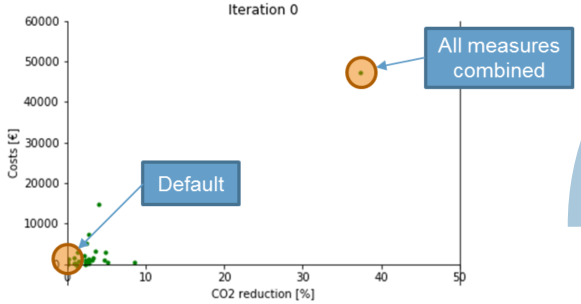
ITERATION 1-X

- Select all combinations that form the outer shell (convex hull) of the point cloud and form new combinations by adding or removing single measures to the combination. Repeat this step untill no new combinations are found.



ITERATION 0

- Calculate CO_2-emissions and costs for default measure, individual measures and combination of all measures.

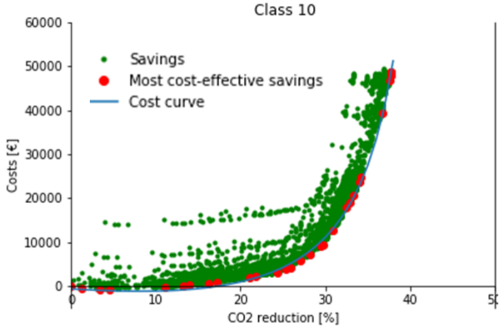


All measures combined

Default

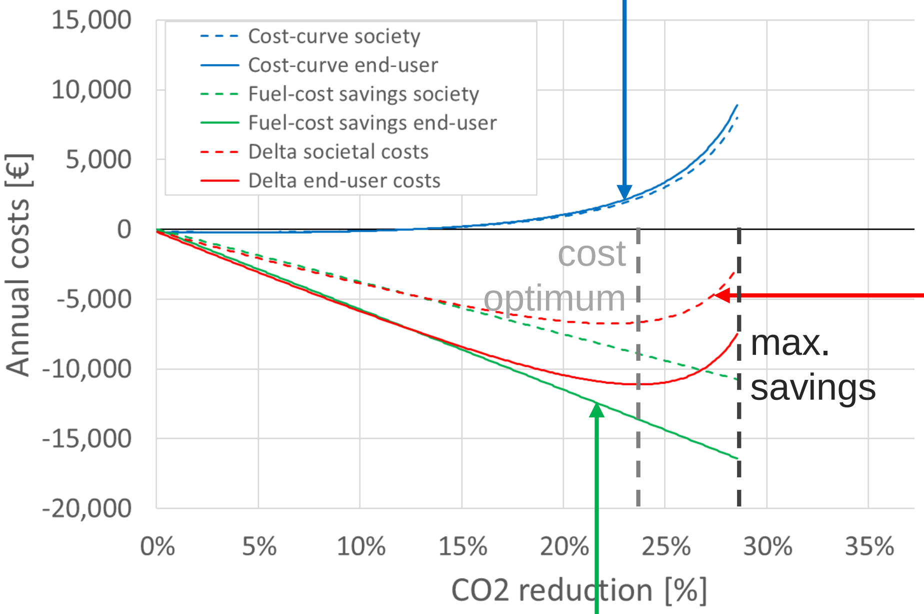
CURVE FITTING

- Finally, fit a cost line to the convex hull of the resulting point cloud.



HOW TO INTERPRET COST CURVES?

The additional vehicle manufacturing or purchase costs are amortized over a 5 year period at discount rates of 4% resp. 8% to determine the **annuity of the additional investment costs** from a societal and end-user perspective.



Annual fuel cost savings increase linearly with CO_2 reduction potential:

- Societal perspective (excl. taxes)
- End-user perspective (incl. excise duty)

Assumptions

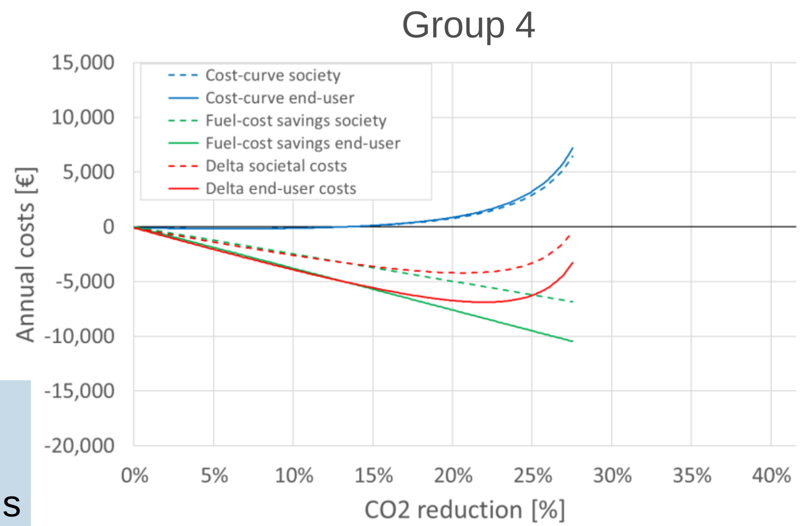
- Expected costs for large scale production of the technologies in 2030
- Discount rate: 4% (societal), 8% (end-user)
- Depreciation period: 5 years
- Diesel price: € 1.27 /l (excl. VAT)
    - Group 4/9 annual mileage: 75,000 km
    - Group 5/10 annual mileage: 110,000 km

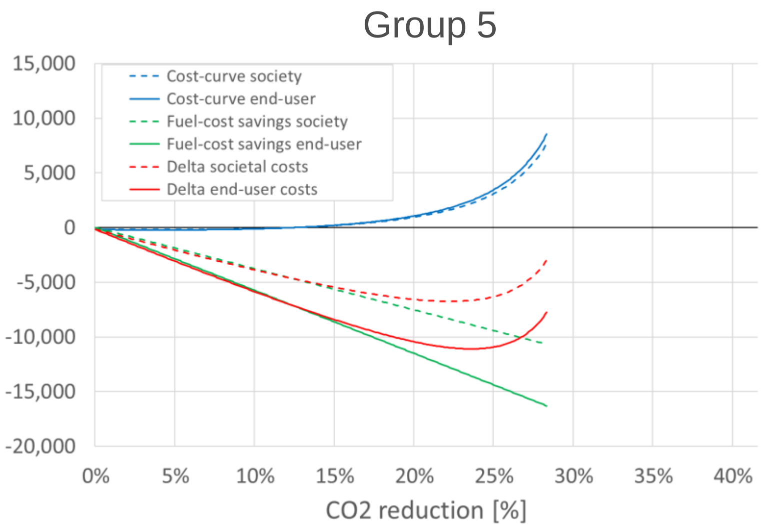
The difference of the annuity of the additional investments and the annual fuel cost savings equals the change in **annual total costs of operation** (ΔTCO) for society and the end-user respectively.

In this example:

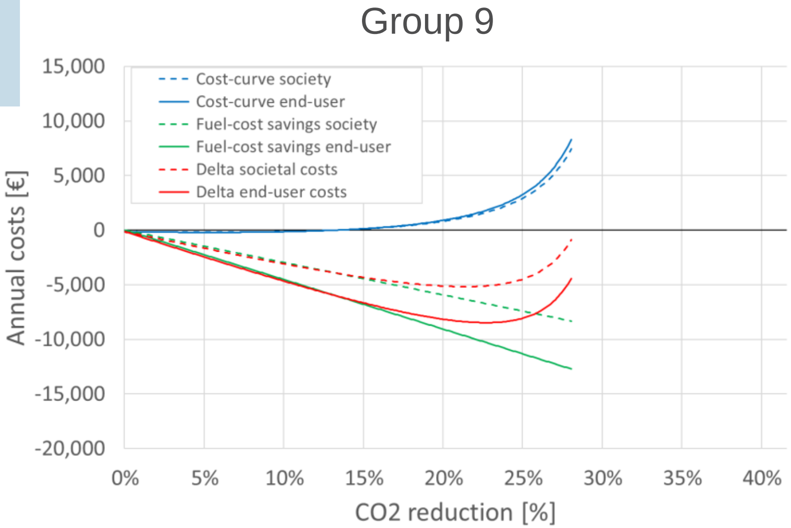
- The additional manufacturer costs increase non-linearly with increasing CO_2 reduction. A maximum CO_2 reduction of 37% results roughly in additional annual vehicle depreciation costs of € 10.000.
- The annual fuel cost savings achieved at a 37% reduction are € 13.000 resp. € 20.000 from a societal or end-user perspective.
- The net costs (annualized investment costs minus the additional fuel costs) are negative. This means the full CO_2 reduction potential (applying all options) can be achieved cost-effectively. Additional investments in vehicle technology are earned back within a 5 year period.

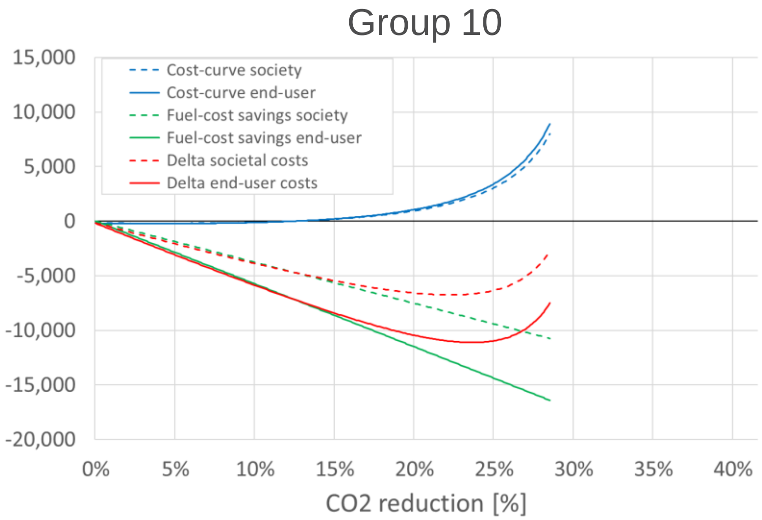
CO$_2$ REDUCTION POTENTIALS (EXCL. TRAILER OPTIONS)





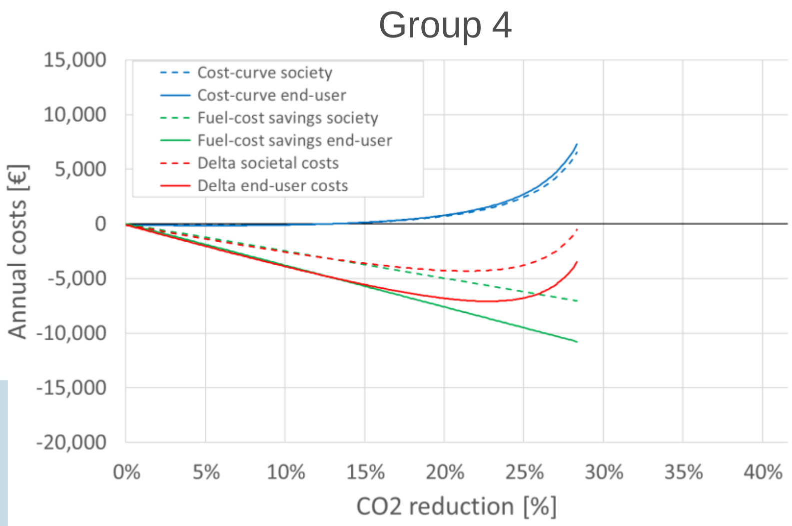
Cost curves **excluding** reduction options applied to vehicle build-up or (semi-)trailer

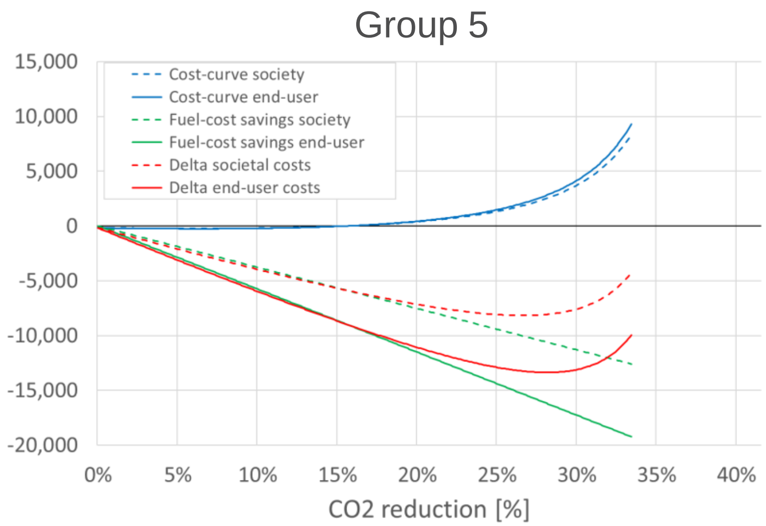


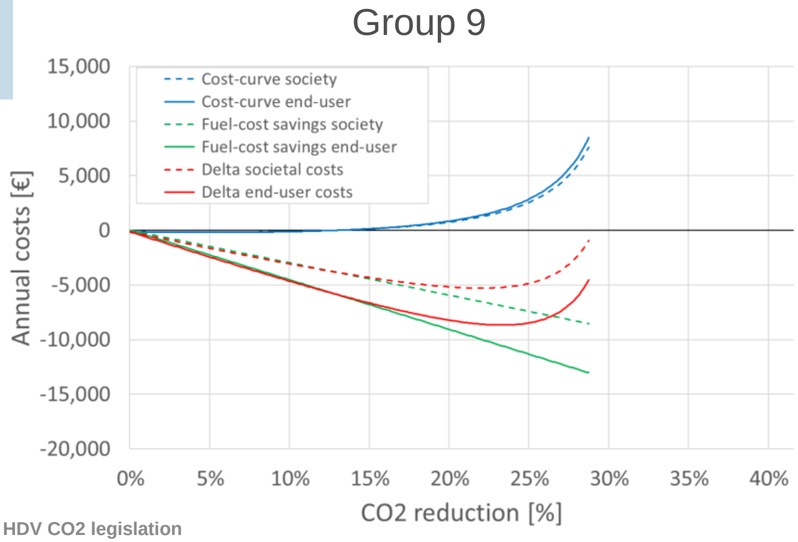


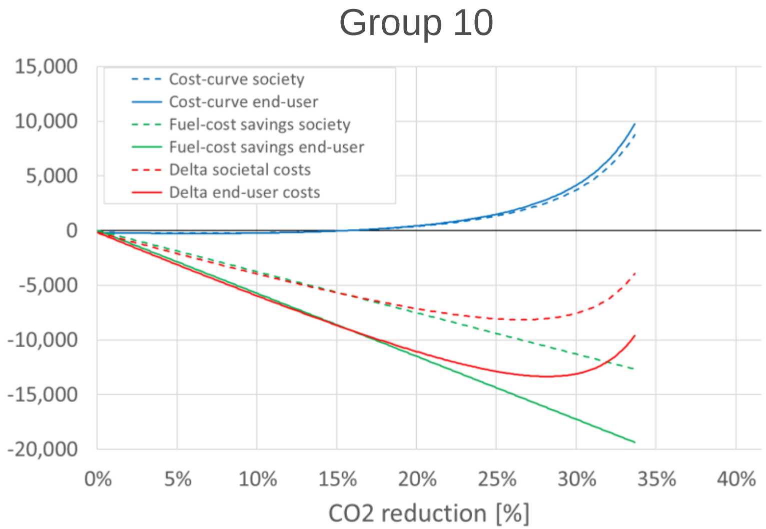
CO_2 REDUCTION POTENTIALS (INCL. TRAILER OPTIONS)

Cost curves **including** reduction options applied to vehicle build-up or (semi-)trailer


Group 4


Group 5

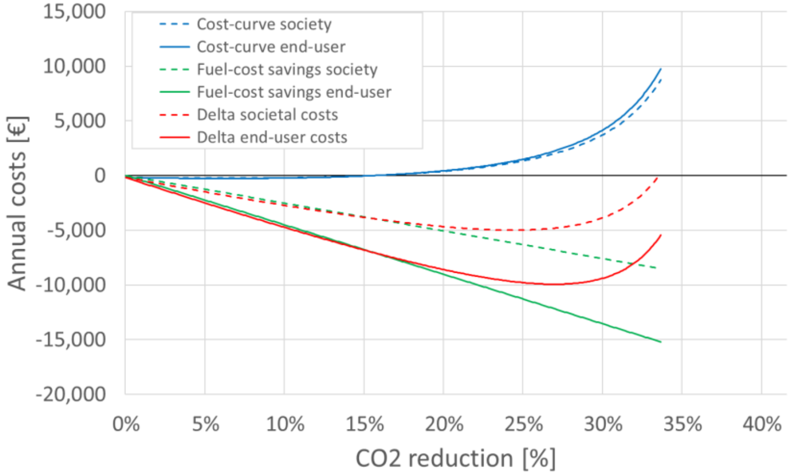

Group 9


Group 10

SENSITIVITY ANALYSIS: DIESEL PRICE

- Cost effectiveness of the full CO_2 reduction potential of technical measures is robust against variations in the price of diesel.

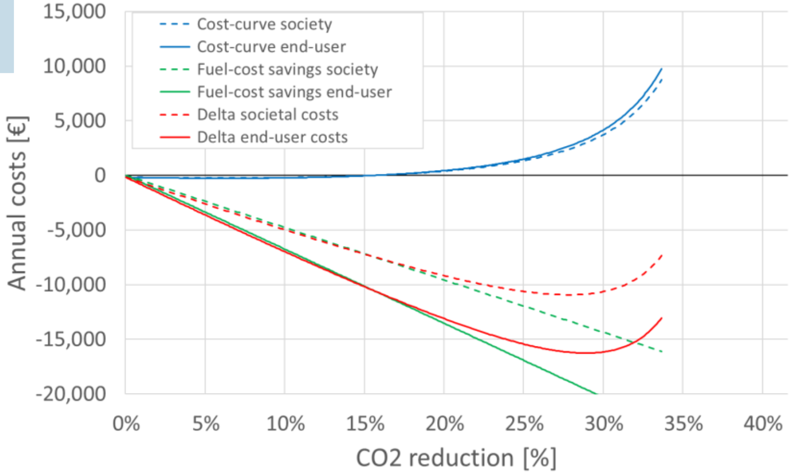
Group 10 | diesel price: **1.00 €/l** (excl. VAT)



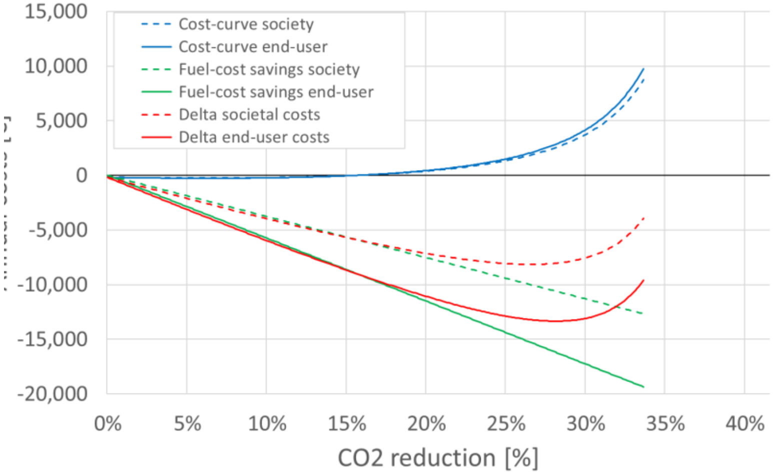
Vehicle group:	group 10
Diesel price:	variable
Depreciation period:	5 years
Annual mileage:	110,000 km

Cost curves **including** reduction options applied to vehicle build-up or (semi-)trailer

Group 10 | diesel price: **1.50 €/l** (excl. VAT)



Group 10 | diesel price: **1.27 €/l** (excl. VAT)

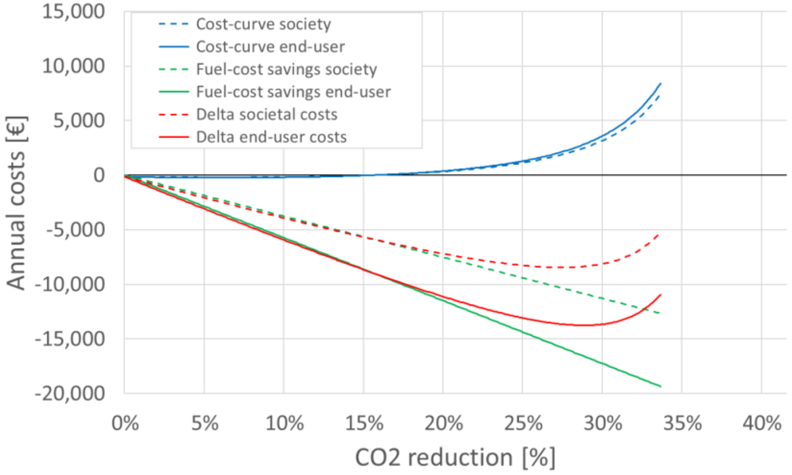


SENSITIVITY ANALYSIS: DEPRECIATION PERIOD

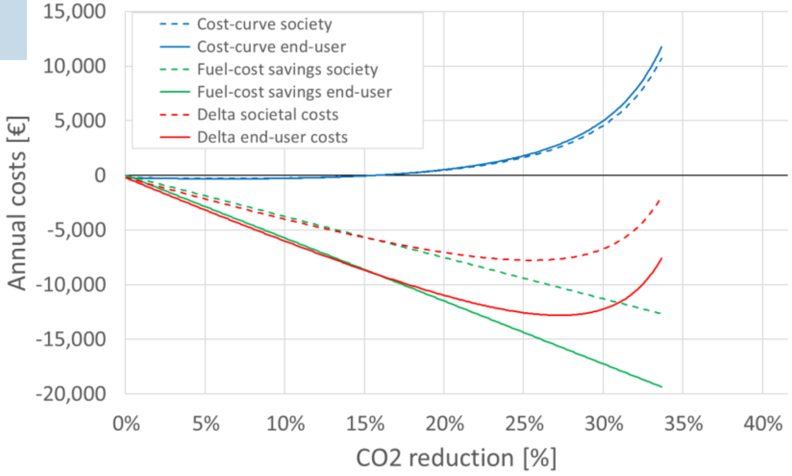
- The full CO_2 reduction potential of technical measures remains cost effective from a societal and end-user perspective also if additional vehicle costs are depreciated over a shorter period.

Vehicle group: group 10
Diesel price: 1.27 €/l (excl. VAT)
Depreciation period: variable
Annual mileage: 110,000 km

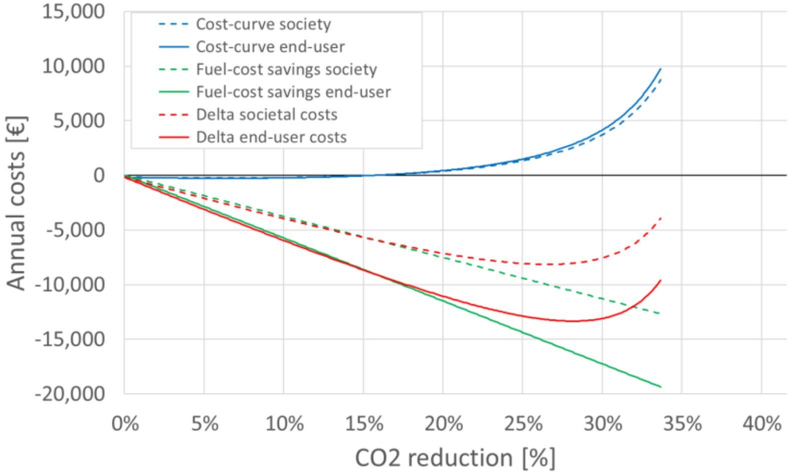
Cost curves **including** reduction options applied to vehicle build-up or (semi-)trailer



Group 10 | depreciation period: **6** years



Group 10 | depreciation period: **4** years



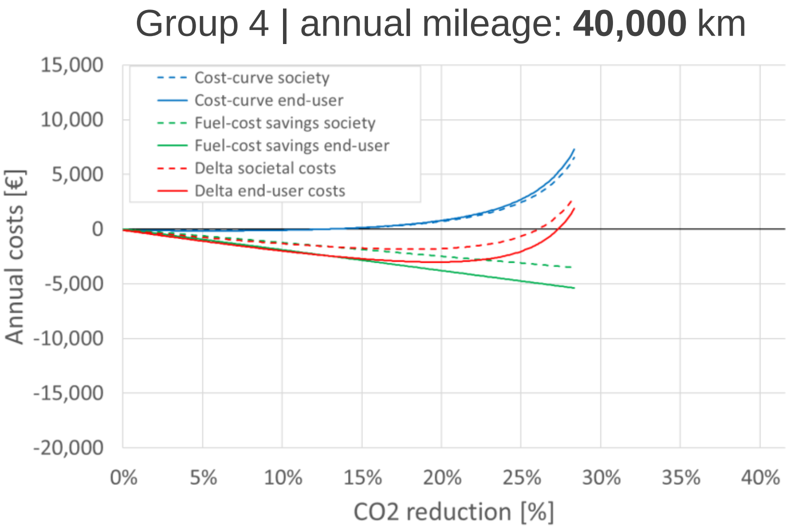
Group 10 | depreciation period: **5** years

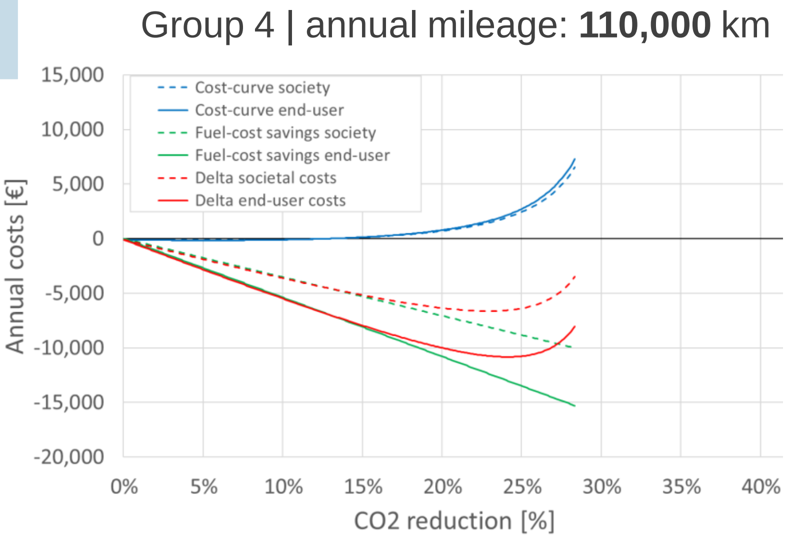
SENSITIVITY ANALYSIS: ANNUAL MILEAGE

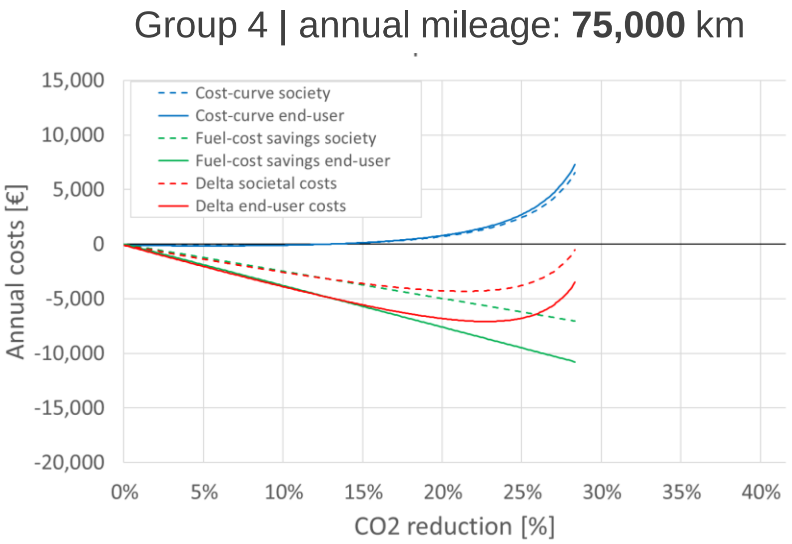
- Cost-effectiveness of CO_2 reduction measures decreases with lower annual mileage.
- For group 4 vehicles the full reduction potential remains largely cost effective also for mileages as low as 40.000 km/y.

Vehicle group:	group 4
Diesel price:	1.27 €/l (excl. VAT)
Depreciation period:	5 years
Annual mileage:	variable

Cost curves **including** reduction options applied to vehicle build-up


Group 4 | annual mileage: **40,000** km


Group 4 | annual mileage: **110,000** km


Group 4 | annual mileage: **75,000** km

CONVENTIONAL HDVs

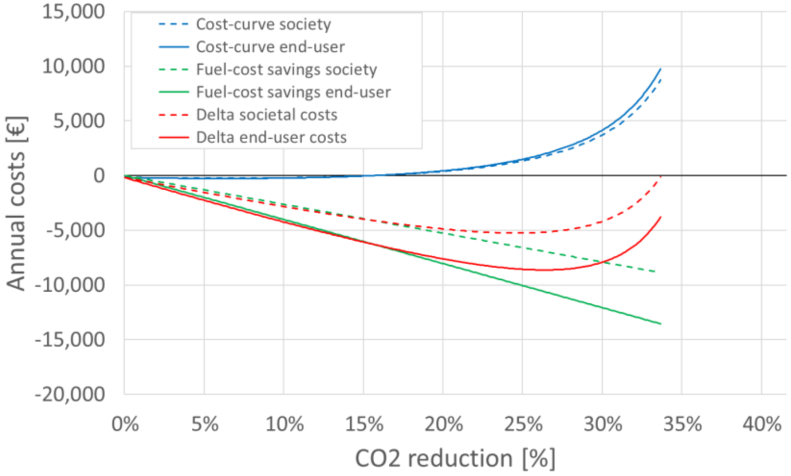
SENSITIVITY ANALYSIS: ANNUAL MILEAGE

- Cost-effectiveness of CO_2 reduction measures decreases with lower annual mileage.
- For group 10 vehicles the full reduction potential remains cost effective for all assessed mileages.

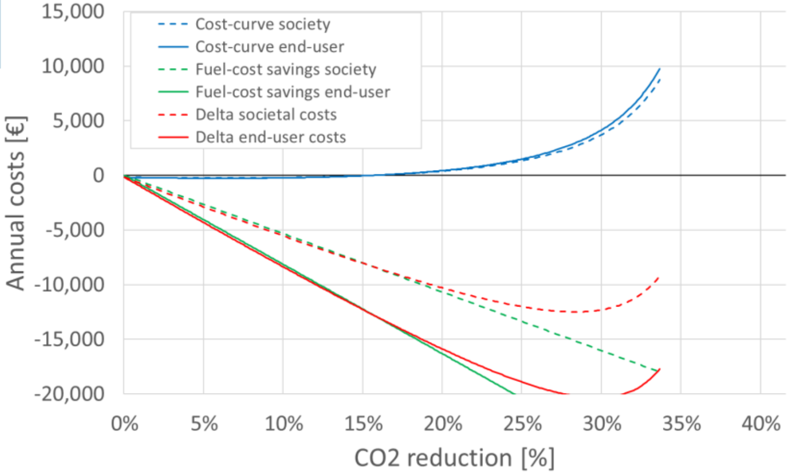
Vehicle group: group 10
Diesel price: 1.27 €/l (excl. VAT)
Depreciation period: 5 years
Annual mileage: variable

Cost curves **including** reduction options applied to vehicle build-up or (semi-)trailer

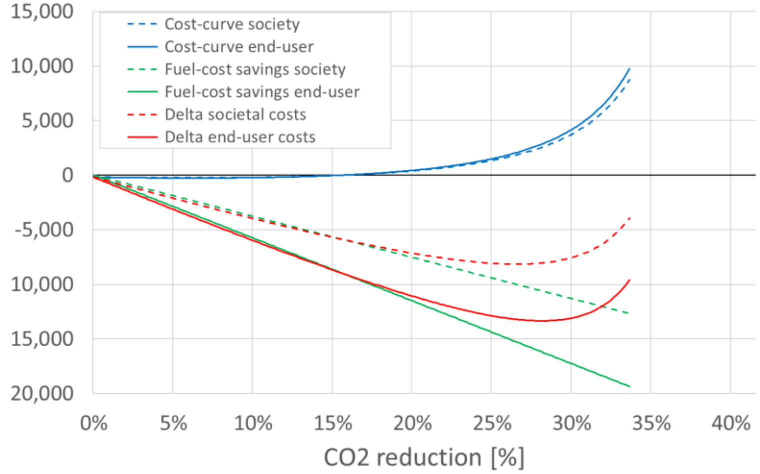
Group 10 | annual mileage: **75,000** km



Group 10 | annual mileage: **155,000** km



Group 10 | annual mileage: **110,000** km



CONCLUSIONS

By 2030 CO_2 emissions from conventional HDVs can be reduced by 28 to 33% relative to 2015 at net negative costs to society and end-user.

- Excluding measures applied to vehicle build-up and (semi-)trailers the CO_2 emissions of trucks in all 4 assessed groups can be reduced by up to 28% by 2030.
- The full CO_2 reduction potential is cost-effective from a societal as well as end-user perspective. Additional vehicle costs are earned back within less than 5 years.
  - Beyond 20 – 25% reduction the marginal costs of additional measures become positive. Up to 30% reduction, however, the application of CO_2 reduction measures generally leads to net cost savings for society and end-user.
- Including measures applied to vehicle build-up and (semi-)trailers the maximum CO_2 reduction potential is around 33%. This potential can also be achieved at a net negative impact on total cost of ownership from a societal as well as end-user perspective.
  - Trailer-based measures are currently not included in the VECTO-based certification method.
- The diesel price, depreciation period, annual mileage and discount rate have a strong influence on the cost-effectiveness of the savings potential.
  - A sensitivity analysis for group 4 and 10 vehicles based on cost curves including trailer-related options, however, indicates that the cost-effectiveness of the measures is robust against variations in the parameters.
  - Only for the most pessimistic assumptions used applying the last few percent of the full reduction potential would lead to $\Delta TCO \geq 0$ for society. From an end-user perspective ΔTCO remains below or at zero for the full potential.

CONTENTS

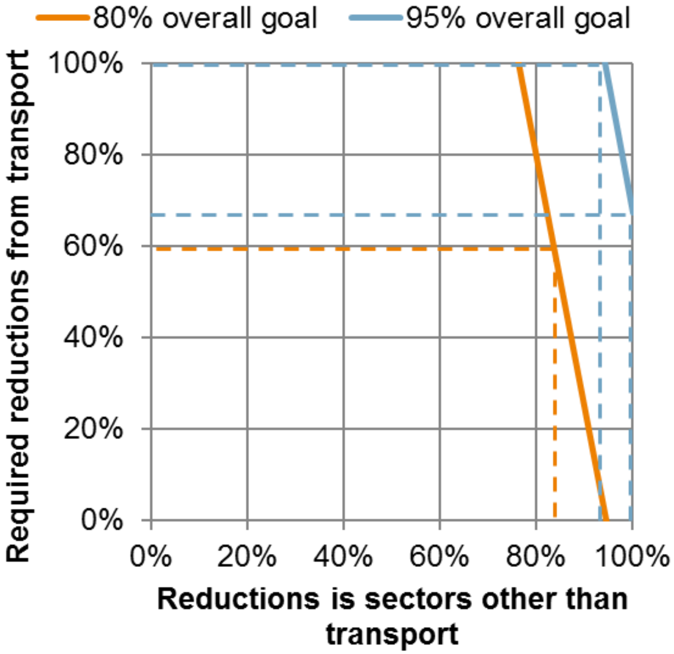
INTRODUCTION

- In order to determine appropriate targets for the CO_2 emissions of new HDVs in 2025 and/or 2030 two complementary approaches can be followed:
  - In a bottom-up approach one can assess **what level of reduction is technically and economically feasible** in the target year(s).
    - This approach can be based on the cost curve assessments as presented in the previous chapter.
  - Alternatively a top-down approach can be followed to assess what level of reduction is necessary for HDVs in view of longer term greenhouse gas (GHG) reduction targets.
    - For this approach a back-casting exercise is necessary, starting from the 1.5 ˚C goal of the COP21 Paris agreement, to determine:
      - what the overall reduction level is that needs to be achieved by Europe in 2025/30;
      - how large the contributions from the transport sector and other sectors should be to meeting these intermediate goals;
      - how that translates to a required pathway for the CO_2 emissions of the European HDV fleet in the period up to the target year(s), and
      - what that means for the **level of reduction that is necessary** for the average CO_2 emission performance for new HDVs sold in the EU in the target year(s), taking into account natural fleet renewal rates.

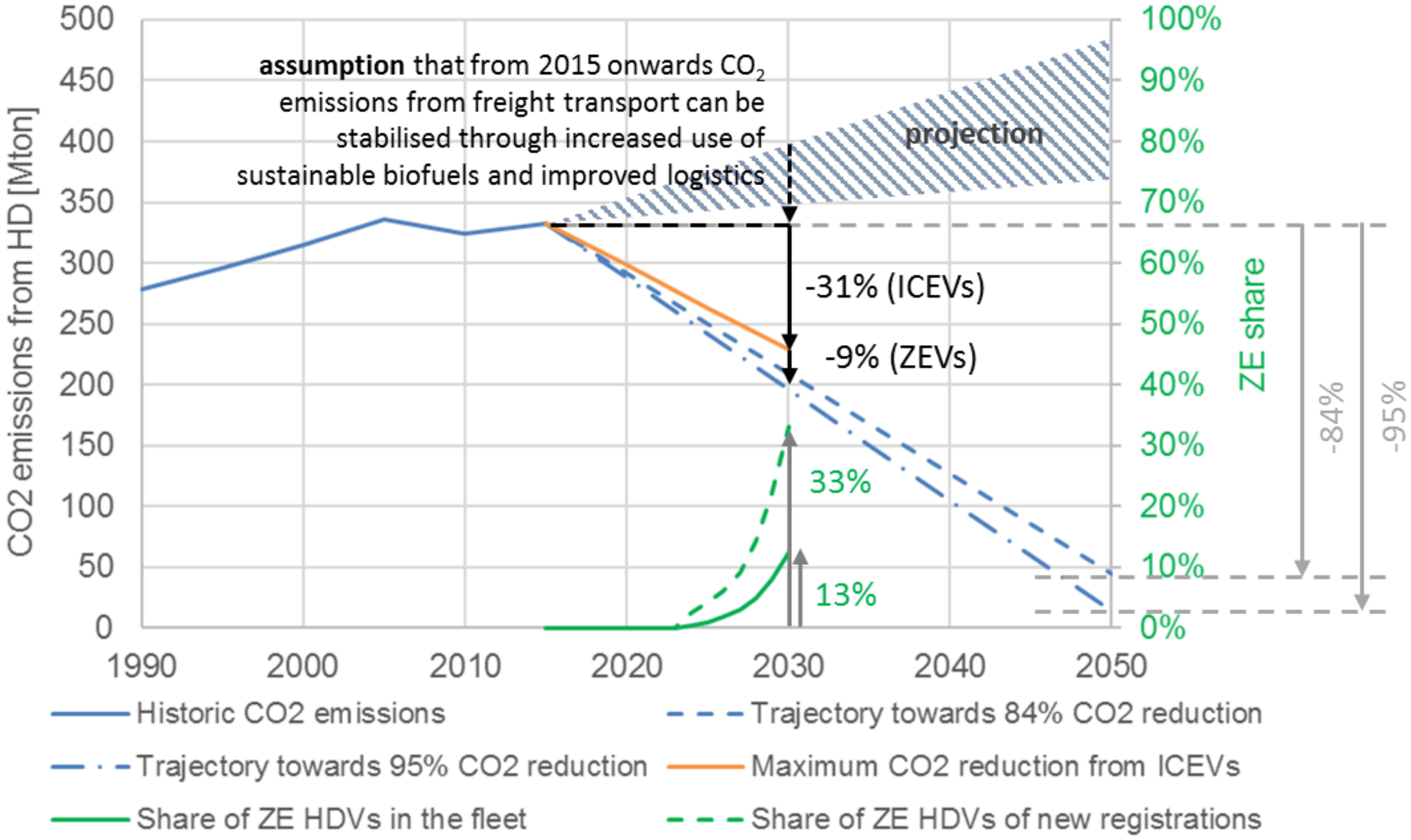
COP21 1.5 ˚C GOAL LIMITS ROOM FOR BURDEN SHARING BETWEEN SECTORS

- The 2˚C goal for average global temperature rise at the end of this century requires the overall GHG emission of Western countries to be reduced by 80% in 2050 compared to 1990 levels.
  - Under this overall goal the EU white paper for transport defined a 60% reduction goal for the transport sector, requiring other sectors to reduce GHG emissions by significantly more than 80%.
- The 1.5˚C goal from the COP21 Paris agreement requires an overall reduction of 95% in 2050 compared to 1990 for the EU.
  - This leaves a much smaller bandwidth for choosing a 2050 reduction target for the transport sector:
    - 67% - if other sectors reduce 100%
    - 100% - if other sectors reduce 94%
- To increase certainty of meeting the target all sectors should strive for 95%, or even better 100%, as it is very likely that one or more sectors will not succeed in meeting the 95% target in time.

The 1.5 ˚C goal from the COP21 Paris agreement leaves little room for giving the transport sector a more lenient GHG reduction goal for 2050 than other sectors.



BY 2030 THE FULL POTENTIAL OF ICEVs + AN ADDITIONAL SHARE OF ZE HDVs IS NEEDED



Assuming aviation and shipping also reduce 95%...

CONCLUSIONS

- The 1.5˚C goal from the COP21 Paris agreement leaves little room for giving the EU transport sector a more lenient GHG reduction goal for 2050 than other sectors. Basically it requires all sectors to reduce CO_2 emissions by 95% or more by 2050 compared to 1990.
- An intermediate target for the EU road freight sector for 2030 can be determined by linear interpolation between the 2015 emission level and a 2050 target that is 95% below the 1990 level. Meeting this target is likely to require the combined impacts of:
  - improved logistics to reduce vehicle kilometres;
  - the full available potential for reduced fuel consumption in conventional HDVs together with an increased share of sustainably produced biofuels or other low-CO_2 fuels, plus
  - an additional contribution from employing zero emission vehicles (ZEVs) in the road freight sector.
- Assuming that from 2015 onwards CO_2 emission from the road freight sector could be stabilised by the increased use of sustainably produced biofuels and improved logistics, a share of around 13% HD ZEVs would be necessary to complement the full potential of improved conventional HDVs.
  - This assumes a full reduction potential for conventional HDVs of around 40% (33% from technical measures on vehicles and trailer / build-up + some additional reduction potential from a range of operational measures).
  - A 13% fleet share equates to ZEV shares in new HDV sales increasing to around 33% by 2030.
  - These HD ZEVs could be **battery-electric vehicles** or **hydrogen-powered fuel cell electric vehicles**.
    - In the next chapter current developments in battery-electric ZE HDVs and their potential for 2030 are explored.

CONTENTS

THE FEASIBILITY OF A LARGE SHARE OF ZE HDVs IN THE 2030 FLEET DEPENDS ON LOT OF FACTORS

SUPPLY

- Technology readiness
- Availability of attractive products
- Cost competitiveness
  - battery price development
  - price of diesel and electricity (incl. cost of (fast) chargers)
- Availability of charging infrastructure
  - e.g. dependent on EU Alternative Fuels Infrastructure Directive and national measures

DEMAND

- Sustainability strategies of the logistics sector
- Effective policies applying to both truck manufacturers and end users
  - Stringent CO_2 target for HDVs
  - ZEV requirements in the HDV CO_2 Regulation
  - National and municipal policies
    - Fiscal stimulation and/or subsidies
    - Urban access restrictions: e.g. Dutch Green Deal Zero Emission City Logistics

BUT THERE'S A LOT HAPPENING w.r.t. ZE HDVS

- Currently, developments with respect to the technical feasibility and costs of battery-electric HDVs are going much faster than anticipated.

ZE VEHICLES

- Fast increase in the commercial availability of electric buses
  - e.g. Solaris, Optare, BYD, VDL, ADL, Van Hool, Volvo, Dennis
- Small OEMs offering battery-electric trucks commercially
  - e.g. GINAF (rigid truck), EMOSS (rigid truck and tractor)
- Many OEMs are developing and testing battery-electric trucks or announce market introduction
  - BYD, Daimler, MAN, VDL (DAF based), Fuso, Tesla, Nicola
- Volvo and Scania test catenary trucks
- Toyota develops a hydrogen truck
- Battery prices are dropping fast

CHARGING

- Rollout of ultra-fast charging (@ 350 kW) networks across the EU (>10,000 charging points) announced by E.ON and two other consortia
  - Backed by several large OEMs
  - This would reduce charging time of 900 kWh long-haul truck to 2.5 hours
- Tesla has announced the deployment of 1 MW chargers.

€

- **Perspective on technical and economic feasibility is rapidly improving**

INDICATIVE ASSESSMENT OF TECHNICAL FEASIBILITY AND COST-EFFECTIVENESS OF BATTERY-ELECTRIC HDVs

- This chapter presents results of an indicative assessment of the applicability of battery-electric propulsion in two different logistic applications for trucks.
- Using an in-house model, developed by TNO, and assumptions on the characteristics of typical reference vehicles, mission profiles for the applications and overnight charging vs. day-time opportunity charging, the following parameters have been estimated:
  - the fuel consumption of the conventional reference trucks:
  - the minimum battery size for full-day operation of the electric trucks;
  - the required power of the electric power train;
  - the electricity consumption of the ZE HDVs, taking into account the impact of battery weight.
- Combining these results with estimates for the future costs of batteries, powertrain components, diesel and electricity, and maintenance, estimates have been made of the:
  - differential in vehicle purchase costs between the conventional HDVs and the ZE HDVs;
  - costs of the energy consumed by both vehicles;
  - the difference in maintenance costs;
  - the resulting overall **difference in total costs of ownership (ΔTCO)** of conventional HDVs and ZE HDVs.

KEY ASSUMPTIONS

- The table below presents the assumptions on a range of input data that have been used for the comparative cost assessment of conventional (ICE-based) and battery-electric HDVs.

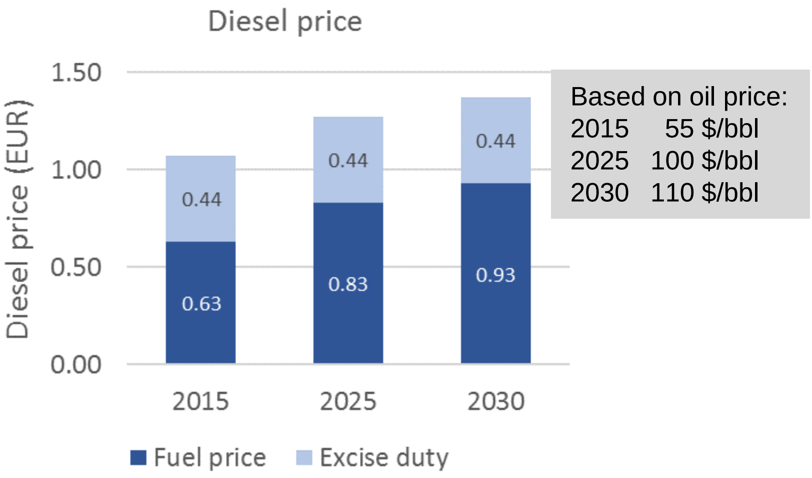
	2015	2025	2030	Source
Battery energy density [Wh/kg]	125	200	200	TNO estimate based on various literature sources
Battery costs [€/kWh]	350	200	120	TNO estimate based on [McKinsey 2017], [Bloomberg 2017], [IRENA 2017]
Costs of other EV components*	€ 5,860 + 26 €/kW	€ 3,050 + 13.5 €/kW	€ 3,050 + 13.5 €/kW	Based on in-house expert knowledge
Costs of replaced ICE components**	€ 50 + 65 €/kW	€ 50 + 65 €/kW	€ 50 + 65 €/kW	Based on in-house expert knowledge
Costs of maintenance [€/km]: EV / ICEV	0.11 / 0.12	0.11 / 0.12	0.11 / 0.12	[ICCT 2017]
Battery lifetime [no. of cycles]	3000	5000	5000	[FREVUE 2017]

*) Electric motor, inverter, boost converter, heat pump, control unit, harness and safety, regenerative braking system

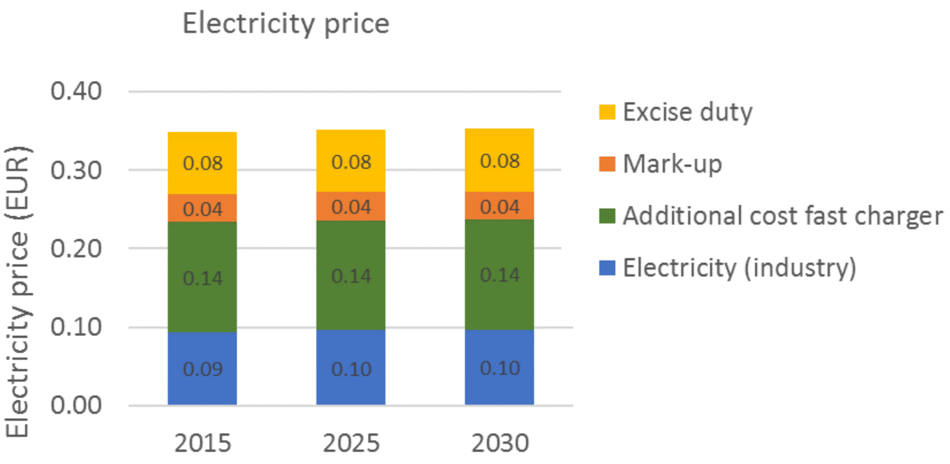
**) Internal combustion engine, aftertreatment system, transmission and fuel tank

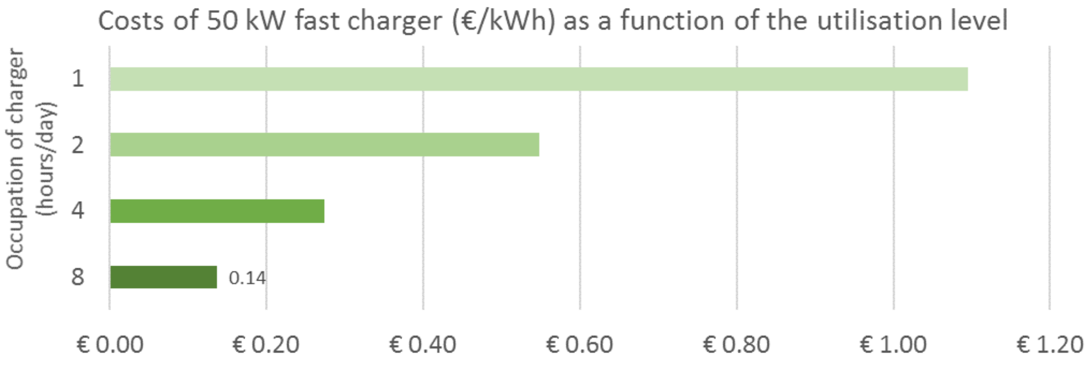
KEY ASSUMPTIONS: FUEL AND ELECTRICITY PRICES

- Assumptions for the diesel price and base electricity price for 2015 and 2030 are based on the EU reference scenario [EU 2015].



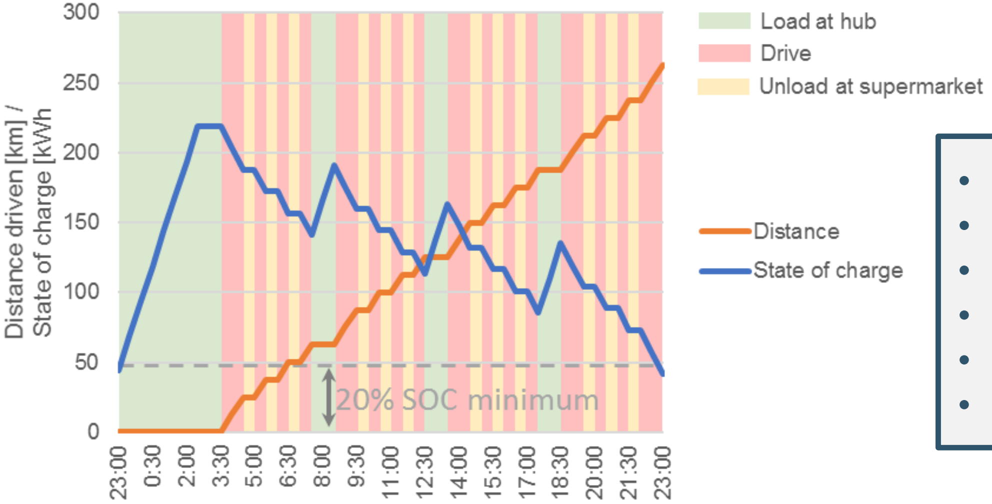
Based on oil price:
2015 55 $/bbl
2025 100 $/bbl
2030 110 $/bbl





- The costs of the charging infrastructure that need to be attributed to the costs of charged electricity strongly depend on the utilisation of the charging station.
- The occupation level has a trade-off with the charger’s availability over the day.

CASE: SUPERMARKET SUPPLY MEDIUM RIGID TRUCK (2350 KG PAYLOAD)

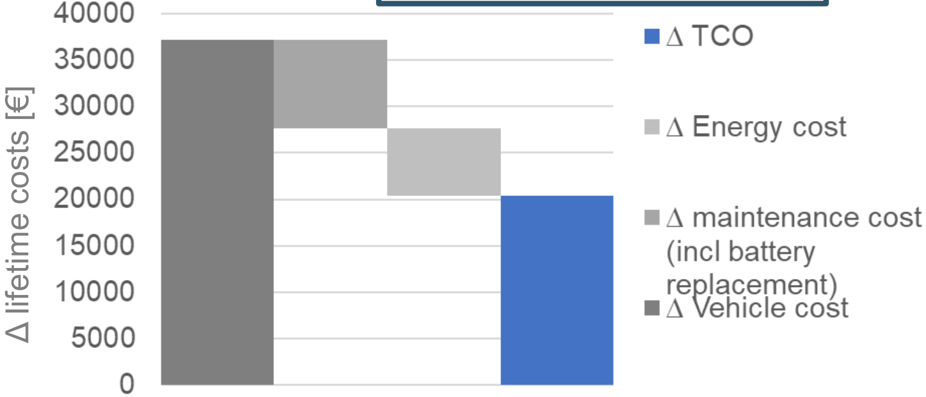


- A smaller battery and faster charging would further improve the business case

- Average speed of 25 km/h
- Drive 10.5 hours per day (= 263 km/day)
- 630,000 km in 8 years lifetime
- Charger: 50 kW
- Required battery: 219 kWh (incl. max. 80% DoD)
- Energy use: 1.4 kWh/km (incl. mass penalty)

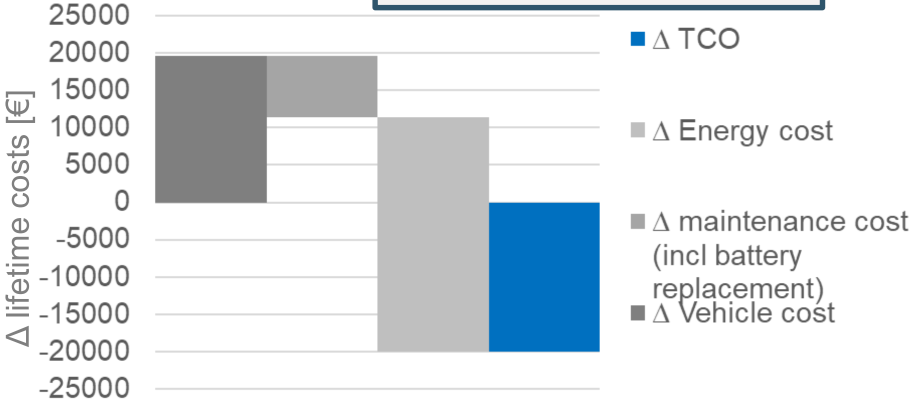
2025

- Electricity price: 0.35 €/kWh
- Diesel price: 1.27 €/l



2030

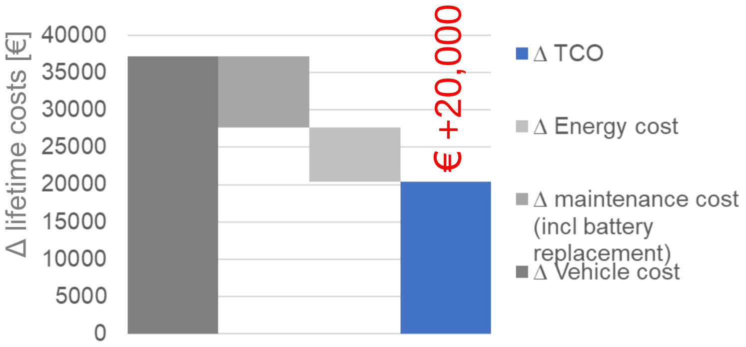
- Electricity price: 0.36 €/kWh
- Diesel price: 1.37 €/l

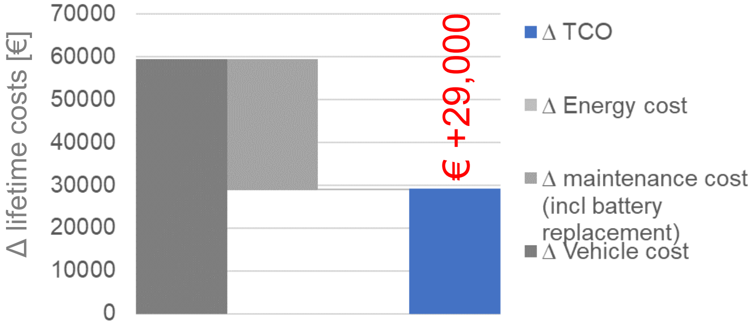


CASE: SUPERMARKET SUPPLY – RIGID TRUCK INFLUENCE OF BATTERY SIZE ON LIFETIME ΔTCO

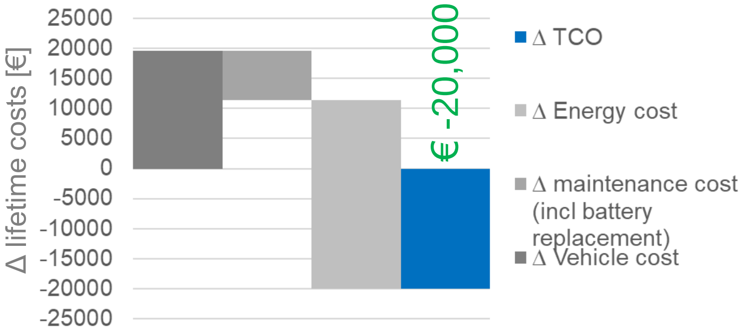
minimum required battery size **battery size +50%**

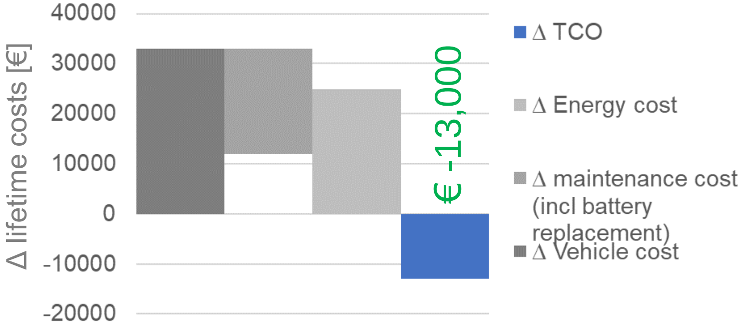
2025





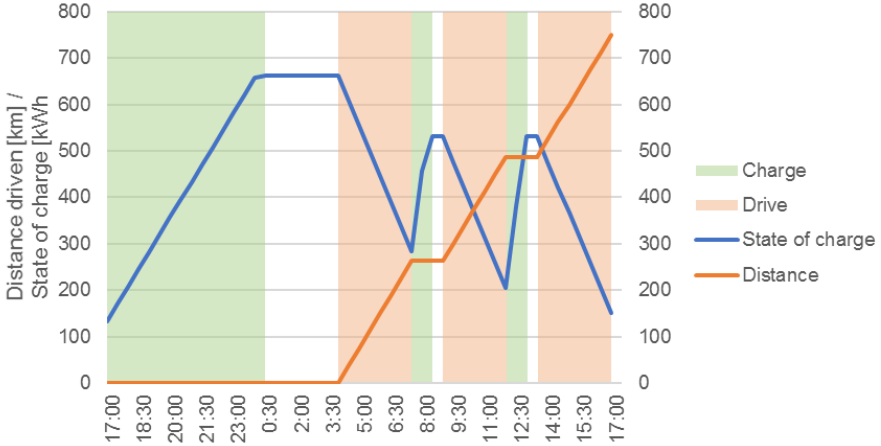
2030





- Developments over time in battery costs and in the price of diesel relative to electricity have a larger impact on the cost-effectiveness of battery-electric trucks than the size of the battery.

CASE: LONG HAUL TRACTOR-TRAILER (24.270 KG PAYLOAD)

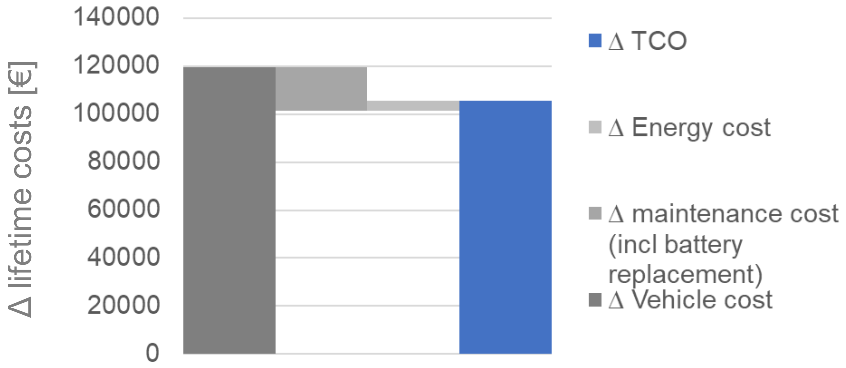


- Average speed of 75 km/h
- Drive 10 hours per day (= 750 km/day)
- 1.8 mln km in 8 years lifetime
- Overnight charger: 75 kW
- Fast charger during rest: 350 kW
- Required battery: 663 kWh (incl. 80% max. DoD)
- Energy use: 1.5 kWh/km (incl. mass penalty)

› A smaller battery and faster charging would further improve the business case

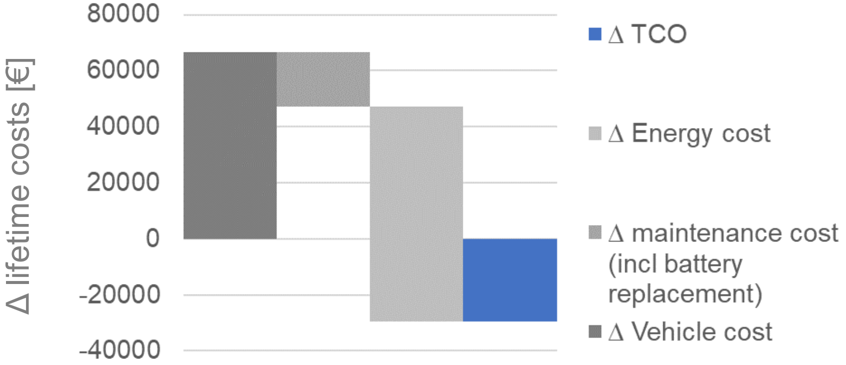
2025

- Electricity price: 0.35 €/kWh
- Diesel price: 1.27 €/l



2030

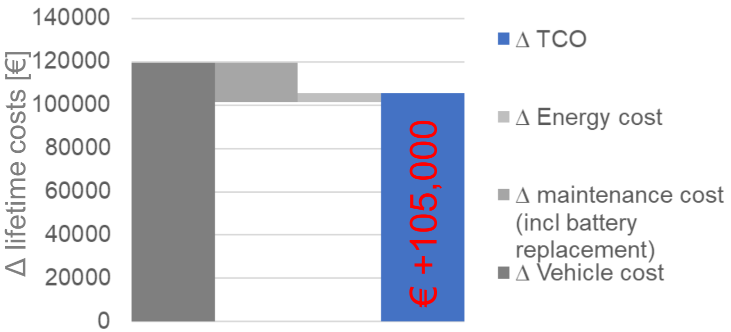
- Electricity price: 0.36 €/kWh
- Diesel price: 1.37 €/l

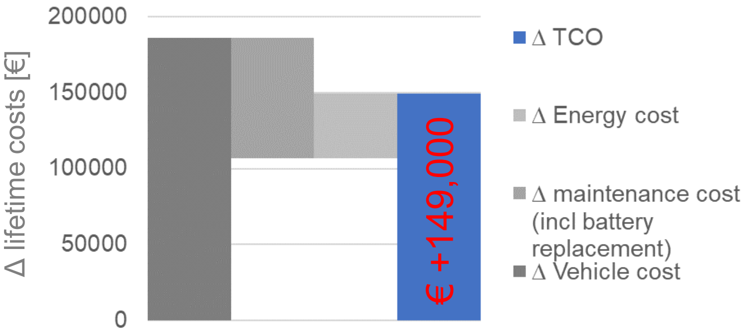


CASE: LONG HAUL – TRACTOR-TRAILER
INFLUENCE OF BATTERY SIZE ON LIFETIME ΔTCO

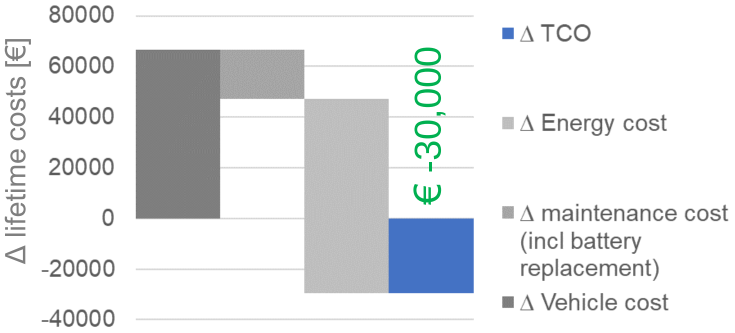
minimum required battery size | **battery size +50%**

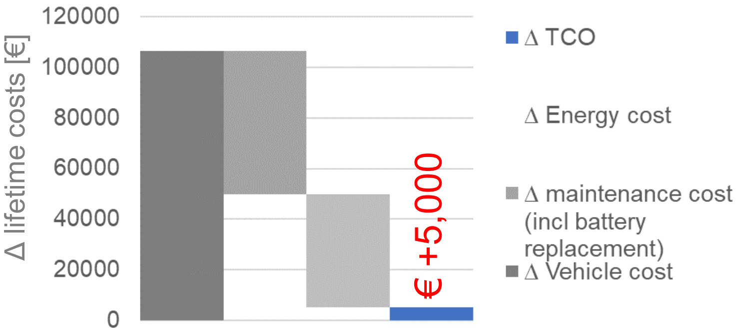
2025





2030



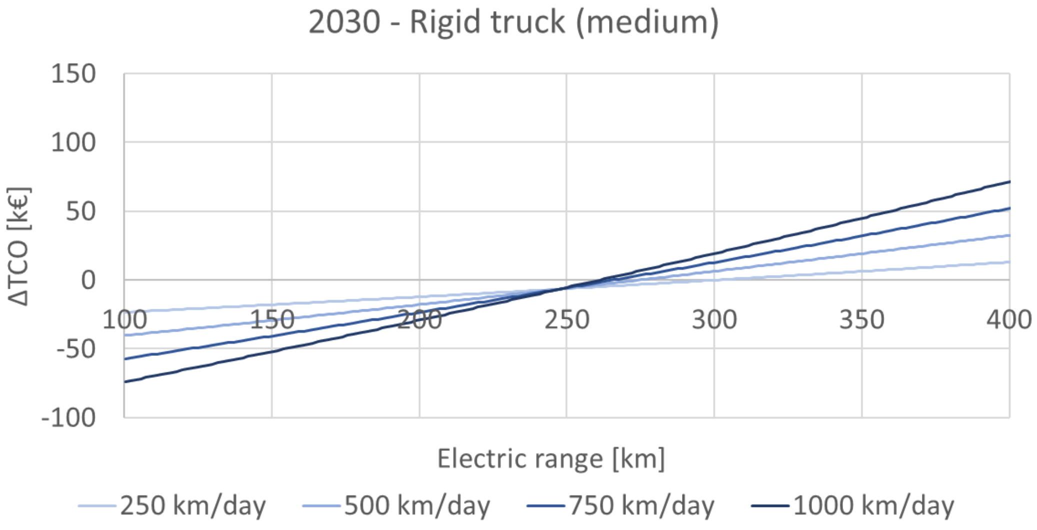


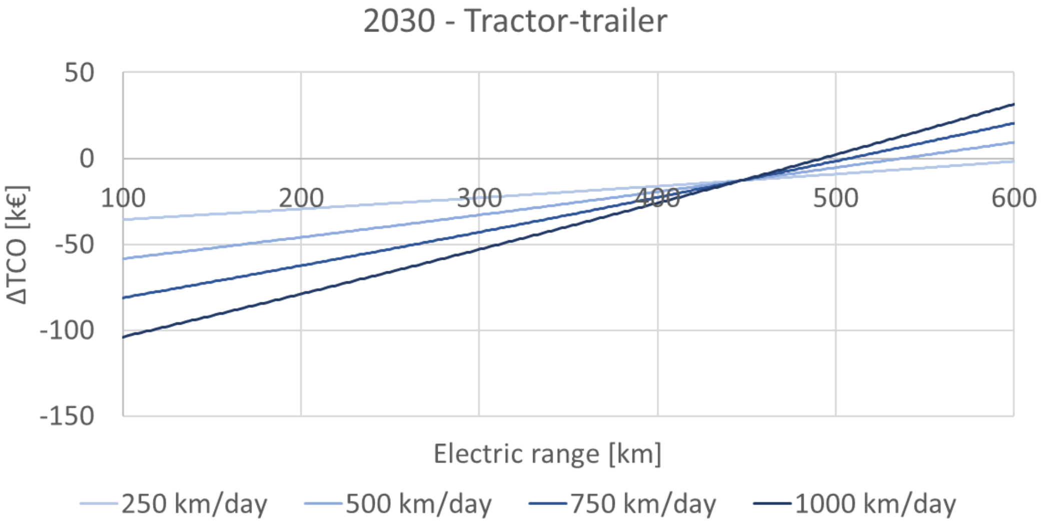
- Developments over time in battery costs and in the price of diesel relative to electricity have a larger impact on the cost-effectiveness of battery-electric trucks than the size of the battery.

DEPENDENCE OF ΔTCO ON ELECTRIC RANGE AND DAILY MILEAGE

- The ΔTCO for battery-electric HDVs compared to conventional HDVs depends on assumptions w.r.t. the electric range (determined by the size of the battery) and the daily driven distance.
- The assessment includes the cost of (multiple) battery replacement(s), which are especially needed when a small battery is chosen.

- Using a larger battery increases energy consumption and therefore leads to a higher TCO.
  - Total battery costs to 1st order do not depend on battery size as a smaller battery needs more frequent replacement over the lifetime of the vehicle.

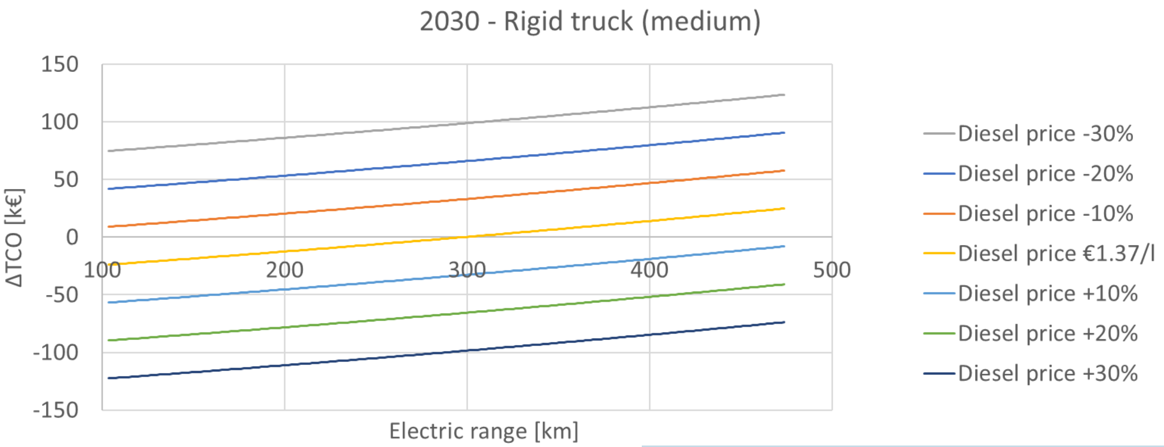




DEPENDENCE OF ΔTCO ON DIESEL AND ELECTRICITY PRICES

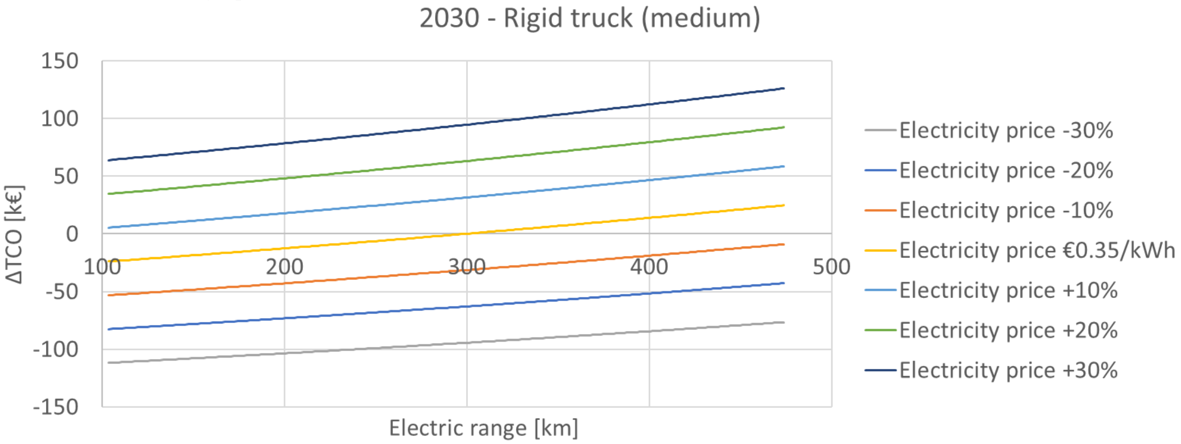
- The ΔTCO for battery-electric HDVs compared to conventional HDVs depends on the price of diesel and electricity.
- Sensitivity analysis for **medium rigid truck**
- A lower electricity price and/or higher diesel price in 2030 improve the economic feasibility of battery electric trucks and also allow their use in applications with lower daily mileage or where a larger battery is required.

Diesel price



Daily driven distance = 263 km/day

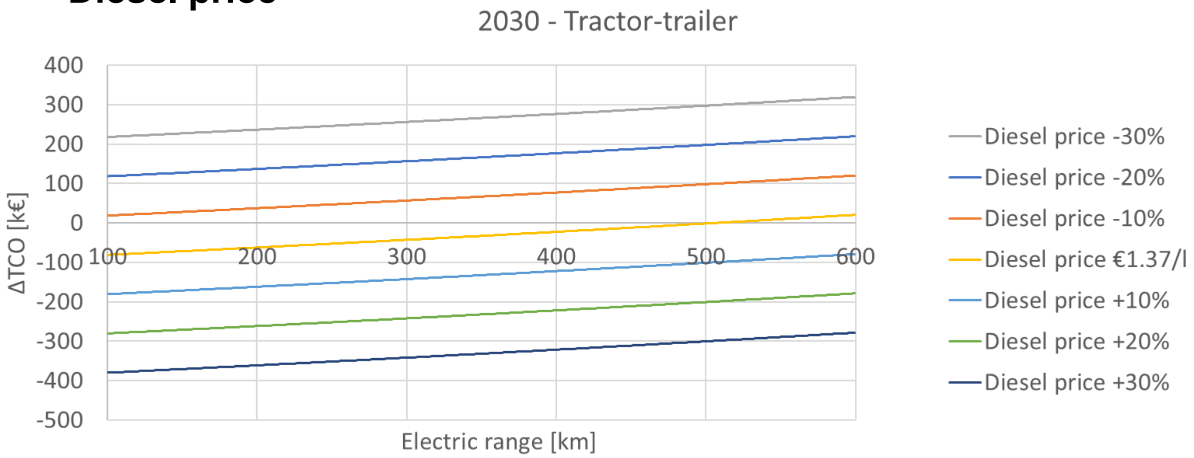
Electricity price



DEPENDENCE OF ΔTCO ON DIESEL AND ELECTRICITY PRICES

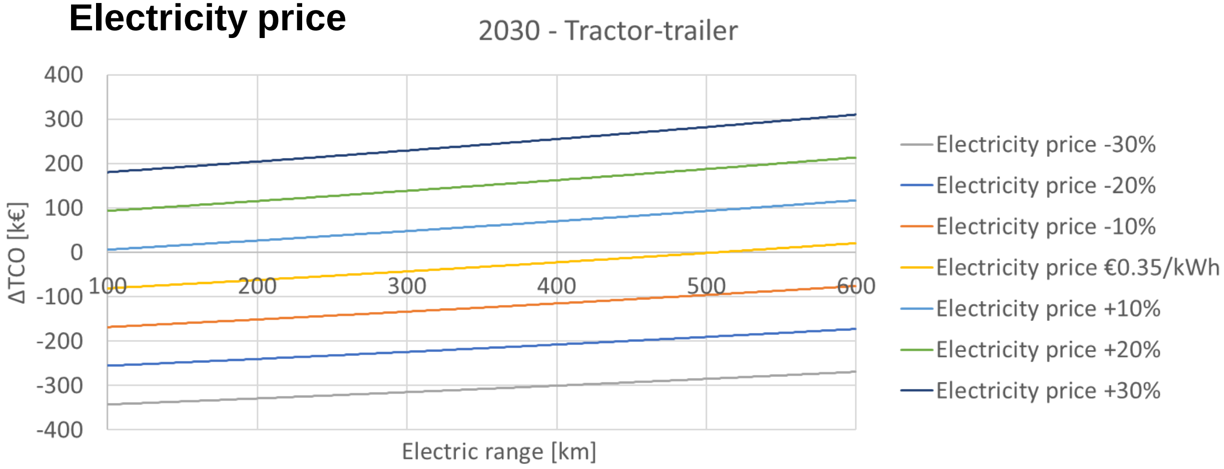
- The ΔTCO for battery-electric HDVs compared to conventional HDVs depends on the price of diesel and electricity.
- Sensitivity analysis for **tractor-trailer**
- Conclusions are similar to the case of the medium rigid truck, with ΔTCO further enhanced by the larger distances driven

Diesel price



Daily driven distance = 750 km/day

Electricity price



CONCLUSIONS

- Developments in product development and market offers for ZE HDVs are currently accelerating.

- Due to an expected rapid decrease in the price of batteries and improvements in battery performance, battery-electric HDVs are expected to be technically feasible and close to economically feasible by 2025 for a limited number of market segments.
- By 2030 battery-electric HDVs may be expected to be to economically competitive for many types of use.
- However, this would require:
  - sufficient availability of sufficiently fast chargers;
  - electricity prices (incl. infrastructure cost) at acceptable levels.
    - This depends strongly on occupation of chargers (> 30%).

- Expectations on the possible contribution of electric trucks to CO_2 reduction in the road freight sector need to be revised.

- For weight-limited transport battery mass goes at the expense of payload. Allowing higher vehicle masses will improve the business case and could lead to quicker uptake of ZE HDVs.

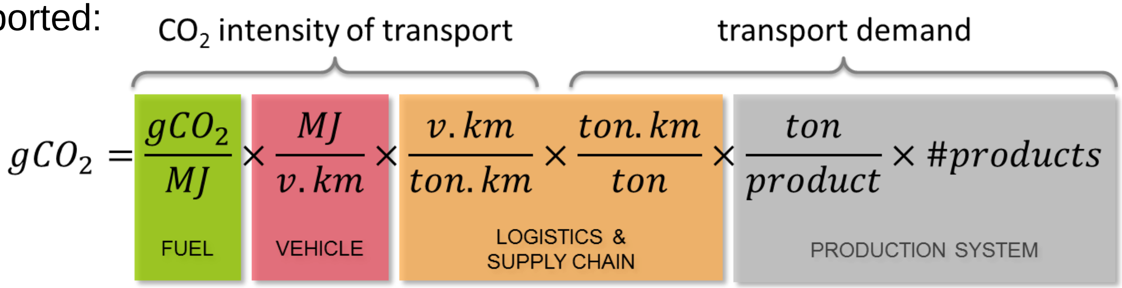
CONTENTS

INTRODUCTION

- Besides the level of the targets for different categories of trucks a wide range of other design elements need to be defined for the EU HDV CO_2 regulation. For each design element different options, or “modalities”, are available. Together with the target level, the choices with respect to options for different design elements determine the stringency of the HDV CO_2 regulation and its effectiveness.
- This chapter contains considerations on the following modalities and issues:
  - the metric
    - g/km vs. g/ton.km or g/m^3.km
  - limits vs. targets
  - options for differentiating targets to specific characteristics and use of vehicles
  - options for introducing flexibilities that may increase the feasibility of meeting the targets and reduce compliance costs
  - options for promoting / demanding ZE HDVs
  - mileage weighting i.r.t. sales weighted targets, transferring CO_2 credits between different vehicle groups and/or exchanging ZEV credits

THE OVERALL OBJECTIVE OF THE REGULATION

- The regulation's **overall objective** is to contribute to reducing the CO_2 emissions from transport, in particular road freight transport. Overall this overarching objective can be reached by:
  - reducing the volume of transported goods, in terms of both the quantity of goods and the distance over which they are transported:
    - less tonne.km or m^3.km
    - reducing the amount of vehicle kilometres per unit of goods transported:
    - less vkm per tonne.km or m^3.km
  - reducing the amount of CO_2 emissions per vehicle kilometre:
    - less CO_2 per vkm
      - This can be achieved by (a combination of) improving the energy efficiency of vehicles and reducing the amount of CO_2 emitted per unit of energy used:
        - less MJ per vkm
        - less CO_2 per MJ



$$gCO_2 = \underbrace{\frac{gCO_2}{MJ}}_{\text{FUEL}} \times \underbrace{\frac{MJ}{v.km}}_{\text{VEHICLE}} \times \underbrace{\frac{v.km}{ton.km} \times \frac{ton.km}{ton}}_{\text{LOGISTICS \& SUPPLY CHAIN}} \times \underbrace{\frac{ton}{product} \times \#products}_{\text{PRODUCTION SYSTEM}}$$

- The above division is also clear from experiences with carbon footprinting in logistics:
  - The relevant carbon footprint KPI* for shippers (companies that contract the logistic services) is g/tonne or g/m^3;
  - The appropriate metric for carriers and logistic service providers is g/tonne.km or g/m^3.km.
- In this sequence the logical metric for companies that provide the vehicles to the carriers and logistic service providers (fleet owners) is g/km.

*) Key Performance Indicator

SPECIFIC OBJECTIVE

- The regulation’s **specific objective** is to reduce the CO_2 emissions from HD vehicles by promoting OEMs to apply energy-efficiency improving technologies and to replace ICEs by other, low-CO_2 or zero emission propulsion technologies.
- **OEMs are the regulated entity.** It is the OEMs’ primary responsibility to apply measures that are within their sphere of influence and that contribute to the specific objective of the Regulation.
  - The focus of what is requested of OEMs should thus be a reduction of the g/km emissions of the vehicles they sell in the EU.
- This chapter includes considerations on:
  - the metric;
  - how to fairly distribute the burden across regulated entities;
    - i.r.t. the choice of metric;
  - how to provide flexibility to facilitate compliance and lower costs.

For the design of CO_2 regulation for LD and HD vehicles the following main **design choices** or **modalities** can be considered (see e.g. [CE/TNO 2017]):

- What is the scope of the Regulation?
  - Regulated vehicle categories
  - Regulated entities
  - Metric
- How to measure the parameters needed for determining the performance of vehicles?
  - Certification and test procedures
- How to determine the overall performance of regulated entities?
  - Monitoring
  - Rewarding or penalising specific technologies
  - Aggregation & weighting
- Target setting
  - Segmentation
  - Target level(s)
- How to fairly distribute the burden across regulated entities?
  - Utility parameter
  - Shape and slope of utility-based target function
- How to provide flexibility to facilitate compliance?
  - Pooling
  - Trading CO_2 credits
  - Banking/borrowing
- Excess emission premiums
- Derogations
- Correction for autonomous changes in vehicle characteristics, sales and use

A NOTE ON TARGETS vs. LIMITS

- In discussing the need to differentiate CO_2 targets for HDVs, it would be good to be aware of the distinction between targets and limits.
  - A **limit** is a requirement that needs to be met, in this case a value that may not be exceeded.
  - A **target** is something to aim for.
    - If target values are set per vehicle group without any option of exchanging CO_2 credits / debits between groups, these values are essentially **limits** for the sales-weighted CO_2 emissions of each vehicle group, but only **targets** for each individual vehicle.
    - If credits / debits can be exchanged between groups or if an overall sales-weighted limit is set, the target values per vehicle group are essentially targets for the sales-weighted CO_2 emissions of each vehicle group.
- Even though it is not yet clear what the Commission will propose, it seems safe to assume that the Commission will not set not-to-exceed limits for each individual vehicle, but will at least work with limits or targets for the sales-weighted average CO_2 emissions per vehicle group.

In the context of the CO_2 legislation the word **target** is used for different purposes:

- In the LDV CO_2 legislation individual vehicles do not need to meet the specific target defined for each vehicle, but instead the sales-weighted average CO_2 emissions of all vehicles sold in the EU by an OEM is required not to exceed the specific target for that OEM, which is calculated as the sales-weighted average of the specific targets for all vehicles sold by that OEM.
- The **specific target** for an OEM therefore in essence is a **limit**.

Setting limits for the sales-weighted average CO_2 emissions per vehicle group already greatly reduces the need to get vehicle-specific targets “exactly right” and “fair” for each individual vehicle.

THE METRIC

- The regulation’s specific objective is to reduce the CO_2 emissions of HDVs. This requires definition of the **regulated parameter**, and the associated **unit** in which the value of this parameter is expressed.
- The main options for this **“metric”** are:
  - g/km
  - g/load.km, with load expressed either in weight (g/tonne.km) or in volume (g/m^3.km)
  - g/capacity.km, with capacity the maximum payload (g/tonne.km) or maximum loading volume (g/m^3.km) of the vehicle
- In principle also combinations are conceivable
- For each truck g/km and g/load.km values will be determined using the VECTO simulation tool as prescribed by Regulation (EU) 2017/2400, adopted on 12 December 2017

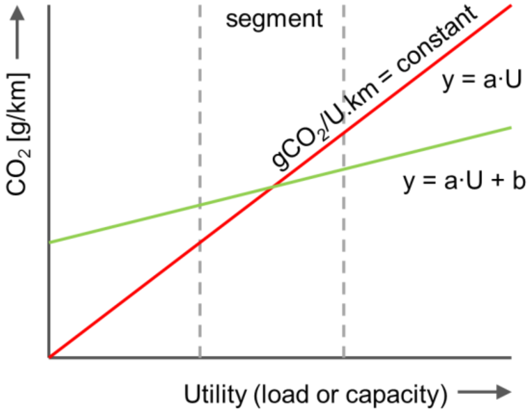
- **Considerations w.r.t. the choice of metric**
  - Practical feasibility and accountability
  - Relation with primary responsibility / influence of regulated entities (= OEMs)
  - Avoid perverse incentives:
    - Disincentivise measures that contribute to the specific objective but counteract the overall objective of the Regulation, e.g. measures that reduce the efficiency of logistics
  - Promote, if possible, measures by OEMs that contribute to improving the efficiency of logistics

THE METRIC

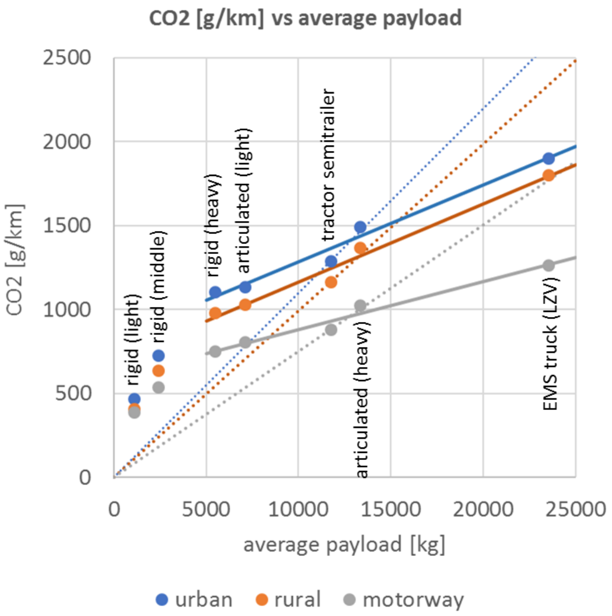
- Motivations for considering a metric that relates the CO_2 emissions to the vehicle's transport performance or utility could be:
  - Allowing larger vehicles, with a higher transport capacity, to emit more CO_2 per vehicle kilometre
    - See next pages
  - Rewarding measures by OEMs that improve the efficiency of logistics
  - Disincentivising compliance measures that would reduce the transport capacity of vehicles and/or the efficiency of logistics
    - Requires load used in metric to be based on actual value for each truck
    - Using g/tonne.km:
      - penalizes OEMs for applying technologies that add weight, e.g. electric propulsion, as lower load leads to lower required g/km emissions
      - unnecessarily rewards OEMs that apply weight reduction by allowing a higher g/km emissions
    - Undesired effects can be counteracted by adapting the "weights and dimensions" regulation
  - The possible use of CO_2 figures derived from the HDV CO_2 legislation in other types of regulation or policies
  - The relevance of the legislative CO_2 figures for vehicle owners and users.
    - For each vehicle certified values in g/km, g/tonne.km and g/m^3.km will be available, as prescribed by Regulation (EU) 2017/2400.
    - g/km emissions are the appropriate metric for selecting the most fuel efficient truck from a range of makes / models that meet the technical specifications associated with the logistic application for which the vehicles are purchased.

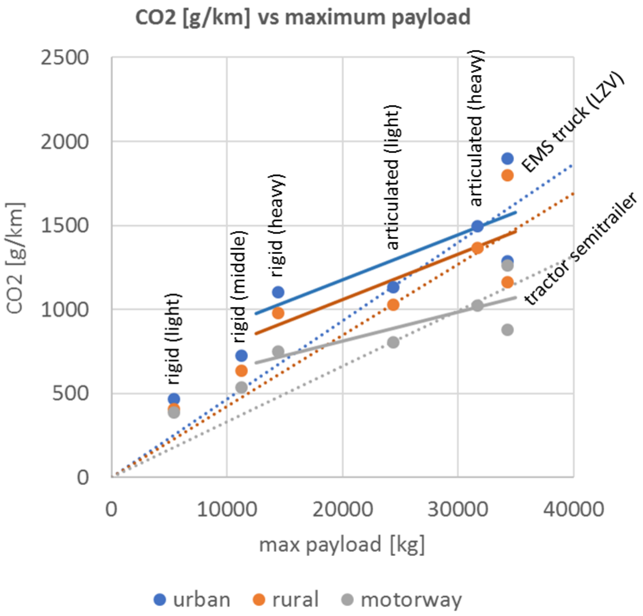
THE METRIC

- **Main arguments against g/ton.km or g/m³.km**
  - Capacity is a declared value and cannot be independently verified.
  - Using the actual load of individual vehicles not feasible. Using the average actual load of a vehicle group is possible, if based on monitoring.
  - Using fixed default load or capacity values makes g/ton.km or g/m³.km equivalent to a constant times a g/km based target.
    - Using g/ton.km or g/m³.km based on default values for the upcoming legislation does open up the way for using actual load or capacity values in later revisions of the legislation.
  - Using g/ton.km or g/m³.km does not adequately cater to the industry's desire for an Integrated Approach. This would only be the case if actual fuel consumption and ton.km or m³.km would be monitored and the regulation would be applied to transport / logistic companies rather than vehicle OEMs.
  - There is no need to use the same parameter for the HDV CO_2 regulation as for other policies or communication to users
  - Using g/ton.km or g/m³.km implicitly makes load or capacity a **utility parameter** but with a utility-based target function that is way too steep.
    - Under a g/load.km or g/capacity.km based target a vehicle with 10% more load or capacity is allowed to emit 10% more CO_2 emissions expressed in g/km.
    - See next page



THE METRIC


CO2 [g/km] vs average payload


CO2 [g/km] vs maximum payload

- The physical relation between CO_2 in g/km and load or capacity of the vehicle depends on vehicle group and mission profile.
- A general comparison of trucks of different sizes shows that a 10% higher average or maximum payload leads to CO_2 emissions in g/km that are generally 4 to 6% higher.

CO_2 emissions of average trucks in different vehicle groups as function of their average and maximum payload

- CO_2 modelled as function of vehicle characteristics using a TNO in-house calculation tool (see [TAP 2016]). For each vehicle group the assumed vehicle mass equals the average empty mass plus an average payload mass.
- Data on the average and maximum payload are based on Dutch statistics [TNO 2016].
- CO_2 emissions are shown for urban, rural and motorway driving. For each vehicle group the average CO_2 emissions will depend on the weighting over different road types, which may be different for different vehicle groups.

- For each road type the solid lines represent least squares fits ($y = a \cdot U + b$) through the data for heavy rigid trucks up to tractor-semitrailers and EMS trucks.
    - This selection was chosen because the correlation appears to be steeper for smaller trucks than for larger vehicle configurations.
- Dashed lines illustrate the relation between CO_2 emissions in g/km and average or maximum payload if a CO_2 emission target would be expressed in g/tonne.km with the tonnes in the denominator either the average payload or the maximum payload (linear function $y = a \cdot U$ with 0,0 intercept).

THE METRIC

Relating the target to the transport performance of trucks by using a g/tonne.km or g/m³.km metric is <u>not</u> an appropriate way to differentiate targets as function of the utility of trucks.

- **Alternatives for differentiating (g/km based) targets as function of utility** are:
  - a **utility-based target function**
    - This function could use actual capacity or actual average load as utility parameter.
      - Determined with a method to be defined;
    - The appropriate slope of the target function can be determined from vehicle data or VECTO simulations.
      - This can be done for each vehicle group separately.
  - using **more vehicle groups** that are **more homogeneous** with respect to vehicle size, capacity and load, and to set appropriate g/km targets for each group
    - If vehicles are sufficiently similar within a group, and if the target is set at the level of the sales average within the group rather than as a not-to-exceed limit for each individual vehicle, a single g/km target can be applied to all vehicles within the same group.
    - This could include a separate group for EMS vehicles.

A utility-based target function defines a specific target for each vehicle as function of the vehicle's utility *U*, and can (if linear) be written as:

$$target_{\text{specific}} = a \cdot (U - U_{\text{average}}) + target_{\text{average}}$$

- The need for a (correct) differentiation of targets can be further alleviated by introducing appropriate **flexibilities** in the legislation.
  - See section on flexibilities.

FLEXIBILITIES

- Flexibilities can be introduced to:
  - increase the feasibility for OEMs to meet the target, or
  - lower the costs for meeting the target.
    - Optimising the distribution of reduction efforts over a larger group of vehicles generally leads to lower cost of compliance.
- The main options are:
  - allowing OEMs to **balance CO_2 credits and debits between vehicle groups**
  - allowing **trading** of CO_2 credits between OEMs
  - **pooling,** i.e. allowing OEMs to join their targets, overall or for specific vehicle groups
  - allowing **banking and borrowing** of CO_2 credits, to allow some level of flexibility with respect to meeting a specific target in a specific target year.
- Appropriate flexibilities also help to reduce the need for a (correct) differentiation of targets as function of the specific characteristics and use of vehicles.

- **Balancing CO_2 credits and debits between vehicle groups**
  - This can be done explicitly in a way that also makes it possible to cap the amount of credits / debits that can be transferred between vehicle groups;
  - An implicit way to do this is to set manufacturer specific overall targets based on weighting the (sales-weighted) targets per vehicle group over lifetime mileage and sales;
  - Transferring credits / debits between different vehicle groups requires **lifetime mileage weighting**.
    - See page 55

FLEXIBILITIES

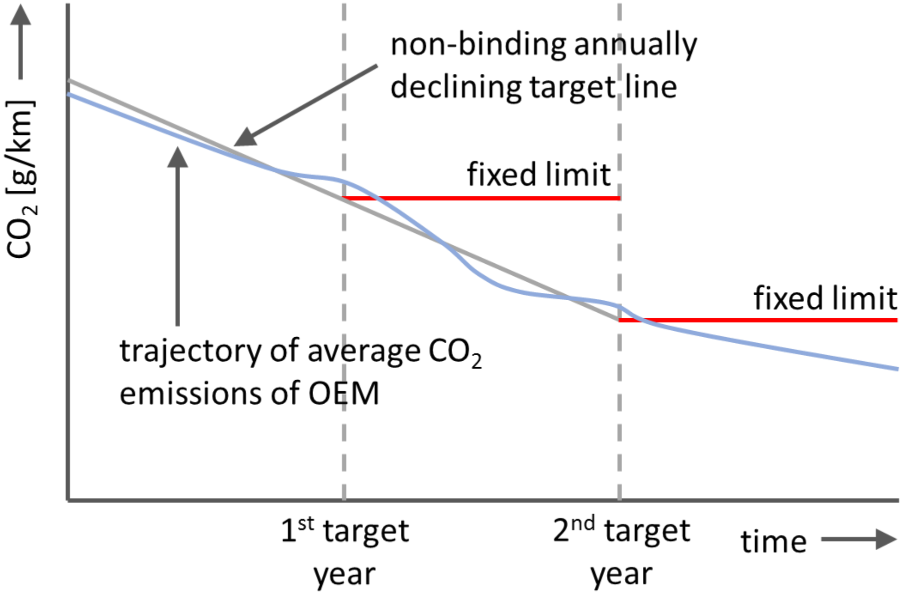
- **Trading** of CO_2 credits between OEMs:
  - Trading can be allowed either only between the same vehicle groups or also between different vehicle groups;
  - Requires an administrative organization to facilitate the trading;
  - Transferring credits / debits between different vehicle groups requires **lifetime mileage weighting**.
    - See page 55

- **Pooling**:
  - Pooling means that OEMs are allowed to join their targets, either for the same specific vehicle groups or for their overall target (if the Regulation sets overall sales weighted targets per OEM);
  - Joining overall targets requires clear procedures for calculating joint targets;
  - Pooling is an implicit way of allowing trading of CO_2 credits between OEMs.

- **Banking and borrowing** of CO_2 credits
  - Provides some level of flexibility with respect to meeting a specific target in a specific target year.
  - This should be combined with an annually declining target trajectory against which credits and debits are defined (see next page)
  - A facultative target trajectory (only applying to OEMs wishing to use banking and borrowing) can in principle be combined with fixed mandatory targets that are valid for a longer period of time.
  - Transferring credits / debits between different vehicle groups requires **lifetime mileage weighting**.
    - See page 55

BANKING AND BORROWING

- **Banking and borrowing** of CO_2 credits can be used to create some level of flexibility for OEMs with respect to meeting a specific target in a specific target year.
  - To avoid surpluses of banked credits in the years before a new target enters into force, banking and borrowing should only be applied in combination with an annually declining target trajectory against which credits and debits are defined.
  - Limits can be set to the amount of banked credits that can be used to compensate debits.
  - Banking and borrowing can be allowed within vehicle groups only or also between vehicle groups. In the latter case lifetime mileage weighting needs to be applied to the transferred credits.
- A facultative, i.e. non-binding, annually declining target trajectory (only applying to OEMs that wish to use banking and borrowing) can in principle be combined with fixed mandatory targets (essentially limits) that are valid for a longer period of time.



MILEAGE WEIGHTING i.r.t. TRANSFERRING CO_2 CREDITS AND DEBITS BETWEEN VEHICLE GROUPS

- As vehicles in different groups have very different lifetime mileages, a g/km saved in one group does not have the same impact on the absolute CO_2 emissions of transport as a g/km saved in another group.
- **Exchange grammes, not g/km**
  - Balancing CO_2 credits and debits between vehicle groups thus requires that g/km credits and debits are multiplied by default values for the average lifetime mileage of vehicles in the group in which the credits or debits are created (lifetime mileage weighting) so that grams are exchanged instead of grams per kilometre;
  - Default average lifetime mileage values per vehicles group can be based on statistics or on-road monitoring.

Typical lifetime mileages as function of engine size:

4-5 litre:	650.000 km
7-9 litre:	850.000 km
11-13 litre:	1.200.000 – 1.800.000 km

Credits gained in vehicle category *a*:

$$credits_a = (target_a – emission_a) \times avg\_mileage_a$$

can be used to compensate the following amount of **debits** in vehicle category *b*:

$$debits_b = (target_a – emission_a) \times avg\_mileage_a = (emission_b – target_b) \times avg\_mileage_b$$

allowing an excess of the average emissions in vehicle category *b* equalling:

$$(emission_b – target_b) = (target_a – emission_a) \times avg\_mileage_a / avg\_mileage_a$$

with $emission_{a,b}$ and $target_{a,b}$ expressed in g/km and $avg\_mileage_{a,b}$ expressed in km.

OPTIONS FOR PROMOTING / REQUIRING ZE HDVS

- European HDV CO_2 legislation can play an important role in stimulating the market introduction of various zero CO_2-emission technologies. Various design options for promoting zero emission vehicles (ZEVs) can be considered for this.
- The need for specific promotion of ZEVs depends on:
  - the overall CO_2 emission target for road transport by 2030 and the need to accelerate the transition to ZE mobility;
  - the stringency of CO_2 standards for HDVs, determined by the values of the target levels per vehicle group.

Stringent HDV CO_2 standards can promote the market introduction of ZEVs in two ways:

- If HDV CO_2 targets are so low that they can not be met by only applying CO_2 reduction measures to conventional HDVs, OEMs will have to sell some share of ZEVs to meet the target;
- But even for HDV CO_2 targets above those levels, the marginal costs for further reduction of the average CO_2 emissions of HDVs by selling ZEVs may at some point become lower than the marginal costs for applying further CO_2 reducing measures to conventional HDVs. This depends on cost developments for ZE technologies and reduction measures for ICE-based HDVs.

- Various modalities can be used in the HDV CO_2 legislation to incentivise ZE HDVs:
  - Zero rating
  - Super credits
  - ZEV credits
    - e.g. allowing ZEV credits earned in non-regulated vehicle groups to compensate deficits in regulated vehicle groups
  - ZEV mandate
    - requiring a minimum share of ZEVs to be sold in the target year
  - A flexible ZEV mandate
    - incentivising OEMs to sell a minimum share of ZEVs in the target year

OPTIONS FOR AWARDING ZEVS

- **Zero rating**
  - Count electric and H_2-trucks as zero-emission
    - Follows from choice to base the CO_2 emission value of HDVs on direct (= exhaust) emissions
    - As in LD CO_2 legislation
  - Relates to modality TTW (tank-to-wheel) vs. WTW (well-to-wheel)
    - Using direct or TTW emissions as basis for the metric makes sense i.r.t. the IPCC definition of EU and national / sectoral targets.
    - The option of using a WTW-based metric has been considered and rejected for the post-2020 LDV CO_2 legislation.

- **Super credits**
  - Count each ZE truck as > 1 vehicle in determining the sales-weighted CO_2 emissions by multiplying sales with a super credit factor
  - Temporary incentive to promote marketing of ZEVs
    - As in LDV CO_2 regulation:
      - Super credit factor for ZEVs decreases over time from e.g. 2 or 1.5 to 1
  - Super credits weakens the legislation and lead to increased CO_2 emissions compared to situation without super credits
    - Adverse effects can be reduced by capping the amount of super credits

OPTIONS FOR AWARDING / REQUIRING ZEVS

- **ZEV credits for ZEVs sold in categories that are not or not yet regulated**
  - Allow OEMs to use these ZEV credits to compensate excess CO_2 emissions from ICEVs sold in regulated vehicle groups:
    - Determining the amount of ZEV credits per vehicle sold in not (yet) regulated vehicle groups requires certification and monitoring of not (yet) regulated vehicle groups.
    - Transferring CO_2 credits requires lifetime mileage weighting.
  - This stimulates action by OEMs to increase the share of ZEVs in non-regulated vehicle groups. The latter include smaller trucks (category 0 to 3) for which e.g. electric propulsion may be expected to become technically and economically feasible earlier than for larger trucks.
  - Allowing banking of ZEV credits may further increase the flexibility for OEMs under a CO_2 regulation.

See page 61

- **A <u>hard</u> ZEV mandate**
  - Regulation could require a minimum share of ZEVs in the sales in (a) given target year(s)
    - Design choices include:
      - Target for ZEV share per vehicle group or overall for the total sales?
        - For the latter with or without lifetime mileage weighting for ZEV shares in different groups?
      - Only for regulated vehicle groups or also including non-regulated vehicle groups?
      - Requires a penalty for OEMs that do not meet the target. Options include refuse access to EU market, a financial penalty (e.g. xx € per missing ZEV) or tightening the CO_2 target(s) proportional to deficit in ZEV share.

OPTIONS FOR AWARDING ZEVS

- **A <u>flexible</u> ZEV mandate**
  - Regulation could set a target for the share of ZEV in (a) given target year(s) combined with a bonus and/or malus if the actual ZEV share is larger / smaller than the ZEV target.
  - The most important design choice relates to the definition of the bonus resp. malus. These could be defined as a relaxation resp. tightening of the CO_2 target proportional to the amount by which the ZEV target share is exceeded / missed. This has the following consequences:
    - **bonus:** Relaxing the CO_2 target, if the ZEV share exceeds the ZEV target, “gives away” the extra CO_2 reduction associated with the extra ZEVs.
    - **malus:** Tightening the CO_2 target makes the overall target for an OEM more stringent, but can only be applied realistically if that target can still be met with additional CO_2 reduction measures applied to ICEVs.
  - **The target level for the ZEV share requires careful consideration in relation to the CO_2 reduction target.**
    - Meeting the targeted ZEV share should not go at the expense of applying cost effective CO_2 reduction measures to the remaining ICEVs.
  - Also here additional design choices include:
    - Target for ZEV share per vehicle group or overall for the total sales?
      - For the latter with or without lifetime mileage weighting for ZEV shares in different groups?
    - Only for regulated vehicle groups or also including non-regulated vehicle groups?

In the recently proposed **post-2020 LDV CO_2 regulation** 15% and 30% CO_2 reduction targets for 2025 resp. 2030 are combined with ZEV targets of 15% resp. 30%. If an OEM meets these ZEV targets the CO_2 targets are also met, without having to apply CO_2 reduction measures to the ICEV sales. However, CO_2 reduction of conventional vehicles is cost-effective up to 40% from a societal and end-user perspective*. As the bonus grants the OEM an increased CO_2 target, meeting the ZEV target may even lead to increased CO_2 emissions of ICEVs compared to the reference year.

*) https://ec.europa.eu/clima/policies/transport/vehicles/proposal_en

ISSUES w.r.t. AWARDING / REQUIRING ZEVS

- **What minimum share / target to be set for 2025/2030?**
  - Balance between what is needed in view of the transition to zero-emission mobility and what is (considered) technically and economically feasible. This is primarily a political choice.
  - The perspective w.r.t. technical and economical feasibility of ZE trucks is rapidly improving. In view of that an exact number is difficult to motivate scientifically at this stage.

The EC should not fix ZE targets for the next 12-17 years based on “old thinking” w.r.t. technical and economical feasibility, the required speed of the transition and the possible contribution of HDVs to decarbonising the transport sector.

- **How to deal with partial-ZEVs?**
  - How to deal with plug-in hybrids, other partial ZEV or Low-Emission Vehicle (LEV) options and complex configurations?
    - Examples include plug-in hybrid tractors, E-highway (catenary) trucks with generator-set or dual mode for off-highway driving, trailer electrification / whole vehicle hybridization, etc.
  - These technologies can be given partial ZEV credits. Certification requires appropriate test methods and assessment procedures.
    - This requires knowledge of real-world use / operation of these vehicles. The share of ZE kms is the critical factor.
      - Data to be based on monitoring vehicles in normal operation.

Moving towards certification & regulation based on on-board monitoring (OBM) could be considered.

MILEAGE WEIGHTING i.r.t. ZEV CREDITS

- Different truck categories have very different lifetime mileage. Balancing CO_2 credits and debits between vehicle groups thus requires that g/km credits and debits are multiplied by default values for the average lifetime mileage of vehicles in the group in which the credits or debits are created (lifetime mileage weighting) so that grams are exchanged instead of grams per kilometre.
- **Lifetime mileage weighting** is also relevant when ZEV credits can be used to off-set emissions from ICEVs in other vehicle groups or to compensate lagging ZEV sales in other vehicle groups.
  - For regulated vehicle groups the CO_2 value (in g/km) of ZEV credits can be based on the target applicable to the group in which the ZEV is sold.
  - If ZEV credits can also be gained in vehicle groups that are not or not yet regulated, monitoring of average CO_2 emissions of ICEVs in all vehicle groups is required to generate a reference against the CO_2 value (in g/km) of ZEV credits can be assessed.

ZEV credits of 1 (p)ZEV in category *y* =

$(target_y - emission_{(p)ZEV}) \times avg\_mileage_y$ for regulated vehicle groups

OR

$(avg\_emission\_of\_ICEVs_y - emission_{(p)ZEV}) \times avg\_mileage_y$ for vehicle groups that are not (yet) regulated

- See also page 55

INTERACTION WITH OTHER POLICIES FOR PROMOTING ZE HDVs

- Upscaling of ZE HDVs can / should not come from EU legislation alone. Stimulation of supply AND demand is necessary.
- The large scale uptake of ZE HDVs needs to be facilitated by appropriate filling / charging infrastructure:
  - EU Alternative Fuels Infrastructure Directive + national measures
- Flanking national, regional and municipal policies are needed:
  - For buses requirements in public transport concessions have proven a powerful instrument.
  - For vans and trucks some options are:
    - Gradual tightening of environmental zoning / ZE zoning for LCVs and HDVs in cities;
      - see e.g. Green Deal Zero Emission City Logistics in the Netherlands;
  - Promoting carbon footprinting and labelling schemes in logistics.

MAIN CONCLUSIONS FROM THIS STUDY (1)

On the CO_2 reduction potential of conventional HDVs

- By 2030 CO_2 emissions from conventional HDVs can be reduced by 28% (excluding trailer-based measures) to 33% relative to 2015 baseline vehicles at net negative costs to society and end-user.

Note: Due to a limited availability of cost data in public literature, the number of CO_2 reduction options included in this study is smaller than in the SR9 support study for DG CLIMA (see note on page 6). This means that the estimated maximum reduction potentials assessed here are likely to be on the conservative side compared to that study.

On the required contribution from HDVs to meeting overall GHG emission reduction targets

- Meeting an intermediate CO_2 reduction target for the EU road freight sector for 2030, that is consistent with the 1.5˚C goal from the COP21 Paris agreement, is likely to require the combined impacts of:
  - improved logistics to reduce vehicle kilometres;
  - the full available potential for reduced fuel consumption in conventional HDVs together with an increased share of sustainably produced biofuels or other low-CO_2 fuels, plus
  - an additional contribution from employing zero emission vehicles (ZEVs) in the road freight sector.

MAIN CONCLUSIONS FROM THIS STUDY (2)

On the feasibility of zero-emission HDVs

- Battery-electric HDVs may be expected to be technically feasible and close to economically feasible by 2025 for a limited number of market segments. By 2030 battery-electric HDVs are likely to be economically competitive for many types of use.
- The EC should not fix ZE targets for the next 12-17 years based on “old thinking” w.r.t. technical and economical feasibility of technologies, the required speed of the transition and the possible contribution of HDVs to decarbonising the transport sector.

On design options (modalities) for the EU HDV CO_2 Regulation

- For a number of reasons the preferred metric for expressing the target is g/km.
- Relating the target to the transport performance of trucks by using a g/tonne.km or g/m^3.km metric is <u>not</u> an appropriate way to differentiate targets as function of the utility of trucks. Differentiating the target to the size or capacity of vehicles can be adequately done by defining separate target for sufficiently homogeneous vehicle groups or by using utility-based target functions within vehicle groups.
- A number of flexibilities can be introduced to increase the feasibility for OEMs to meet the target, or lower the costs for meeting the target. Appropriate flexibilities also help to reduce the need for a (correct) differentiation of targets as function of the specific characteristics and use of vehicles.

LITERATURE

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