Support for the revision of Regulation (EC) No 443/2009 on CO_2 emissions from cars

Service request #1
for Framework Contract on Vehicle Emissions - No ENV.C.3./FRA/2009/0043

Richard Smokers, Filipe Fraga, Maarten Verbeek

Stakeholder Meeting, Brussel, December 6, 2011

Objective

- Assist European Commission with carrying out review clauses in Regulation (EC) No 443/2009 to reduce the CO_2 emissions from passenger cars
  - defining the modalities of reaching, by the year 2020, a long-term target of 95g/km in a cost-effective manner
  - implementation aspects including excess emissions premium
  - review availability of data on footprint and its use as utility parameter for specific emissions target

Tasks

1. Cost and potential of CO_2 reduction options for 2020 and further

2. Alternative utility parameters

3. Modalities for 95 g/km in 2020

4. Investigation of further aspects

Construction of cost curves for passenger cars in 2020

- Potential and costs of CO_2 reducing technologies
- Construction of cost curves for 2020
- Alternative costs curves / scenarios

Cost and potential of CO_2 reduction options for the longer term

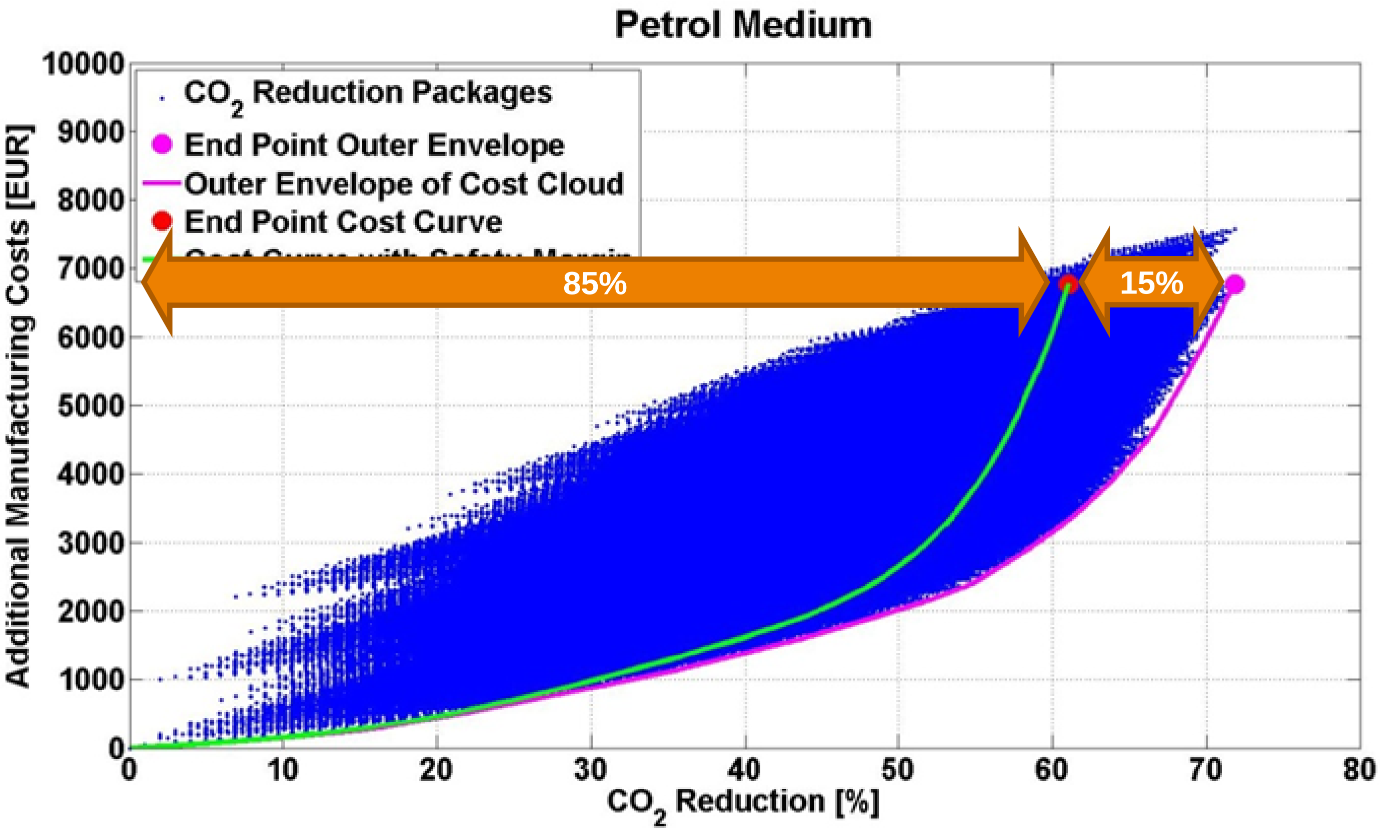
- Quantification of costs and reduction potential of technical options to reduce CO_2 emissions in passenger cars on petrol and diesel
  - Collection of data from:
    - Recent literature, in-house expertise
    - Automotive manufacturers, suppliers and trade associations
      - Detailed questionnaire + consultations
  - Consolidation of data set

- Electric and plug-in vehicles modelled separately
    - In collaboration with recent study by CE Delft / ICF / Ecologic

Construction of cost curves for 2020

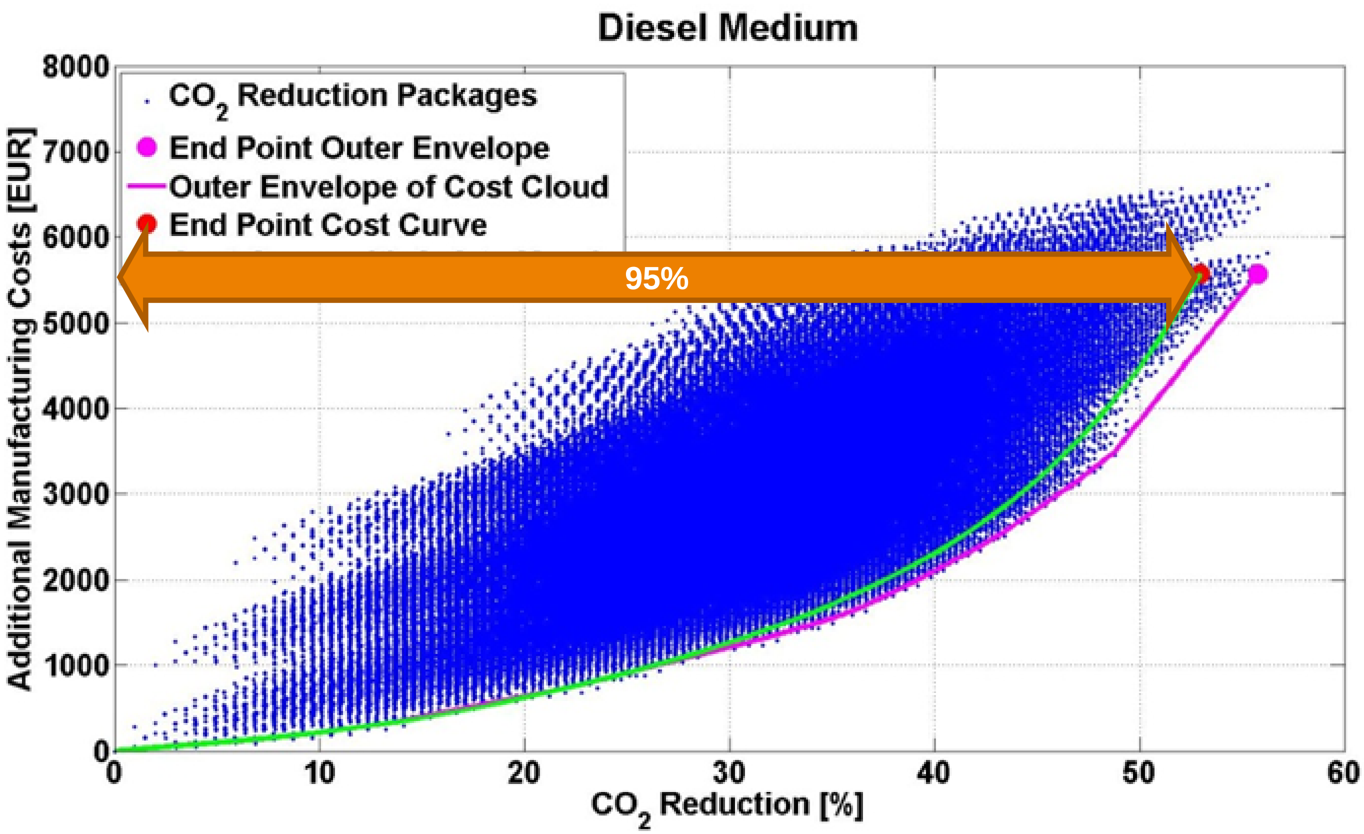
- Combine compatible options into packages:
  - $$E_{package} = E_{baseline} \times \prod_{i=1}^{n} (1 - \delta_i)$$
    - Subtract "safety margin" to avoid overestimation of combined reduction potential of options targeting the same energy loss
  - $$C_{package} = \sum_{i=1}^{n} C_i$$
- Safety margin assumed to increase linearly with reduction potential:
  - maximum value
    - 15% for petrol cars
    - 5% for diesel cars
  - based on available simulations from Ricardo + extrapolation of existing advanced vehicles + expert judgement

Definition of cost curves for 2020 - petrol



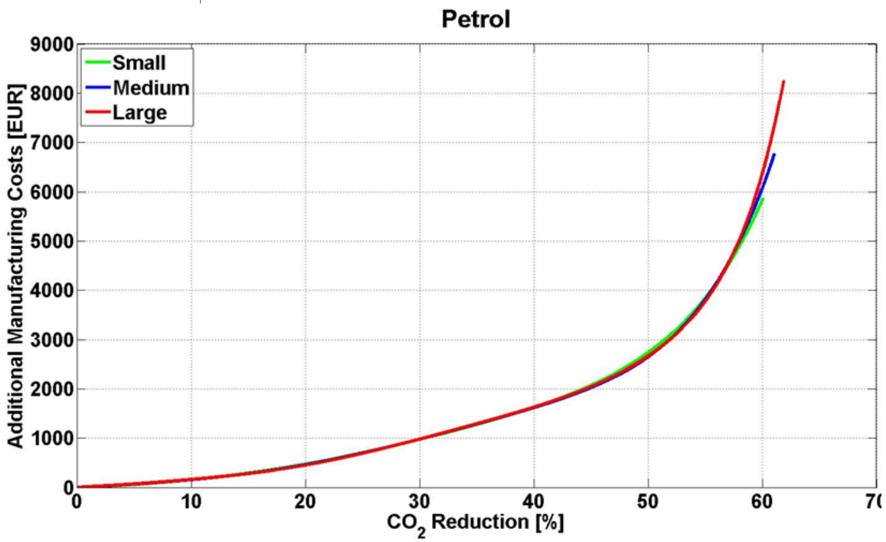
- Additional manufacturer costs as function of reduction percentage
- 6^{th} to 9^{th} order polynomials necessary to describe non-linearity of cost curve

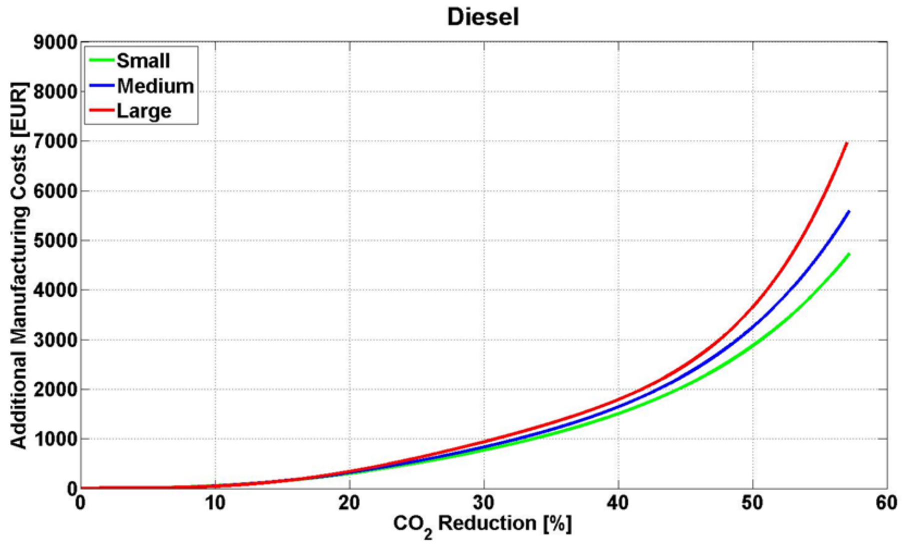
Definition of cost curves for 2020 - diesel



- Additional manufacturer costs as function of reduction percentage
- 5th to 6th order polynomials necessary to describe non-linearity of cost curve

Cost curves for 2020 - overview



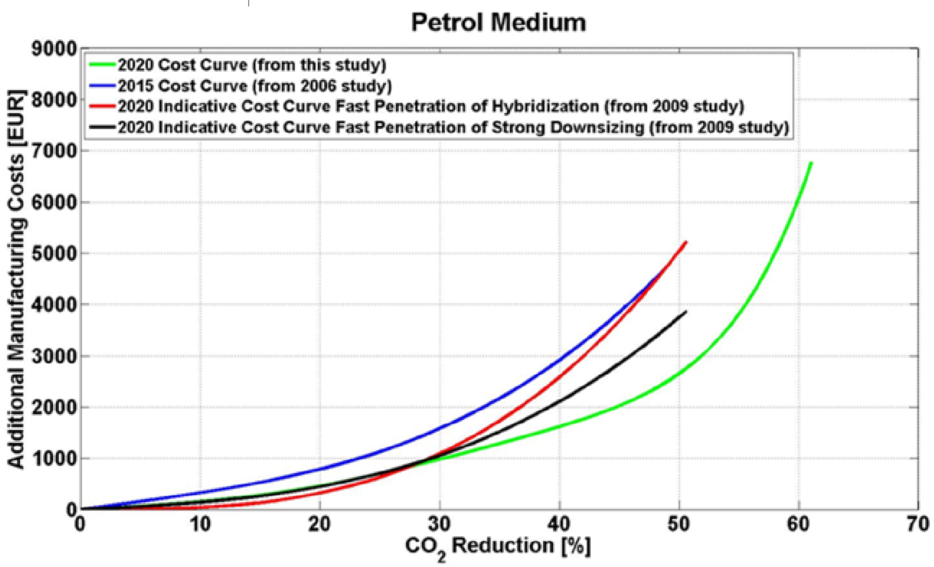


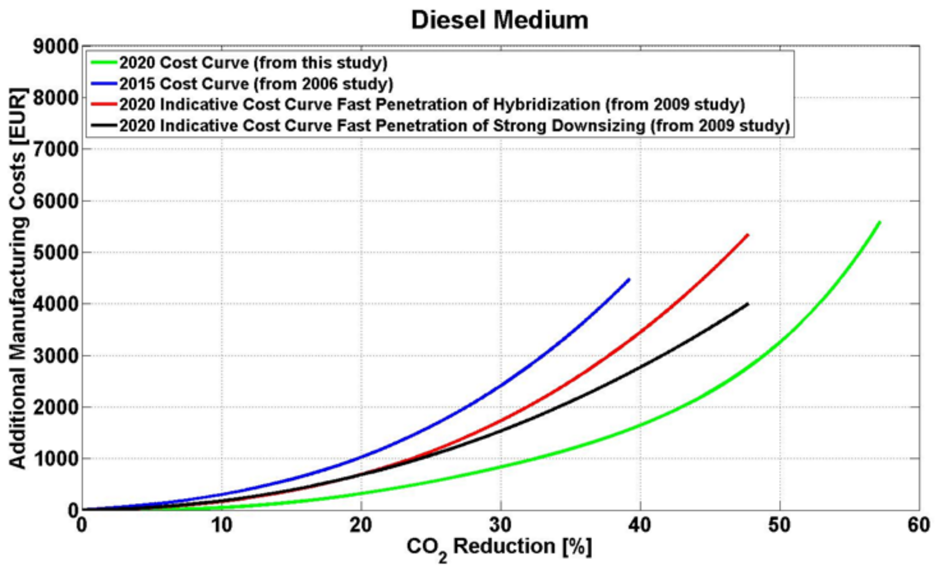
$$y = \sum_{i=1}^{9} a_i \cdot x^i$$

	a9	a8	a7	a6	a5	a4	a3	a2	a1	End %	End €
p,S				8.134E+05	-9.302E+05	3.859E+05	-6.922E+04	1.319E+04	6.453E+02	60.1%	5870
p,M				1.207E+06	-1.386E+06	5.381E+05	-7.426E+04	9.017E+03	9.985E+02	61.1%	6775
p,L	9.431E+07	-2.233E+08	2.180E+08	-1.121E+08	3.226E+07	-5.187E+06	4.602E+05	-1.672E+04	1.574E+03	61.9%	8265
d,S					2.193E+05	-1.757E+05	5.709E+04	9.584E+01	1.657E+03	53.0%	4711
d,M					4.147E+05	-3.757E+05	1.308E+05	-9.708E+03	2.151E+03	53.0%	5571
d,L				-1.549E+05	1.069E+06	-8.804E+05	2.701E+05	-2.236E+04	2.585E+03	52.8%	6946

Framework Contract on
Vehicle Emissions
ENV.C.3./FRA/2009/0043
Service request #1

Comparison with previous studies





- 2015 cost curves from TNO/IEEP/LAT 2006
  - also used in IEEP/CE Delft/TNO 2007
- indicative 2020 cost curves from AEA/CE Delft/TNO/Öko 2009

- For petrol lower costs than 2009 study for high reduction levels
- For diesel lower costs than 2009 study over entire range

Scenario variants

- In the course of the study two issues arose that justified critical evaluation of the cost curves as presented before:
  - Observed **progress** in CO_2 reduction in European new passenger car fleet **in the 2002-2009 period**
  - Technical **data** becoming available **from EPA studies** in support of the US legislation on CO_2 emissions from light duty vehicles
- These data seem to suggest that the costs of reducing CO_2 emissions in passenger cars could be lower than estimated in this study.

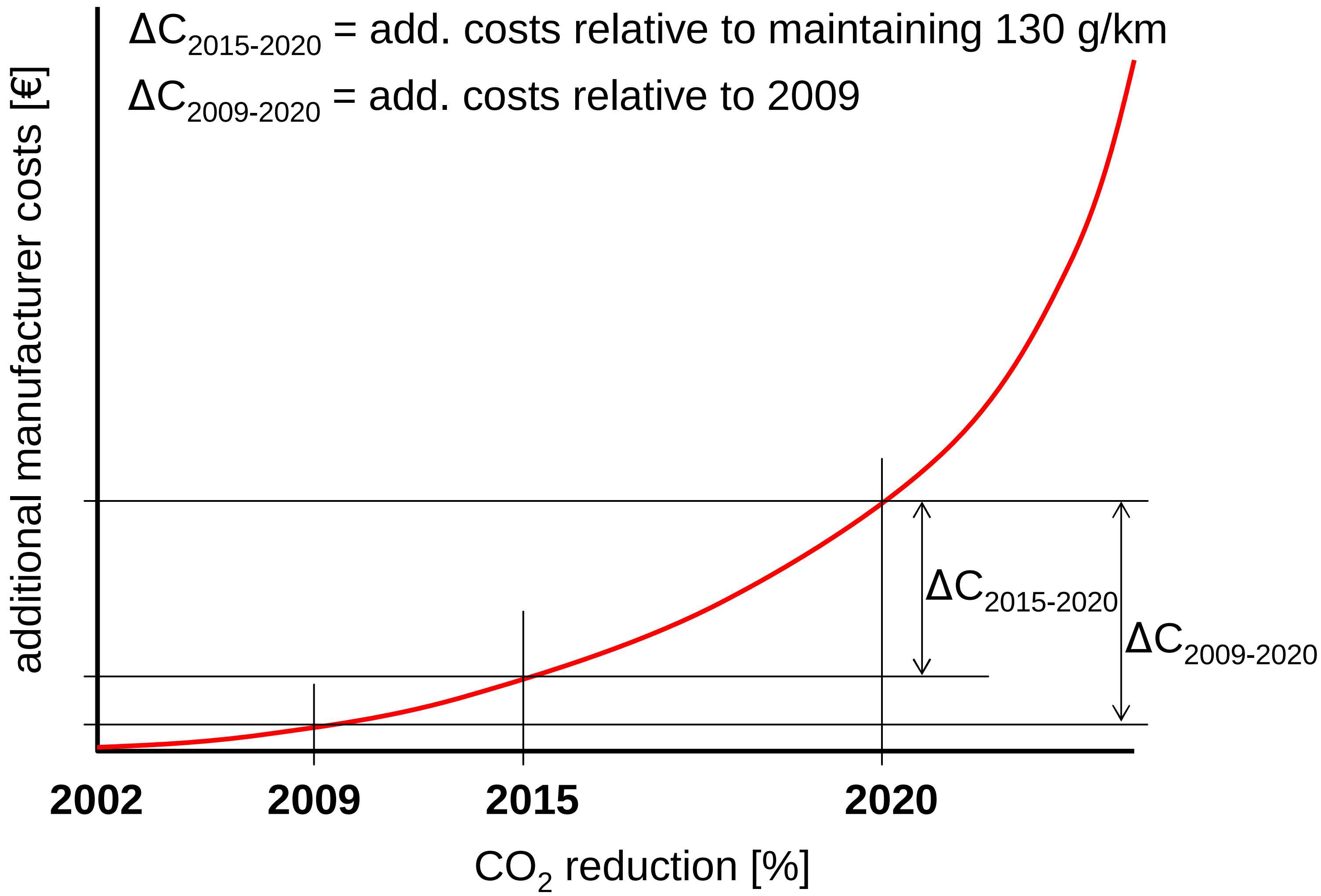
- As detailed assessments were not possible within scope of study and given limited availability of data, it was decided to deal with these issues in the form of scenarios
  - **a)** Alternative accounting for progress observed in 2002-2009 period
  - **b)** Alternative cost curves based on a modified technology table
  - **c)** Combination of a) and b)

Scenario a) Alternative accounting for progress observed in the 2002-2009 period

- Variant including additional reduction step based on assumption that part of the reductions achieved in the 2002-2009 period are to be attributed to other causes than application of technologies as included in the technology tables:
  - technical options not included in cost curves
  - effects of optimising the powertrain calibration by improving trade-offs against other parameters
  - possible utilization of flexibilities in the test procedure

- Based on detailed comparison of base models in 2002 and 2010 and of average reductions per segment the following additional reduction potentials were chosen for the scenario analysis:
  - petrol: 10%
  - diesel: 9%

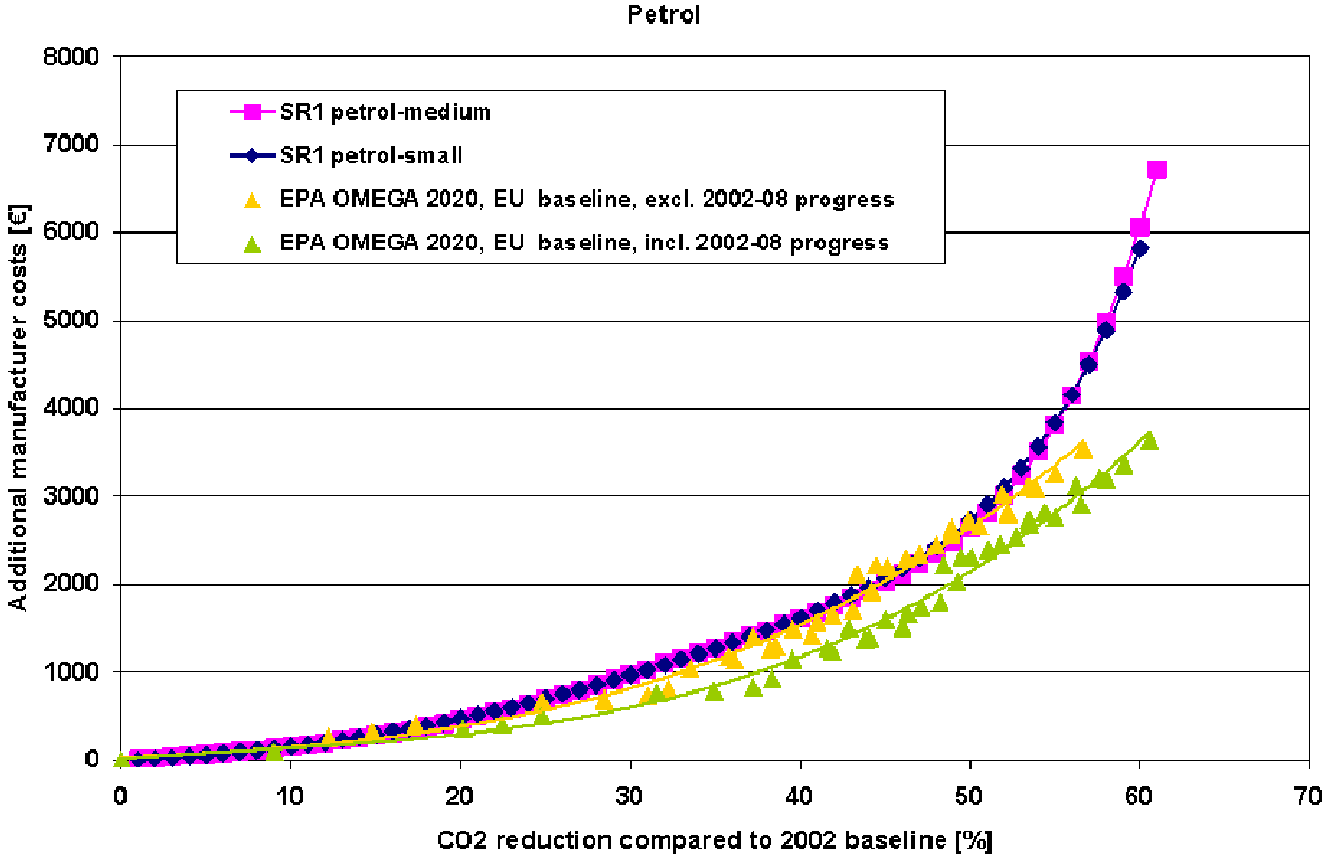
Scenario a) Alternative accounting for progress observed in the 2002-2009 period



Scenario b) Alternative cost curves based on a modified technology table

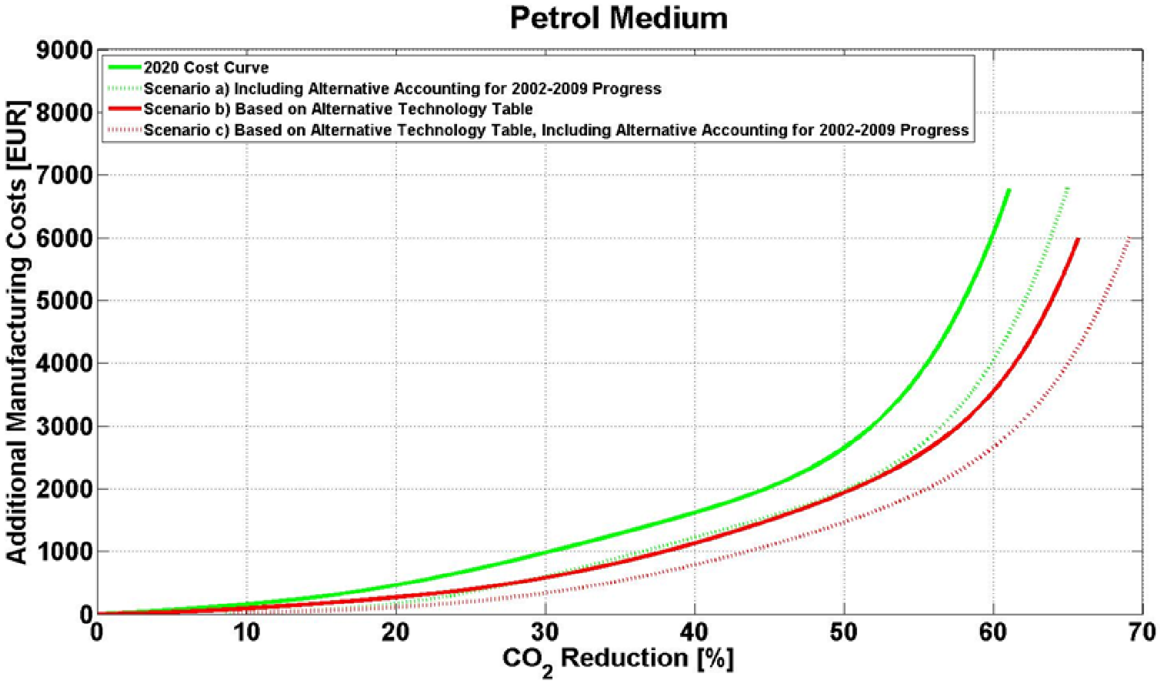
- Available results from EPA studies in support of US CO_2 target for passenger cars provide strong indications that costs for meeting the EU 95 g/km target for 2020 could be lower than the estimates based on the cost curves from this study.
- Due to large differences in technology definitions, baseline vehicles and drive cycles, however, the direct use of EPA data for the European assessment was considered not appropriate.
- To test the possible impact of the most striking differences between US and EU data a selection of data derived from the EPA studies, specifically for **full hybrids and the various levels of weight reduction**, has been used to construct a modified technology table. Alternative cost curves have been constructed on the basis of this table.
- More in-depth assessment needed as soon as complete EPA data are available.

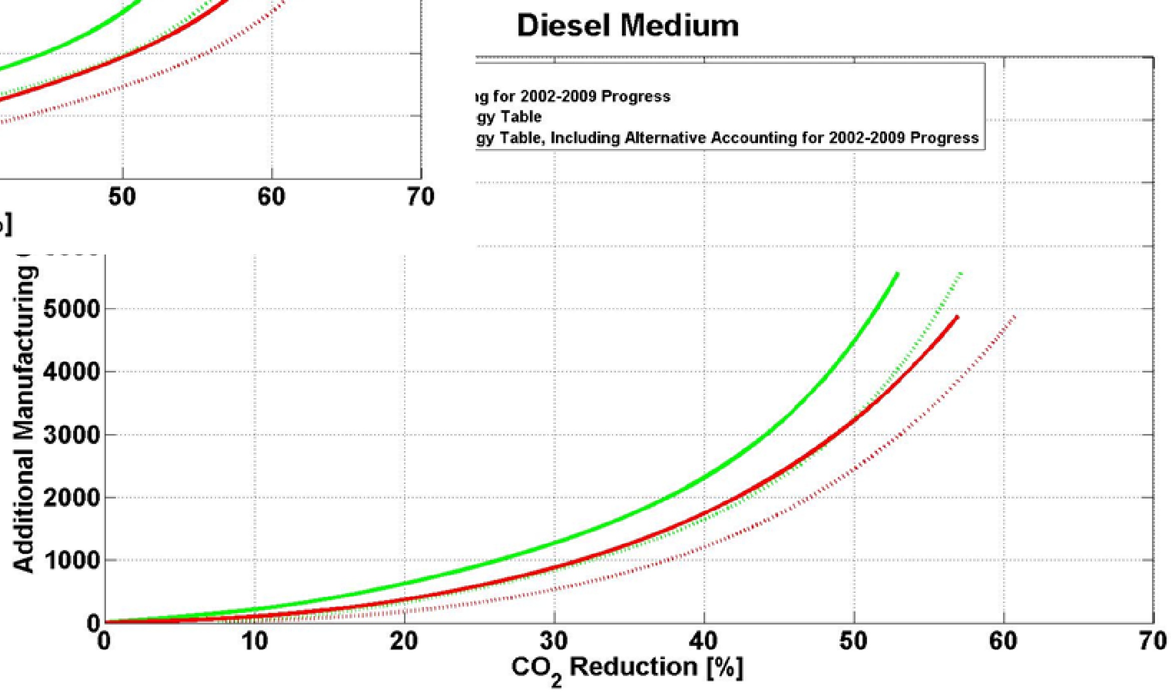
Scenario b) Alternative cost curves based on a modified technology table



Assumptions for translating EPA data to EU baseline:
- EPA data for 2020 considered applicable to EU 2020
- DCT brings AT to efficiency level of 5sp MT
- DCT is 10% (8 -13%) more efficient and $170 cheaper than 4sp AT
- no additional potential for moving from 5sp MT to 6sp DCT
- 2002-08 progress: 9% for €100

Scenario a), b) and c): Comparison of cost curves





Conclusions wrt cost curves

- Cost curves created for 2020, which, compared to cost curves for 2015:
  - show lower costs for same reduction
  - provide larger reduction potential at higher costs
  - show stronger non-linearity
    - marginal costs more strongly increasing at higher reductions

- Scenario variants created to assess possible impacts of indications that costs for meeting 2020 may be lower than expected from SR1 cost curves

Assessments with respect to the attainability of the 2020 target

- Current state-of-the-art technologies
- Compatibility of model cycles

Current state-of-the-art technologies for passenger cars

- Many options included in the technology tables are already applied in the market today, especially in so-called "eco-models"
- A review has been carried out to identify and analyse the lowest emitting vehicles on the market in the B-, C- and D-segments compared to equivalent 'standard' models

- Large variation found in price and CO_2 emission differentials, also relative to estimates based on technology tables
  - Pricing strategies possibly affected by tax regimes

- Costs of technologies can not be derived from available price information

Evaluation of model cycles

- Product development process can vary from 18 months to up to 5 years
- On average vehicle models have a platform change every 6 – 8 years
  - are refreshed with face-lift 2-4 years after a platform change
- Engine platforms have a long lifespan, typically 10 – 15 years
  - during that time will have minor or major upgrades and additional variants added

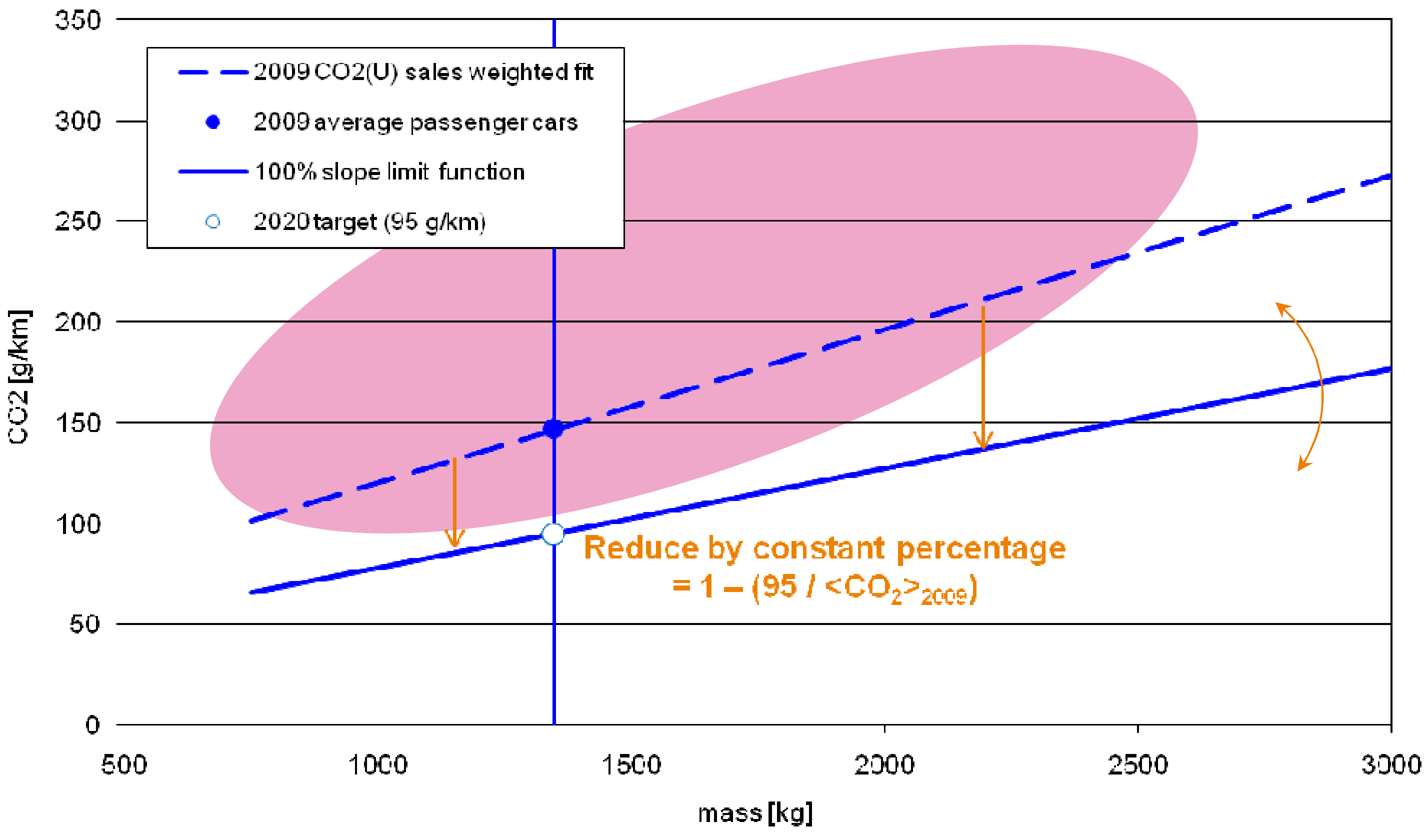
- The analysis indicates that OEM development cycles are well timed to meet planned introduction dates of noxious emissions but currently less aligned to the planned 95 g/km CO_2 target in 2020
  - potential need for 95 g/km CO_2 legislation to be finalised as early as possible and as a minimum 5 years before its implementation date
  - will provide certainty for OEMs and enable them sufficient time to consider it in their vehicle and engine cycle plans whilst they are not heavily detailed and the product development processes are not yet underway
  - but tension does not appear insurmountable

Evaluation of alternative utility parameters and different types of utility-based limit functions

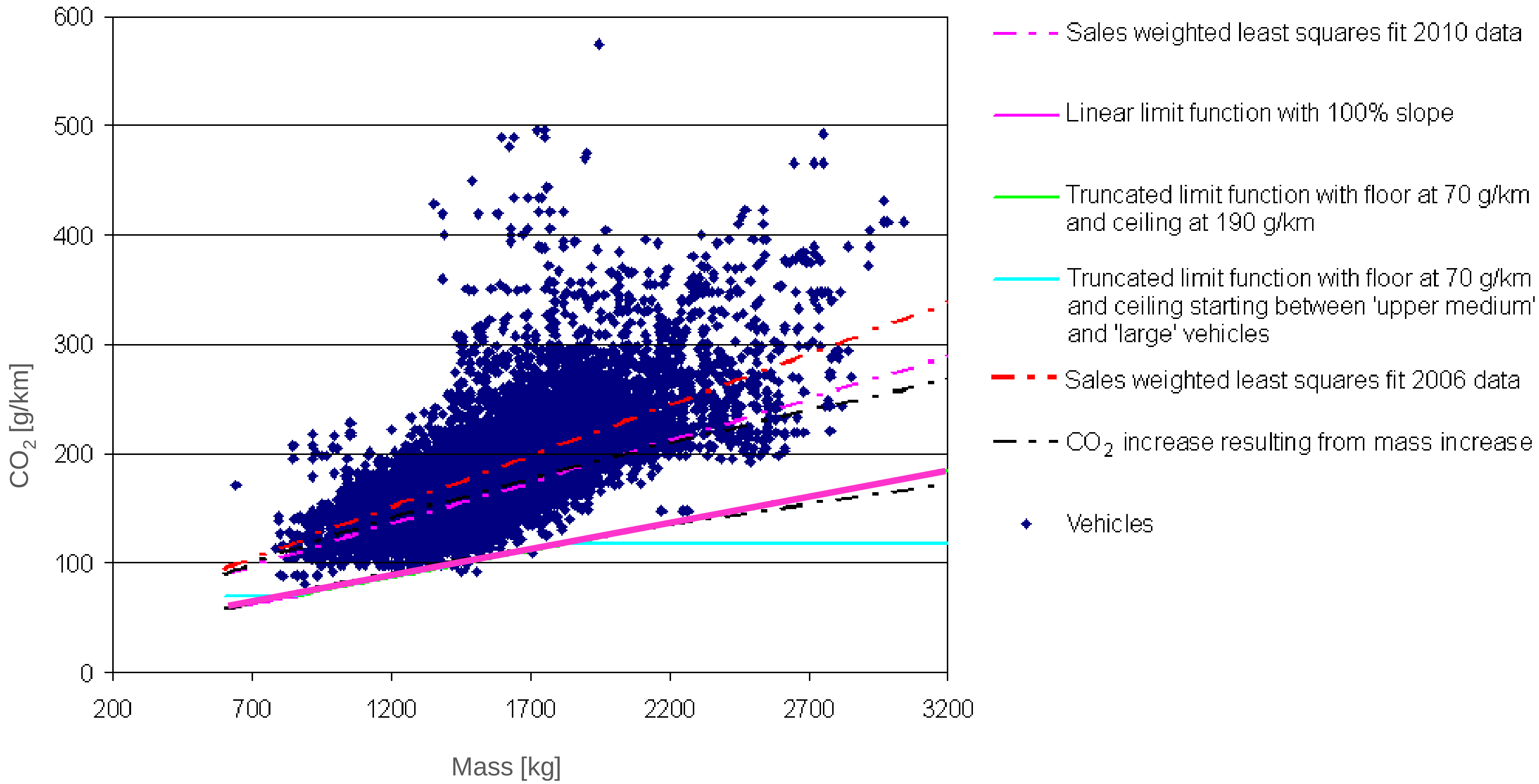
- Mass and footprint
- Other alternative utility parameters (see report)
- Linear and alternatively shaped limit functions

Framework Contract on Vehicle Emissions
ENV.C.3./FRA/2009/0043
Service request #1

Method of determining the 100% slope utility-based limit functions



Mass as utility parameter



- Significant progress from 2006 – 2010
- 100% slope limit function is already quite flat
- Floor and ceiling can not be defined in a meaningful way
  - Unrealistic values needed to affect significant number of vehicles

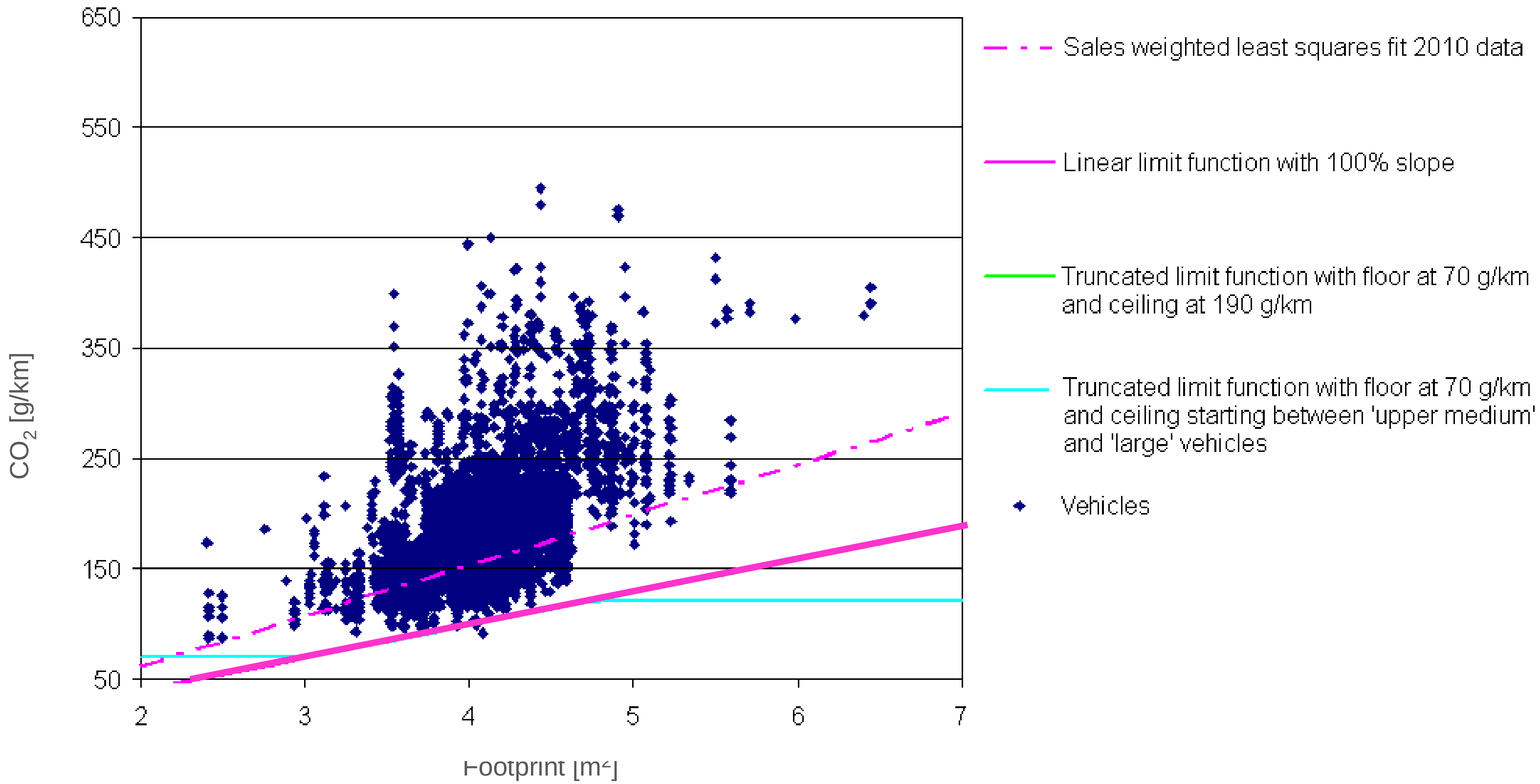
Reference mass

+ Easily / objectively measured
+ Accepted by industry
  - continuation of present system
  - (part) of industry seems in favour of using mass also for 95 g/km
+ Good correlation with CO_2

o …

- Not a measure of utility
- Possibilities for gaming depend on slope of limit function
  - 100% slope for 95 g/km target is flatter than 60% slope for 130 g/km target
  - Lower slope may lead to difficulty in meeting target for manufacturers of large cars (larger share of total reduction potential used)
- Easy options for gaming: “Brick in the boot”
- Makes weight reduction as CO_2 reduction measure less attractive
  - unless limit function is continually updated on basis of changing average mass
  - but effect of applying weight reduction measures may be masked by autonomous mass increase…

Footprint as utility parameter



- Footprint also has good correlation with CO_2
- Floor and ceiling can not be defined in a meaningful way
  - Unrealistic values needed to affect significant number of vehicles

Footprint (wheelbase x track width)

- \+ Easily / objectively measured
- \+ Better proxy for utility than mass
  - See # of seats + trunk volume: true utility may not provide a solid basis for CO_2 differentiation
- \+ Used in US legislation
- \+ Gaming is considered relatively difficult due to required changes in structural design of vehicle and associated consequences for mass and vehicle CO_2 emissions
  - Footprint is not necessarily better than weight with respect to avoiding all possibilities of perverse incentives, but possibilities of cheap gaming options are much reduced.
  - Possible impact of changing footprint on CO_2 is weaker than for mass so does not provide better threshold against gaming or perverse incentives than mass.
  - But the scale of the perverse incentives appears much less as utility can only be increased by effectively increasing the size of the vehicle, with all the cost and complexity that that entails, and resulting in what is essentially a different vehicle.
  - Also, incremental increases in footprint result in proportionately smaller increases in CO_2 emissions than increases in weight, so the adverse environmental impact is less.
- \+ Good correlation with CO_2
- o …
- \- Relatively tough on compact / high cars (e.g. MPVs)
- \- May promote tendency towards larger cars
  - This can be compensated by adjusting limit function for growth in average footprint.

Conclusions on utility parameters and limit function

- Main options for utility parameter:
  - **mass** and **footprint**
  - both to be used for detailed cost assessment

- Limit function
  - Floor and ceiling can not be defined in a meaningful way
    - Unrealistic values needed to affect significant number of vehicles
  - No reason to move away from **linear limit function**

Assessment of average additional vehicle costs per manufacturer for manufacturer-based modalities

- Average costs for meeting target
- Distributional impacts
- Marginal costs
- Impact of marketing EVs and PHEVs
- Impact of scenarios with alternative cost curves

Aspects of the cost assessment

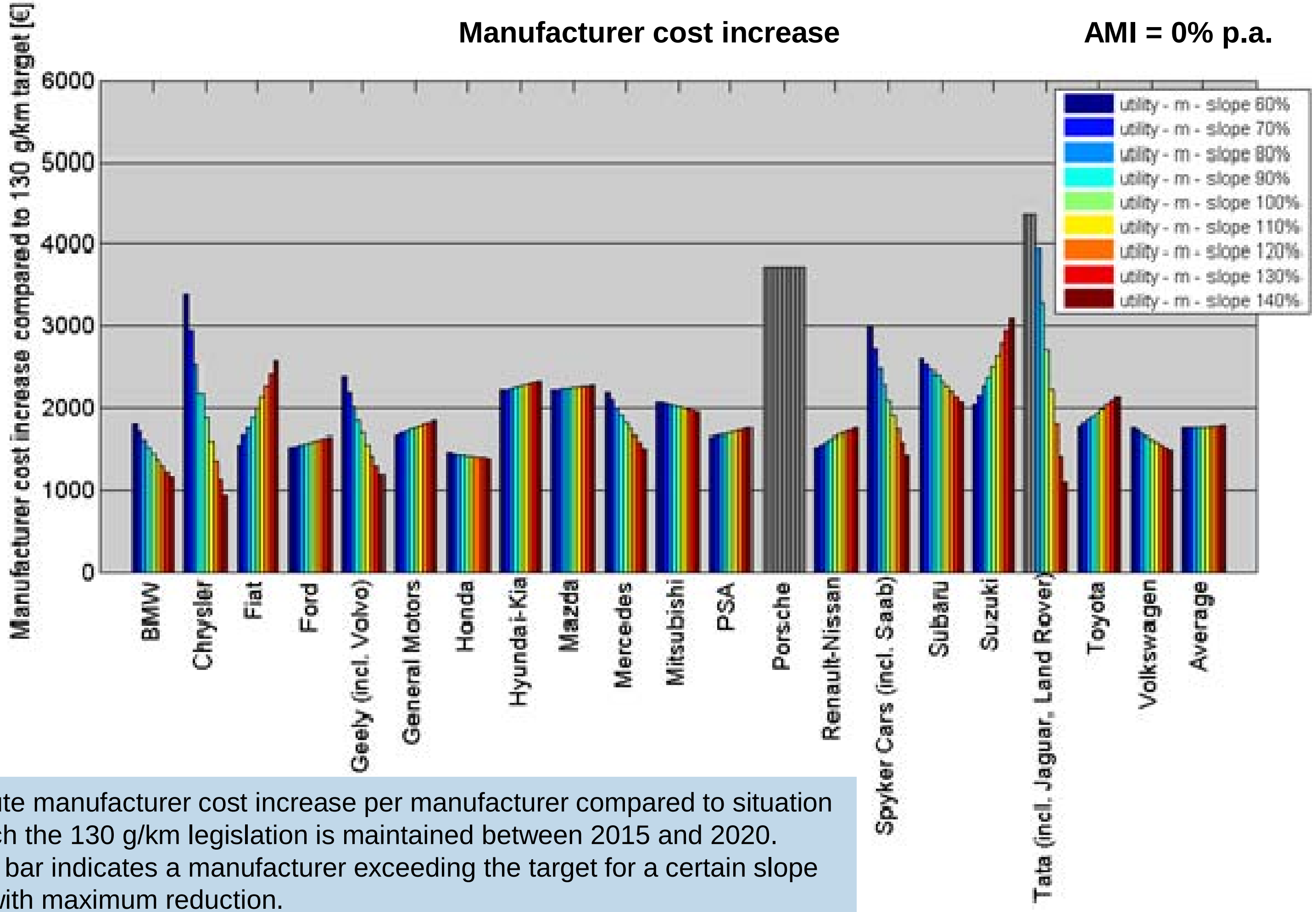
- Separate assessments for mass and footprint
  - For linear utility-based limit functions with different slopes
- Assessment of:
  - Average costs for meeting the target
  - Distributional impacts, i.e. costs per manufacturer
    - Absolute additional manufacturer costs per vehicles
    - Relative retail price increase
- Calculate cost differential relative to reference situation
  - 2009, based on database
  - 2020, with manufacturers maintaining individual targets under 130 g/km legislations between 2015 and 2020
    - Cost for meeting 130 g/km in 2020 based on 2020 cost curves
- Impact of introducing (PH)EVs

Cost assessment model for passenger cars

- All relevant manufacturer groups included
- Sales divided over 6 segments: petrol / diesel x small / medium / large
- Cost assessment methodology
  - Calculate target per manufacturer group
  - Account for effects of possible autonomous mass increase
  - Determine distribution of reductions that meets target at lowest additional manufacturer costs
  - Calculate cost differential relative to reference situation
    - 2009, based on database
    - 2020, with manufacturers maintaining individual targets under 130 g/km legislation between 2015 and 2020
      - Cost for meeting 130 g/km in 2020 based on 2020 cost curves

Distributional impacts – mass – 95 g/km in 2020

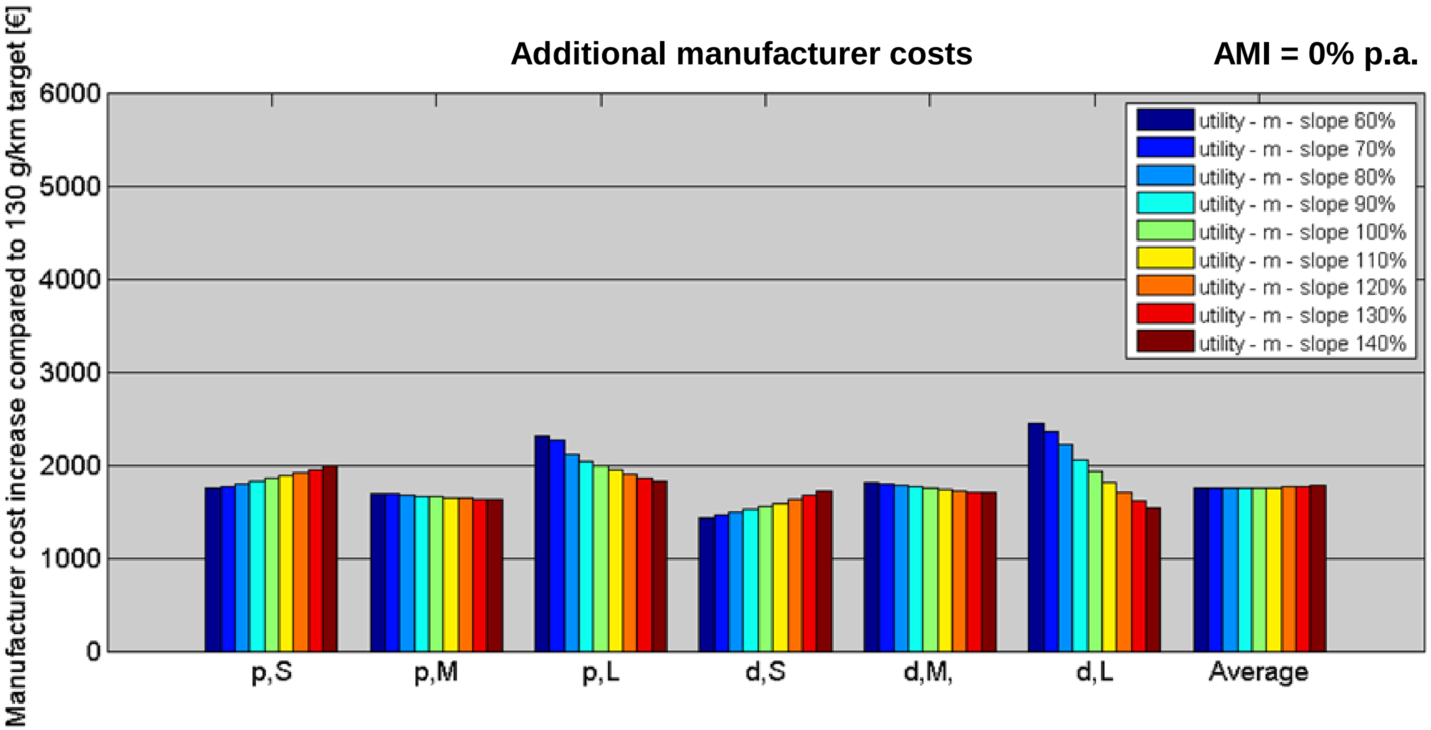
- Porsche not able to meet its 2020 target
- Problem for Tata with small slope values



- Absolute manufacturer cost increase per manufacturer compared to situation in which the 130 g/km legislation is maintained between 2015 and 2020.
- A grey bar indicates a manufacturer exceeding the target for a certain slope even with maximum reduction.

Distributional impacts – mass – 95 g/km in 2020

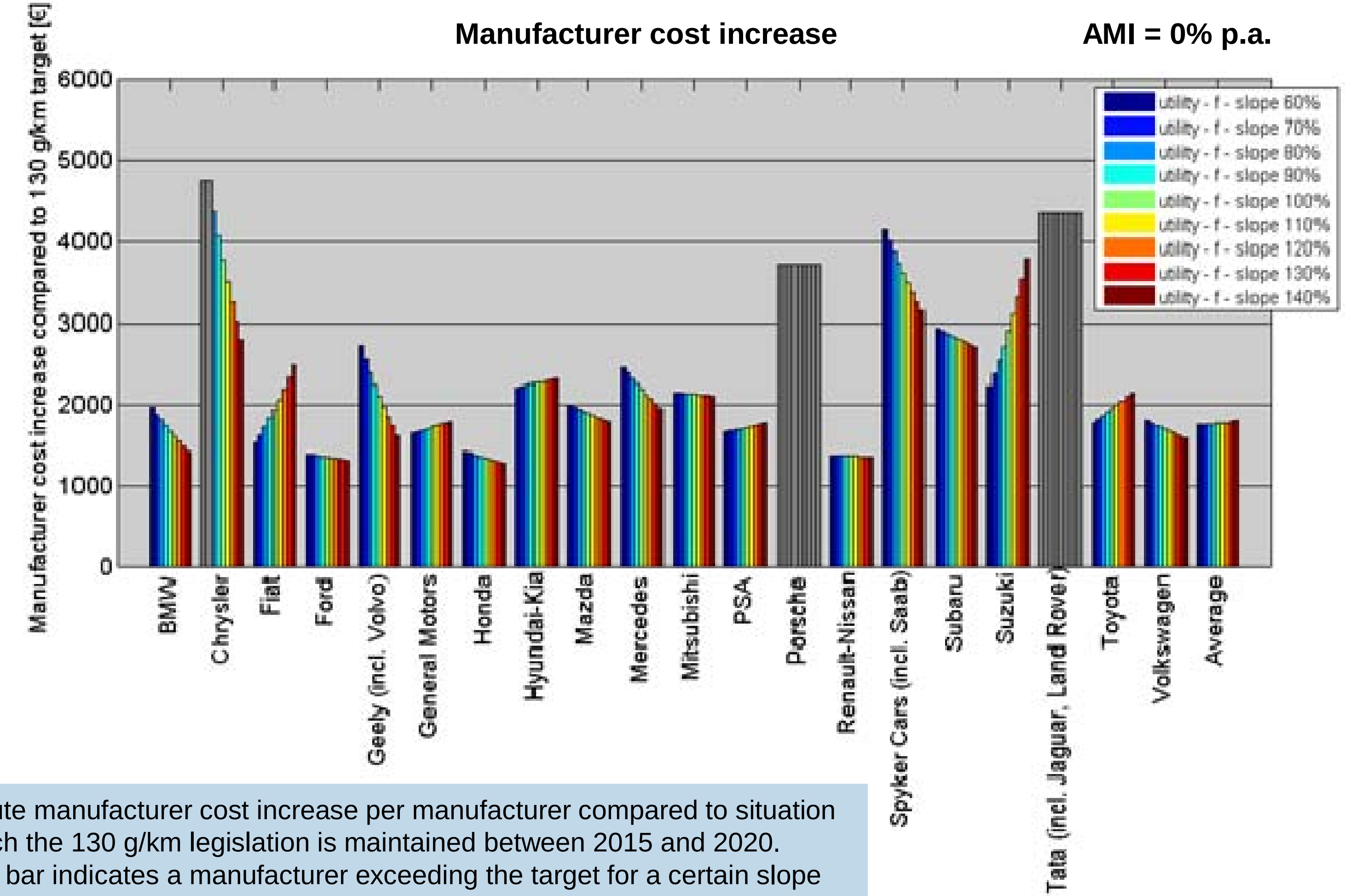
- Higher absolute costs for larger vehicles
  - But relative price increase largest for small vehicles



- Absolute manufacturer cost increase per manufacturer compared to the situation in which the 130 g/km legislation is maintained between 2015 and 2020.

Distributional impacts – footprint – 95 g/km in 2020

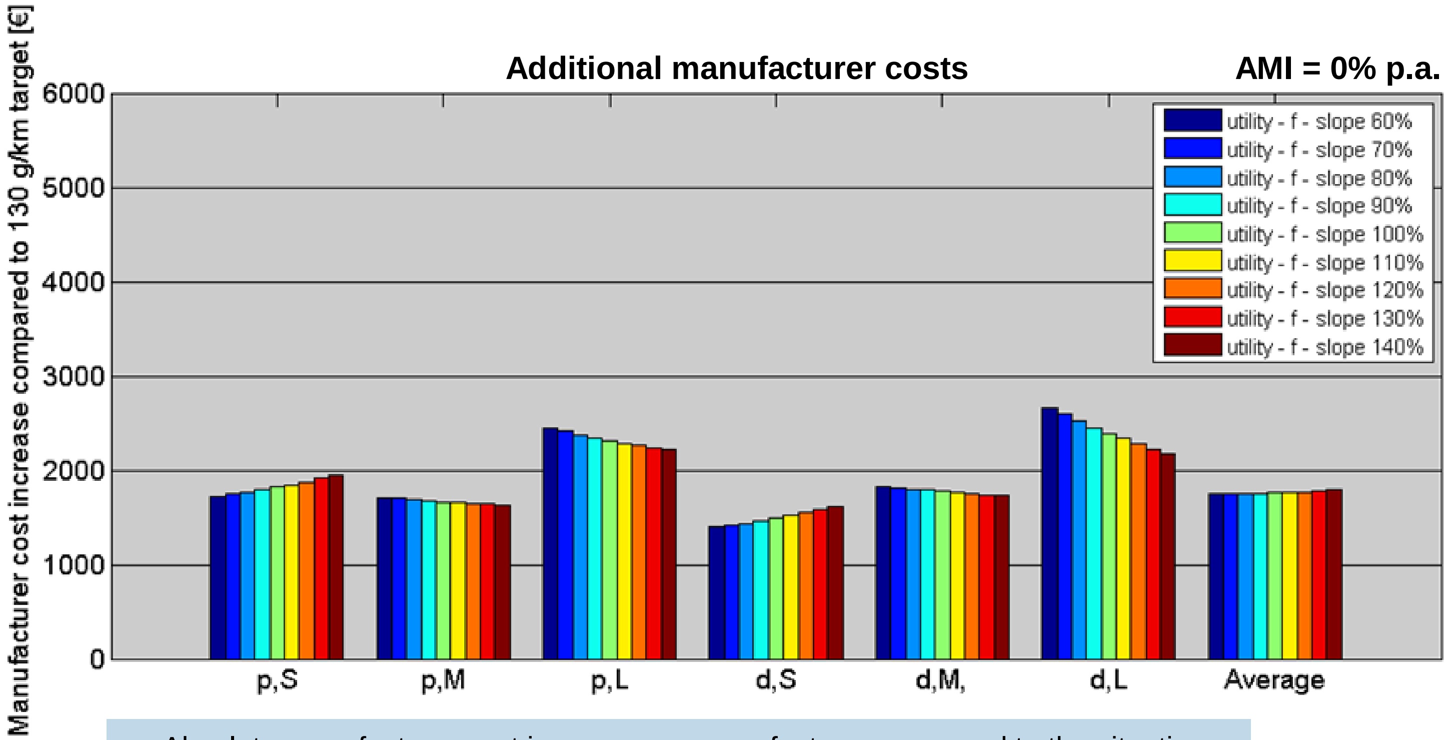
- Porsche + Tata not able to meet their 2020 targets
- Problem for Chrysler with small slope values



- Absolute manufacturer cost increase per manufacturer compared to situation in which the 130 g/km legislation is maintained between 2015 and 2020.
- A grey bar indicates a manufacturer exceeding the target for a certain slope even with maximum reduction.

Distributional impacts – footprint – 95 g/km in 2020

- Higher absolute costs for larger vehicles
  - But relative price increase largest for small vehicles
  - Costs for large vehicles slightly higher than in case of U = mass



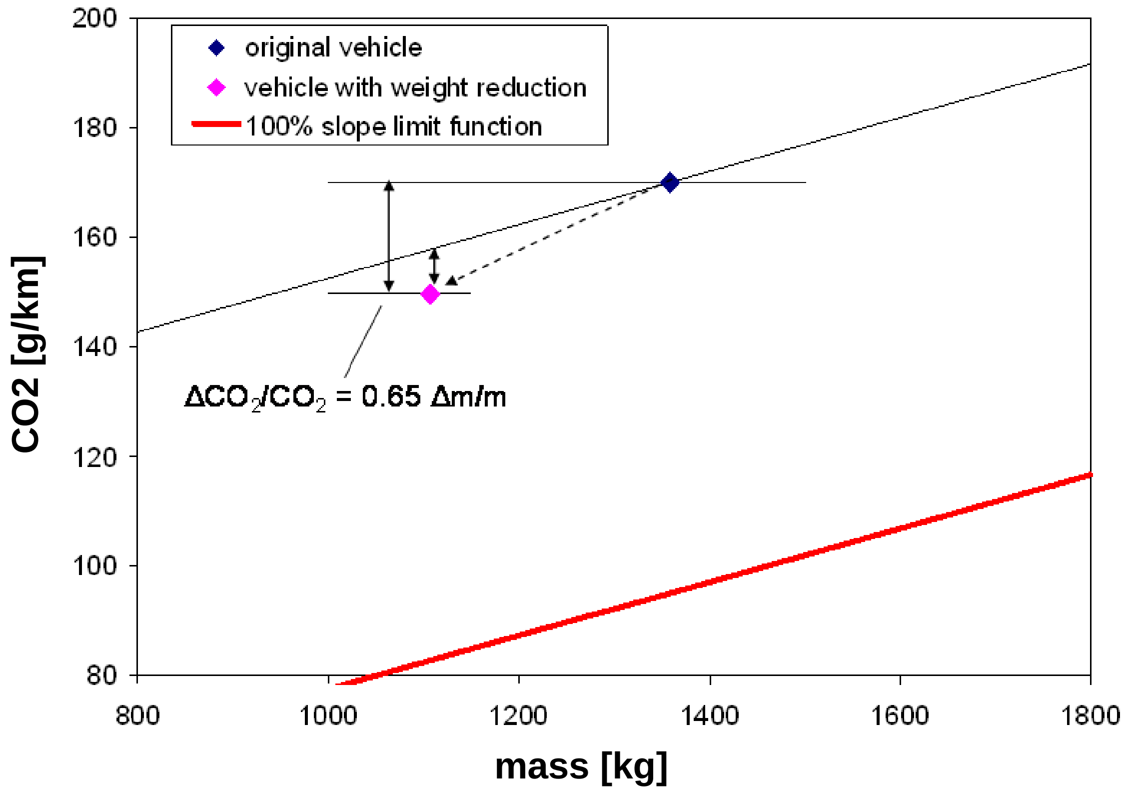
- Absolute manufacturer cost increase per manufacturer compared to the situation in which the 130 g/km legislation is maintained between 2015 and 2020.

Conclusions on costs and distributional impacts

- Cost of meeting 95 g/km (additional manufacturer costs):
  - ~1750 €/vehicle relative to maintaining 130 g/km between 2015-2020
    - equivalent to ~11% relative price increase
  - ~2190 €/vehicle relative to 2009
- Costs for footprint-based target marginally (10 €) higher than for mass
  - Result of different distribution of efforts
  - Reduced effect of weight reduction in case of U = mass is not accounted for in cost curves => see next slides
- For footprint more manufacturers run risk of hitting ceiling of cost curves

- Distribution of relative price increase more even for slopes < 100%

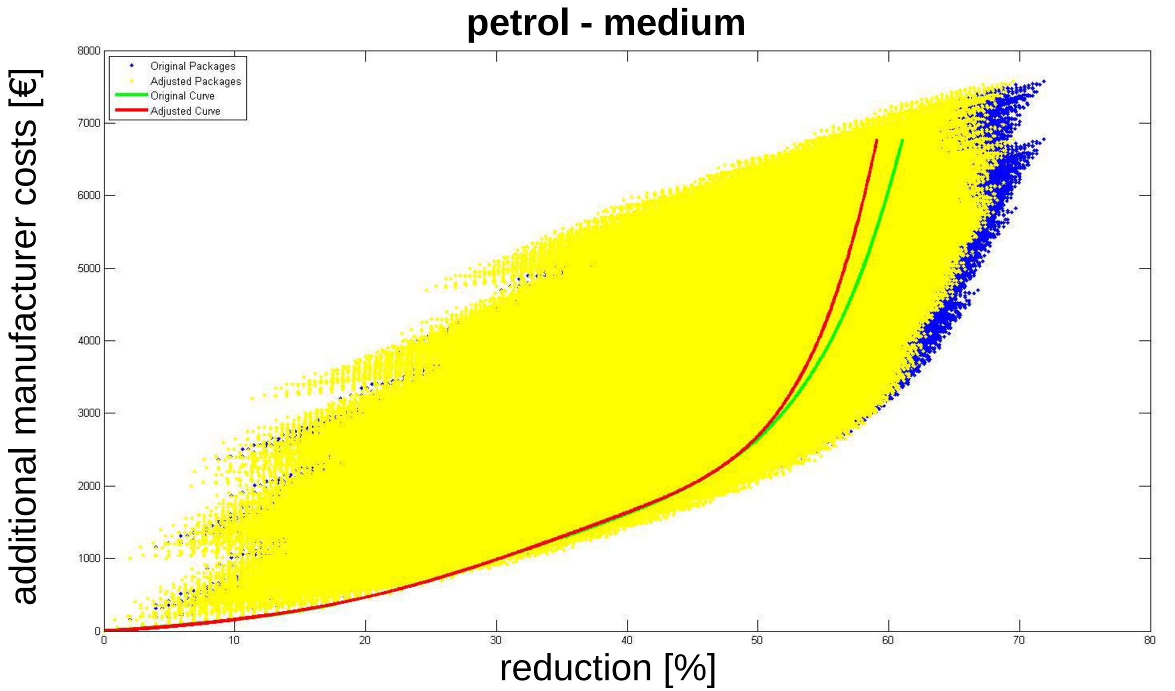
1st order estimate of effect of reduced cost effectiveness of weight reduction in case of mass as utility parameter



› Reduction in distance to target is less then CO_2 reduction

1st order estimate of effect of mass as utility parameter on cost for meeting target

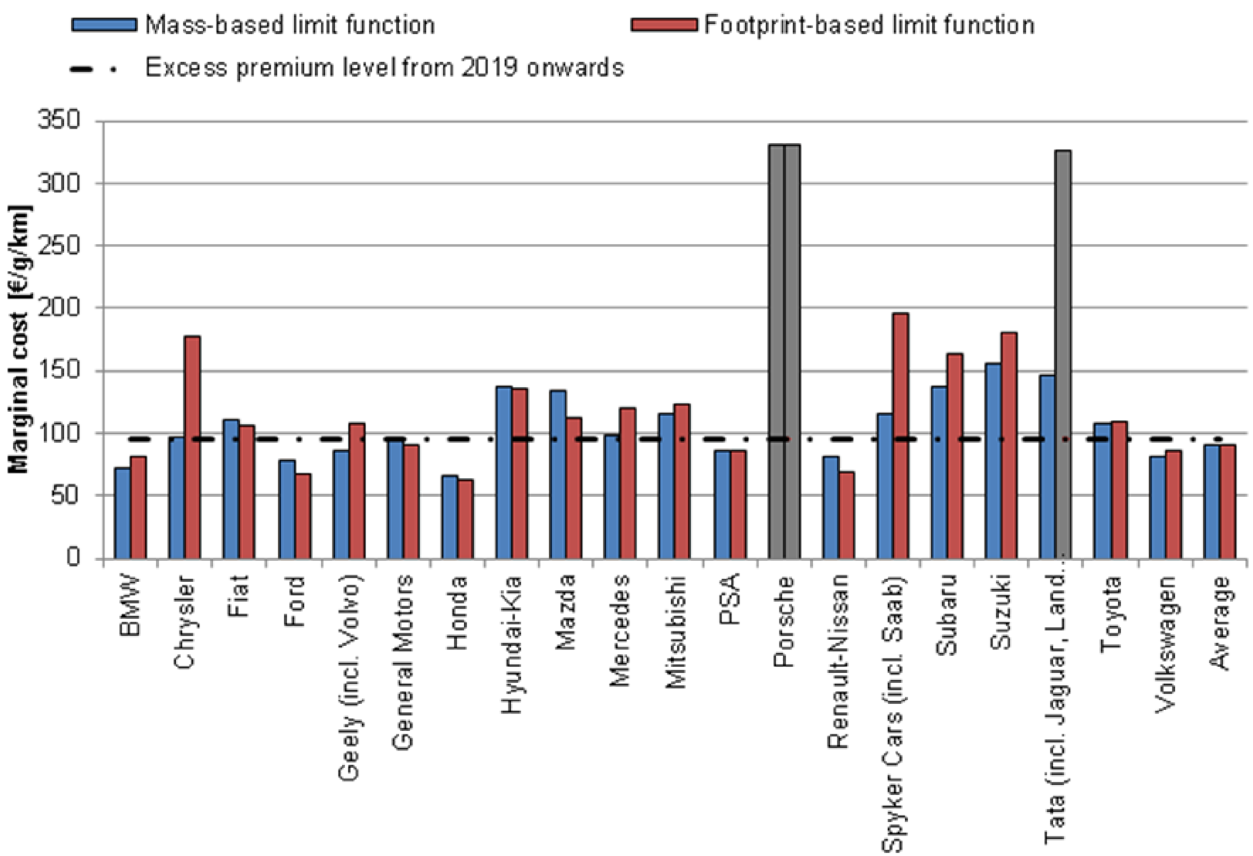
- Amended cost curves reflecting reduced effectiveness of weight reduction for U = mass start to deviate from original cost curves in region of required reduction levels for meeting 2020 target



- Average costs for meeting 95 g/km target with 100% slope increase from € 2188 to € 2249 (difference € 61)

Marginal costs – implications for excess premiums

- Excess premium can be based on marginal costs of meeting target
- 95 € per g/km could be maintained beyond 2020



Impact of introducing (PH)EVs

Utility parameter = mass Slope = 100%	Baseline scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4 (TNO)
Scenario characteristics					
Sales share FEVs	0.0%	0.8%	0.3%	1.7%	10.0%
Sales share PHEVs	0.0%	3.4%	1.8%	6.2%	0.0%
Sales share EREVs	0.0%	1.2%	0.5%	2.3%	0.0%
Total sales share EVs	0.0%	5.5%	2.7%	10.2%	10.0%
Average CO_2 emissions per EV [g/km]	-	48	45	47	0
Scenario impact on ICEVs					
Sales share of ICEVs	100%	94.5%	97.3%	89.8%	90.0%
Average ICEV emissions to reach 95 g/km [g/km]	95	97.7	96.4	100.5	105.6
Results					
Average additional manufacturer cost per EV [€]	-	5302	5186	5358	8323
Average ICEV costs to meet target ICEV [€]	2188	1952	2061	1741	1420
Average overall costs to meet 95 g/km target [€]	**2188**	**2136**	**2145**	**2110**	**2111**

- Cost = absolute manufacturer cost increase relative to 2009 reference situation

- Cost savings on ICEVs outweigh additional costs of (PH)EVs
  - 95 g/km target provides (small) net incentive for marketing (PH)EVs
- Super credits:
  - further increase the fleet-wide WTW CO_2 emission relative to situation without (PH)EVs
  - do not seem necessary as additional stimulation measure

Impact of scenarios with alternative cost curves

- a) Alternative accounting for progress observed in 2002-2009 period
- b) Alternative cost curves based on a modified technology table with data from EPA studies
- c) Combination of a) and b)

Utility parameter	Slope	Additional manufacturer cost relative to 130 g/km target [€] based on 2020 cost curves	based on "Scenario a)"	based on "Scenario b)"	based on "Scenario c)"
Mass	60%	1748	1159	1280	765
	100%	1750	1158	1277	760
Footprint	60%	1754	1164	1290	775
	100%	1760	1168	1294	772

- Scenario a) and b) lead to ~ 500 - 600 € lower costs
- Scenario c) leads to ~ 1000 € lower costs
- Results for the scenarios a) to c) would change the conclusion from the assessment of impacts of introducing EVs by 2020.

Conclusions wrt modalities including results of cost assessments

Choice of utility parameter

Mass vs footprint

Reference mass	
Pros	**Cons**
Easily / objectively measured	Not a direct measure of utility
Accepted by industry (continuity with current legislation)	Possibilities for gaming depend on slope of limit function
Good correlation with CO_2 emissions	Easy options for gaming: "Brick in the boot"
	Makes weight reduction as CO_2 reduction measure much less attractive

Footprint	
Pros	**Cons**
Easily / objectively measured	Relatively tough on compact / high cars (e.g. MPVs)
Gaming is considered relatively difficult due to required changes in structural design of vehicle and associated consequences for mass and vehicle CO_2 emissions	May promote tendency towards larger cars unless compensated for such autonomous footprint increase
Better proxy for utility than mass	
Used in US legislation	
Good correlation with CO_2 emissions	

- No arguments to favour one over the other from assessments of
  - average costs and distributional impacts
  - impact of (PH)EVs
  - impact of additional provisions

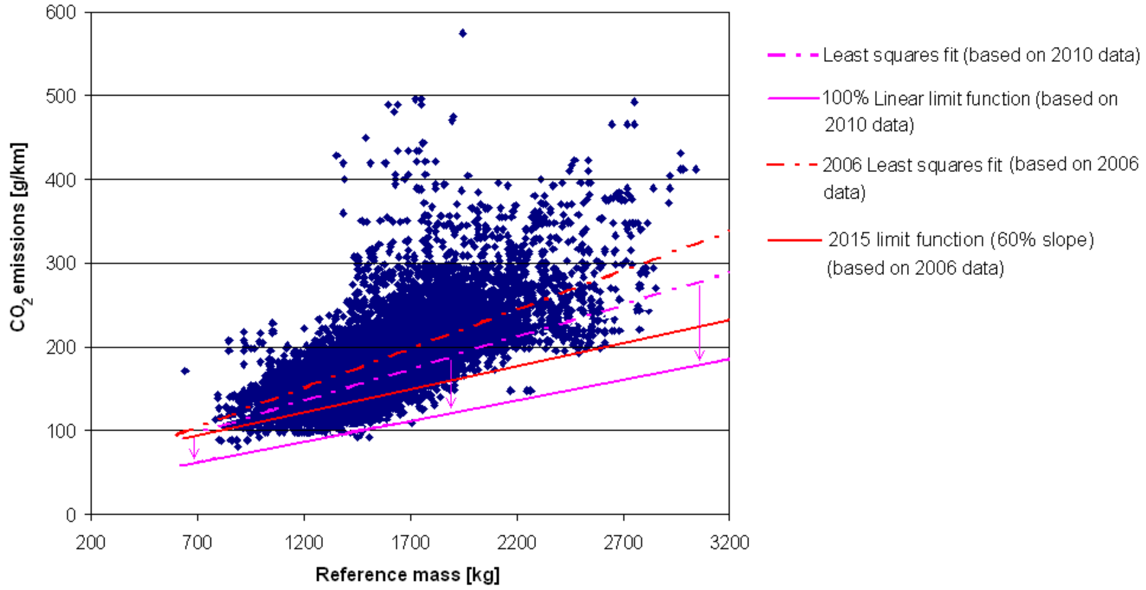
Choice of utility parameter

Mass vs footprint

- Arguments in favour of footprint
  - Mass reduction will be an important measure for future CO_2 reduction beyond 130 g/km. Mass as a utility parameter makes this option unattractive.
  - Since footprint is a much better proxy for vehicle size and resulting utility than mass, footprint seems favourable from a consumer perspective.
  - Consistency with US legislation

Limit function

- No reason to move away from linear limit function



Slope of limit function

- 100% slope for 2020 is flatter than 60% slope for 2015
  - So no flattening needed to counteract gaming with mass
- Flatter slope could be justified for reason of equalising burden over manufacturers and segments

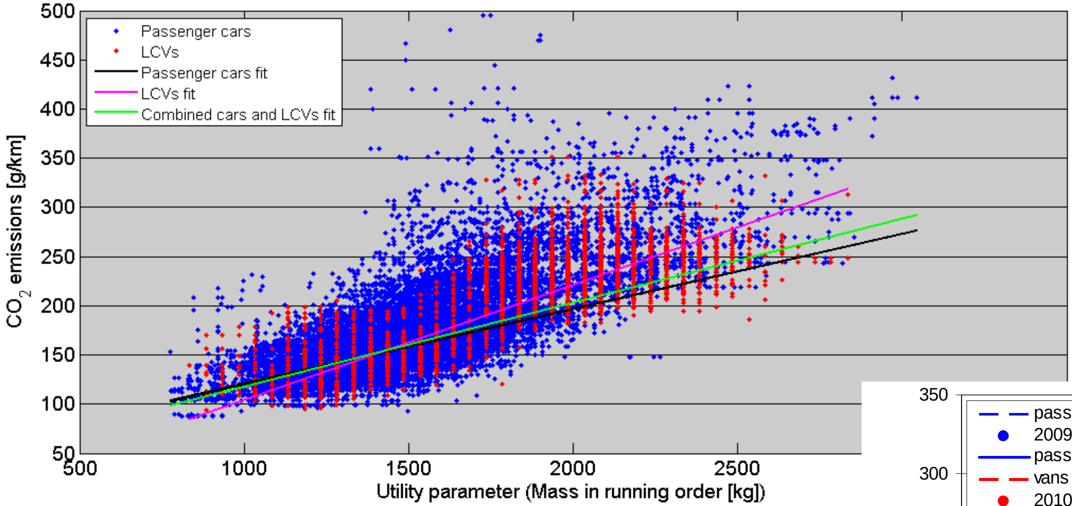
Questions

?

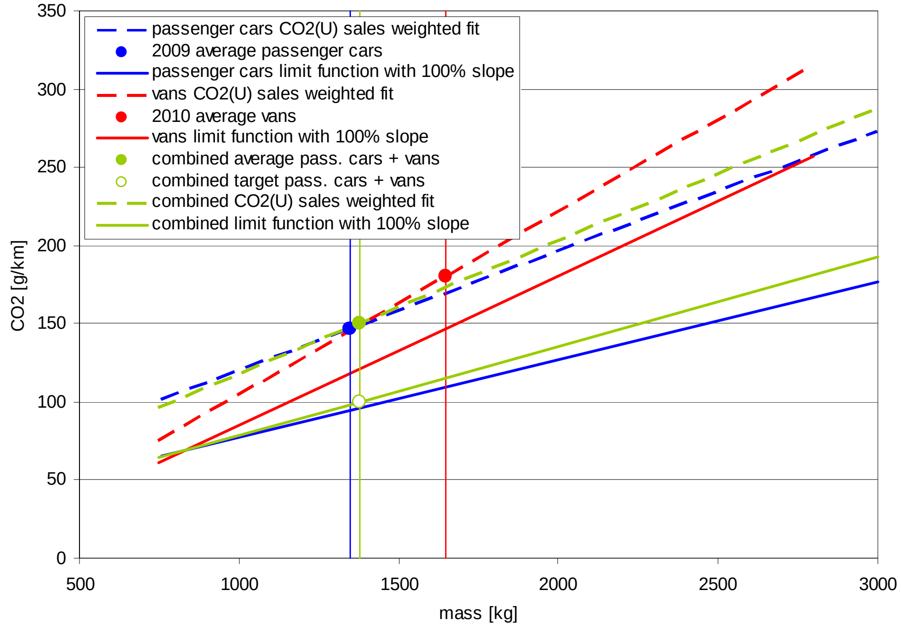
Conclusions regarding possible additional measures and provisions

- Combined target for passenger cars and vans
- Stepwise approach to target
- Mileage weighting
- Additional vehicle-based target

Impacts of a combined target for passenger cars and vans - mass

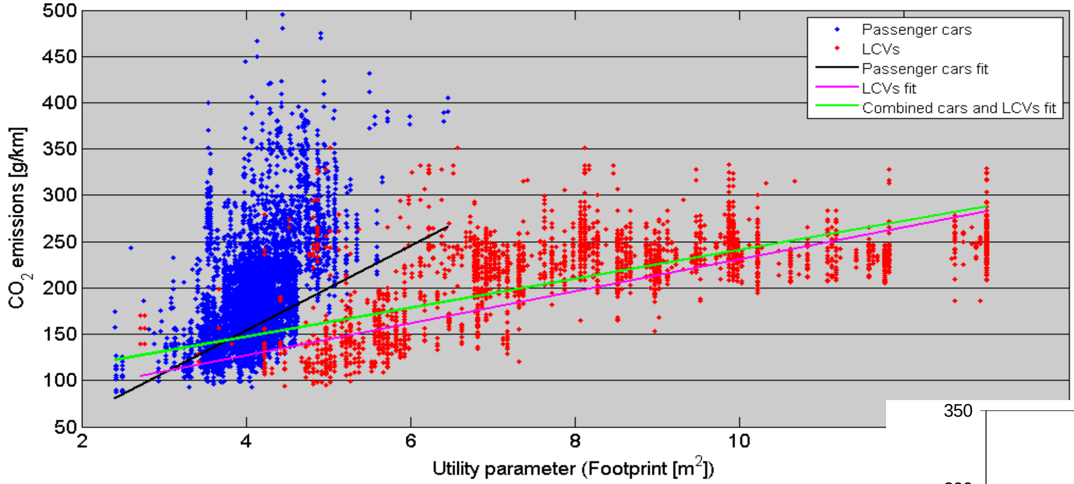


U = mass



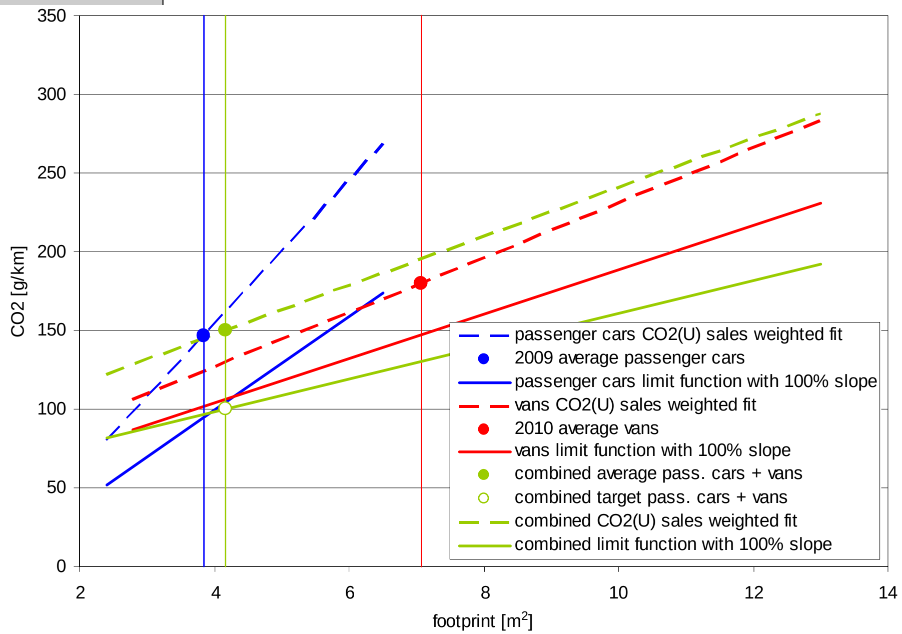
- Combined target close to limit function for passenger cars
- Difficult / impossible to attain for medium-size vans

Impacts of a combined target for passenger cars and vans - footprint

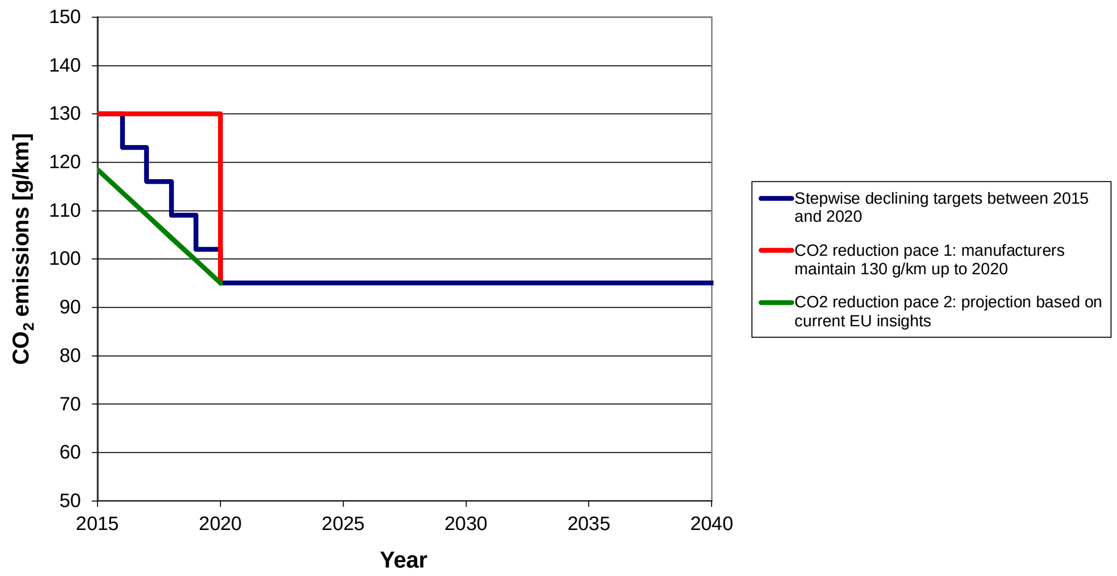


U = footprint

- Combined target close to limit function for vans
- Difficult / impossible to attain for large passenger cars
- Also more stringent for large vans



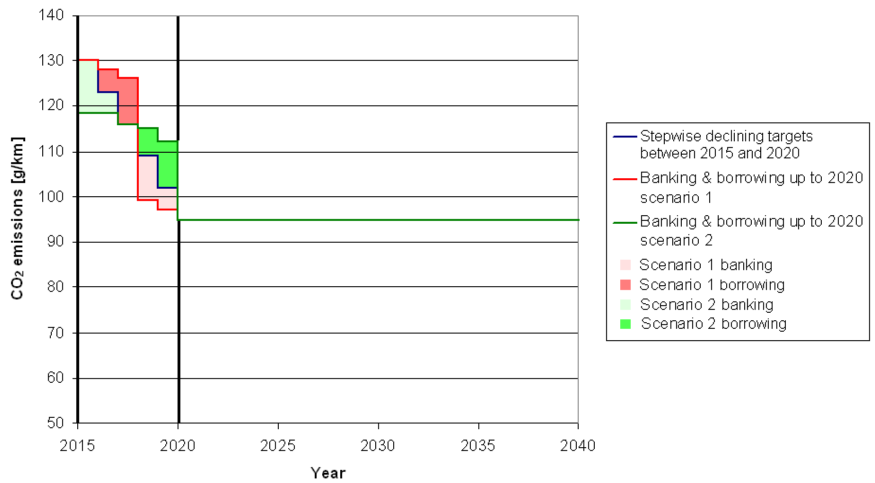
Consequences of establishing a trajectory of declining annual target values from 2015 to 2020



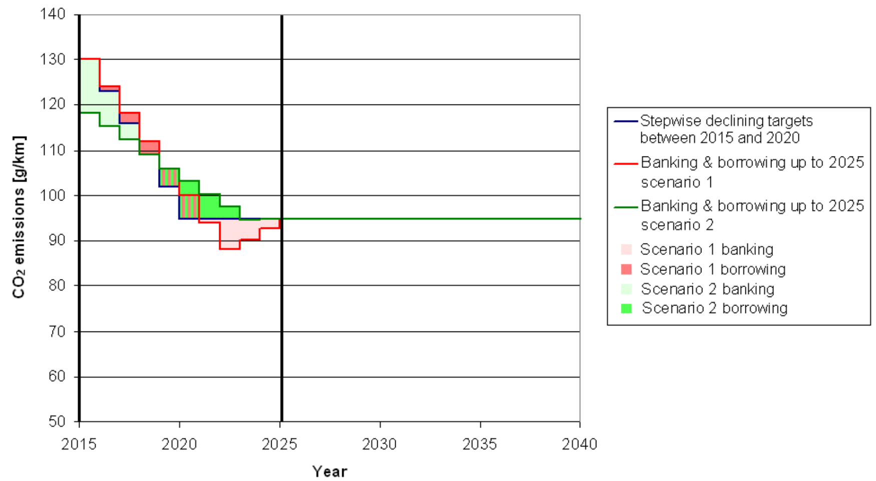
- Avoids additional total fleet CO_2 emissions due to late approach towards 2020 target
  - Effect < 3%, but still equivalent to increasing target by 3 g/km
- Enhances probability of manufacturers meeting their 2020 targets
- But requires banking and borrowing to create sufficient flexibility

Consequences of introducing provisions for banking and borrowing

Neutralise debits/credits before 2020



Neutralise debits/credits before 2025



- Total impact on the CO_2 emission in 2015-2040 is small
- Borrowing CO_2 credits prior to banking increases the net costs of meeting the target averaged over a longer time period
  - Allowing banking does not create incentive to postpone reductions
- To reduce risks a maximum amount of borrowed CO_2 credits can be considered.

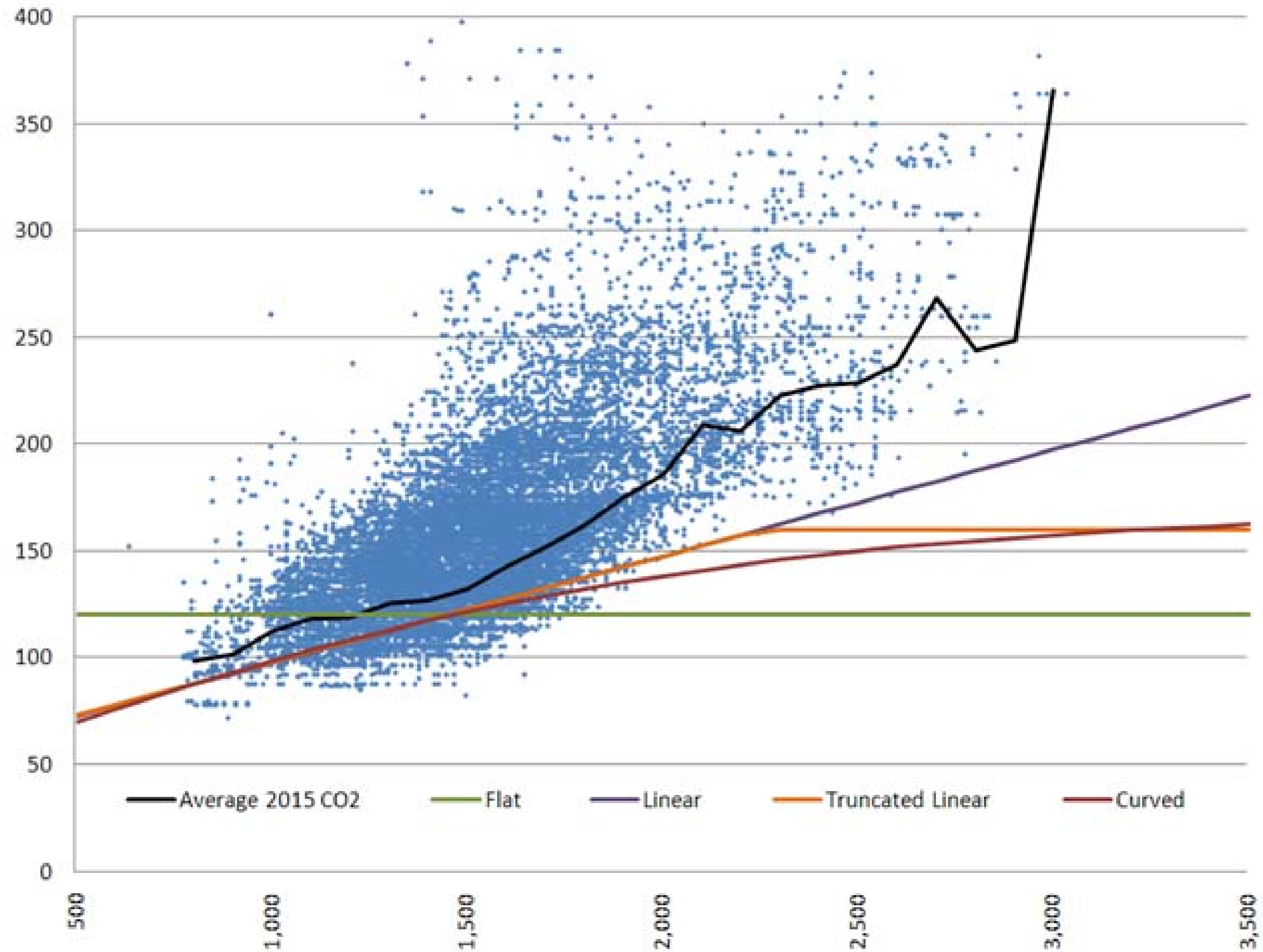
Consequences of mileage weighting

- Requires relations between lifetime mileage and utility
  - Separate for petrol and diesel
  - Possibly per manufacturer
  - How to establish undisputable numbers?
- Can be based on
  - existing utility-based limit curve (derived from sales-weighted fit) or
  - limit curve derived from sales + mileage weighted fit
- Mileage weighting
  - makes net lifetime GHG emissions from new cars insensitive to way in which manufacturers choose to divide reduction efforts over models / segments
  - can improve efficiency in reaching EU GHG emission targets
- More study needed
  - Consequences of using a limit function based on mileage weighting

Vehicle type	Lifetime mileage [km]
PCDL	444,662
PCDM	362,316
PCDS	379,465
PCGL	300,347
PCGM	285,222
PCGS	250,952

Based on FLEETS

Assessment of impacts of additional vehicle-based CO_2 limit



Assessment of impacts of additional vehicle-based CO_2 limit

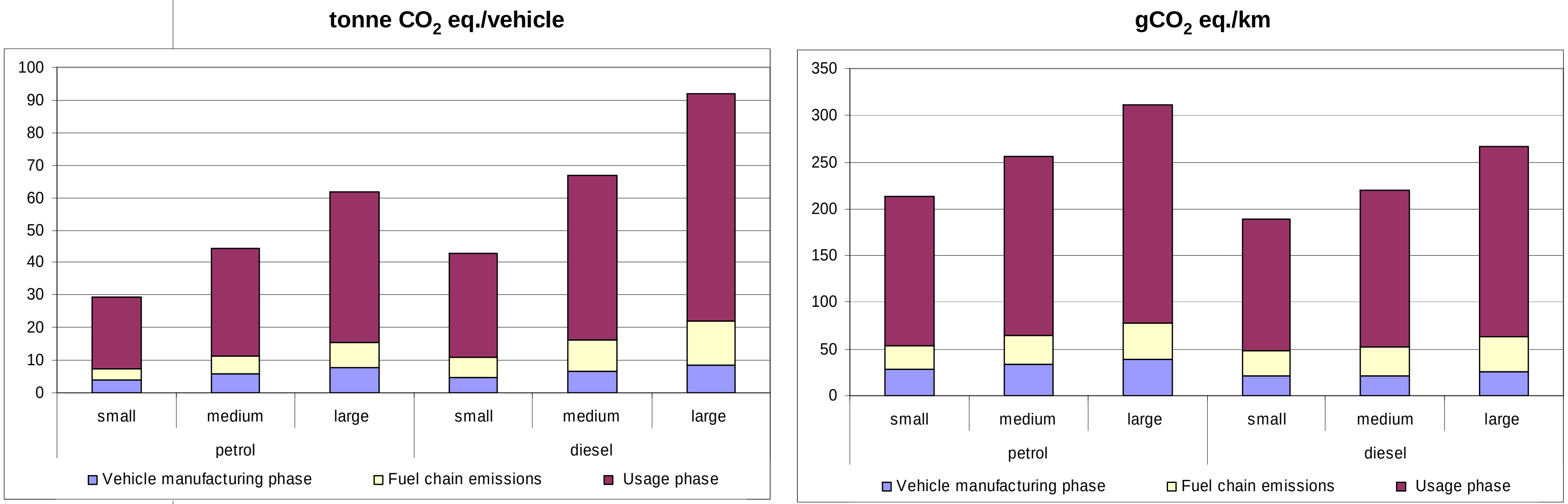
- Vehicle-based CO_2 limits in addition to sales-average target
  - With buy-out premium for vehicles sold that exceed limit
- Feasible to incorporate into emissions reduction legislation
- Could make a useful contribution towards achieving the overall 95 gCO_2/km target
- Of options considered a linear sloped limit is most cost effective

Conclusions with respect to additional issues affecting the impacts of CO_2 legislation for passenger cars

- CO_2 emissions of various life-cycle aspects
- Rebound effects
- Note on costs and prices

CO_2 emissions of various life-cycle aspects

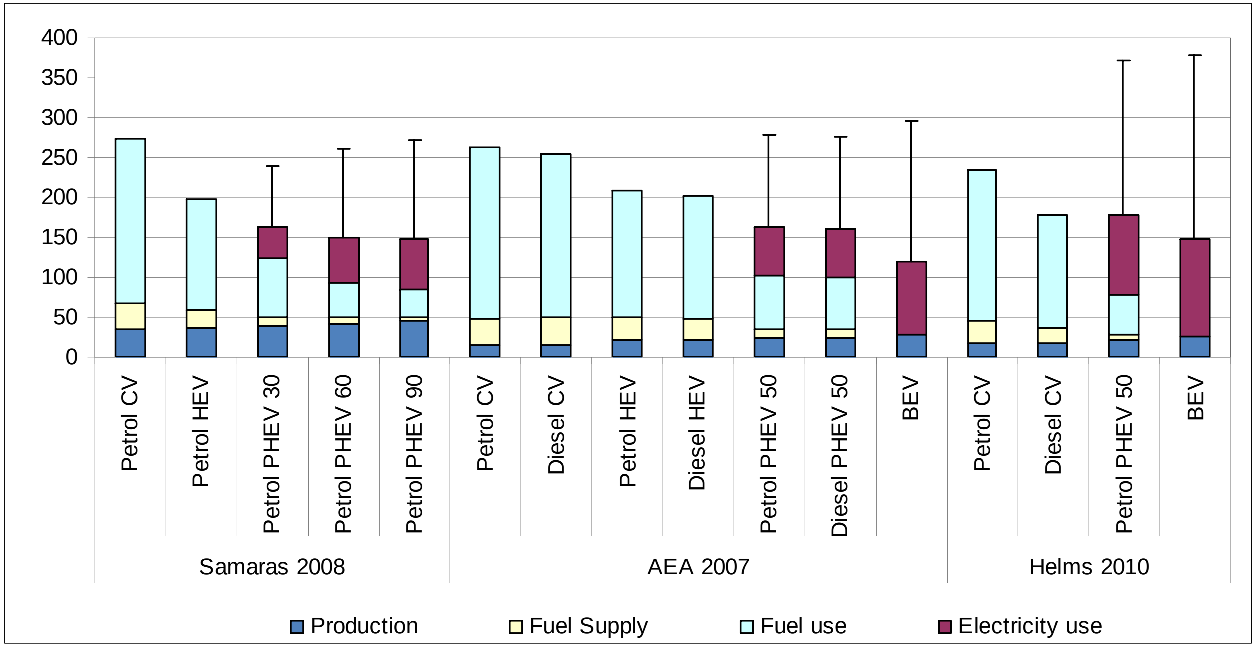
Contribution of different life cycle phases to the total life cycle GHG emissions



- Efficiency improvements due to CO_2 legislation more than outweigh additional emissions from manufacturing phase
- Light-weight materials do not increase CO_2 emissions from vehicle production

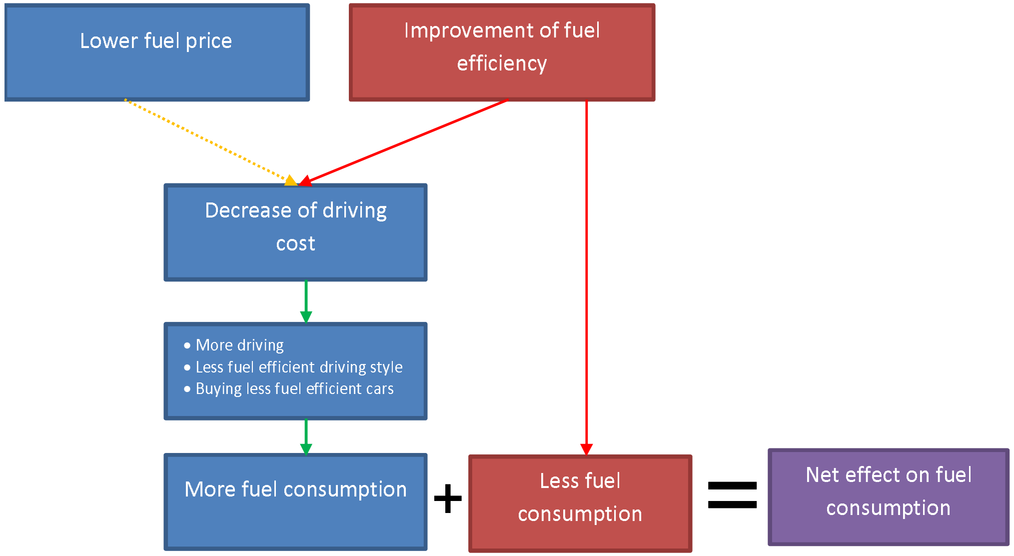
CO_2 emissions of various life-cycle aspects

Contribution of different life cycle phases to the total life cycle GHG emissions (tonne CO_2 eq./vehicle)



- For HEVs, PHEVs and BEVs emissions from production are significantly higher: 5 to 20 g CO_2 eq./km for BEVs
  - But increase is outweighed by reduction in use phase, especially of renewable electricity is used

Rebound effects



- Elasticity of fuel consumption with regard to fuel price (literature):
  - -0.25 (ST) to -0.6 (LT)
- A 27% improvement of fuel efficiency (1 – 95/130) leads to 22.1% (ST) and 15.2% (LT) due to the rebound effect of lower cost of fuel
- Based on analysis of TREMOVE runs the combination of improved fuel efficiency and a price increase of 11% may lead to 1 - 2% additional fuel saving (positive knock-on consequence)

Summary of note on costs and prices

- Additional costs for CO_2 reducing technologies are calculated relative to an “all-else-remaining-equal” baseline.
- How these costs affect prices depends on ways in which manufacturers are able to pass through these costs.
- Whether pass through of costs leads to net increase in real car prices depends on baseline price development upon which increases are superimposed.
  - Multitude of factors determine baseline price development
  - Manufacturers can influence baseline in response to CO_2 legislation
- Fact that **average car prices appear to have declined in real terms over the last years** does not provide evidence that ex ante assessments overestimated the costs for meeting the 130 g/km target.
  - At the same time there is also no proof of the contrary.

Contact info

› **Richard T.M. Smokers – lead consultant**

Mail: richard.smokers@tno.nl

Tel. +31-88-86 68628

› **Jordy Spreen – project manager**

Mail: jordy.spreen@tno.nl

Tel. +31-88-86 61163

Additional slides

Consortium

TNO innovation for life	✓ CO_2 and pollutant emissions from LD and HD vehicles ✓ potential and costs of technical options for reduction of CO_2 and pollutant emissions ✓ vehicle testing and development of test procedures ✓ development of engine, power train and exhaust aftertreatment technology
RICARDO	✓ engine, powertrain and exhaust aftertreatment design and development ✓ performance and costs of technical options for reduction of CO_2 and pollutant emissions ✓ advanced automotive technology research and development ✓ technology roadmapping and technical market assessment
IHS GLOBAL INSIGHT	✓ automotive market history and forecasts at make/model/powertrain/CO_2 level ✓ automotive technology history and forecasts ✓ alternative fuels research ✓ EU automotive market and automotive industry economics

Consortium

Ökopol – Institut für Ökologie und Politik GmbH	➢ data collection and analysis in successive projects for the Monitoring Mechanism (Decision 1753/2000/EC)
TRANSPORT & MOBILITY LEUVEN – Your link to integrated analyses !	➢ modelling of environmental and economic impacts of policy measures using TREMOVE and other models ➢ welfare analysis, cost-benefit analysis
CE Delft	➢ environmental impacts of transport ➢ policy analysis and policy development ➢ economic and cost/benefit analysis
AEA	➢ environmental impacts of transport ➢ vehicle technology assessment ➢ theoretical assessment of powertrain and non-powertrain technologies ➢ economic and cost benefit analysis ➢ alternative fuels research

Reduction technologies for petrol cars in 2020

Technology options for petrol cars		Small		Medium		Large	
Description		Reduction potential [%]	Cost [€]	Reduction potential [%]	Cost [€]	Reduction potential [%]	Cost [€]
Engine options	Gas-wall heat transfer reduction	3	50	3	50	3	50
	Direct injection, homogeneous	4.5	180	5	180	5.5	180
	Direct injection, stratified charge	8.5	400	9	500	9.5	600
	Thermodynamic cycle imporvements e.g. split cycle, PCCI/HCCI, CAI	13	475	14	475	15	500
	Mild downsizing (15% cylinder content reduction)	4	200	5	250	6	300
	Medium downsizing (30% cylinder content reduction)	7	400	8	435	9	510
	Strong downsizing (>=45% cylinder content reduction)	16	550	17	600	18	700
	Cam-phasing	4	80	4	80	4	80
	Variable valve actuation and lift	9	280	10	280	11	280
	Low friction design and materials	2	35	2	35	2	35
Transmission options	Optimising gearbox ratios / downspeeding	4	60	4	60	4	60
	Automated manual transmission	5	300	5	300	5	300
	Dual clutch transmission	6	650	6	700	6	750
	Continuously variable transmission	5	1200	5	1200	5	1200
Hybridisation	Start-stop hybridisation	5	175	5	200	5	225
	Micro hybrid - regenerative breaking	7	325	7	375	7	425
	Mild hybrid - torque boost for downsizing	15	1400	15	1500	15	1500
	Full hybrid - electric drive	25	2250	25	2750	25	3750
Driving resistance reduction	Mild weight reduction	2	128	2	160	2	192
	Medium weight reduction	6	320	6	400	6	480
	Strong weight reduction	12	800	12	1000	12	1200
	Lightweight components other than BIW	2	120	2	150	2	180
	Aerodynamics improvement	2	50	2	50	1.5	60
	Tyres: low rolling resistance	3	30	3	35	3	40
	Reduced driveline friction	1	50	1	50	1	50
Other	Thermo-electric waste heat recovery	2	1000	2	1000	2	1000
	Secondary heat recovery cycle	2	200	2	200	2	200
	Auxiliary systems efficiency improvement	12	420	12	440	12	460
	Thermal management	2.5	150	2.5	150	2.5	150

› Relative to 2002 reference vehicles

Reduction technologies for diesel cars in 2020

Technology options for diesel cars		Small		Medium		Large	
Description		Reduction potential [%]	Cost [€]	Reduction potential [%]	Cost [€]	Reduction potential [%]	Cost [€]
Engine options	Combustion improvements	2	50	2	50	2	50
	Mild downsizing (15% cylinder content reduction)	4	50	4	50	4	50
	Medium downsizing (30% cylinder content reduction)	7	400	7	450	7	500
	Strong downsizing (>=45% cylinder content reduction)	15	500	15	600	15	700
	Variable valve actuation and lift	1	280	1	280	1	280
Transmission options	Optimising gearbox ratios / downspeeding	3	60	3	60	3	60
	Automated manual transmission	4	300	4	300	4	300
	Dual clutch transmission	5	650	5	700	5	750
	Continuously variable transmission	4	1200	4	1200	4	1200
Hybridisation	Start-stop	4	175	4	200	4	225
	Micro hybrid - regenerative breaking	6	375	6	375	6	375
	Mild hybrid - torque boost for downsizing	11	1400	11	1500	11	1500
	full hybrid - electric drive	22	2250	22	2750	22	3750
Driving resistance reduction	Mild weight reduction	1.5	128	1.5	160	1.5	192
	Medium weight reduction	5	320	5	400	5	480
	Strong weight reduction	11	800	11	1000	11	1200
	Lightweight components other than BIW	1.5	120	1.5	150	1.5	180
	Aerodynamics improvement	2	50	2	50	1.5	60
	Tyres: low rolling resistance	3	30	3	35	3	40
	Reduced driveline friction	1	50	1	50	1	50
Other	Thermo-electric conversion	2	1000	2	1000	2	1000
	Secondary heat recovery cycle	2	200	2	200	2	200
	Auxiliary systems improvement	11	420	11	440	11	460
	Thermal management	2.5	150	2.5	150	2.5	150

- Relative to 2002 reference vehicles

Database

- 2009 Polk database acquired for EU 5 + 2
  - Germany
  - France
  - UK
  - Italy
  - Spain
  - Poland
  - Hungary

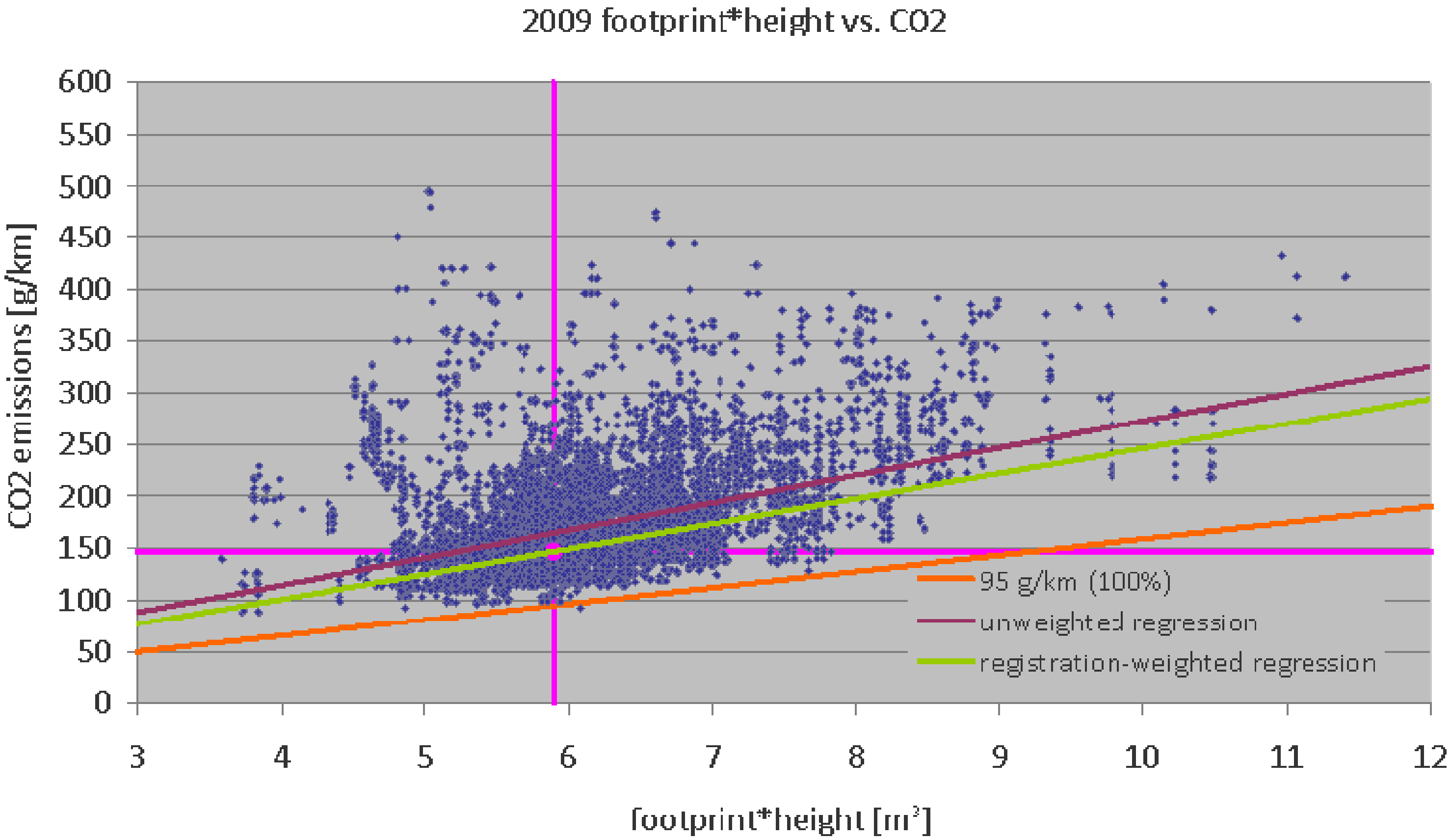
2009 database EU5+2

2009 charcteristics	Ref. mass [kg]	Footprint [m2]	CO2 [g/km]	Sales [#]
BMW	1565	4.1	152	550370
Chrysler	1938	4.4	217	33872
Fiat	1121	3.5	135	1008100
Ford	1311	3.9	141	857890
Geely (incl. Volvo)	1680	4.3	171	81000
General Motors	1293	3.8	146	894118
Honda	1381	3.9	150	141893
Hyundai-Kia	1328	3.8	143	352901
Mazda	1334	3.9	150	128161
Mercedes	1511	4.0	165	522280
Mitsubishi	1373	3.9	163	55546
PSA	1316	3.8	136	1343392
Porsche	1780	4.0	262	25216
Renault-Nissan	1276	3.9	143	1298526
Spyker Cars (incl. Saab)	1669	4.1	174	12649
Subaru	1558	4.0	182	17377
Suzuki	1218	3.6	140	91492
Tata (incl. Jaguar, Land Rover)	2061	4.4	224	67986
Toyota	1235	3.7	136	408494
Volkswagen	1423	4.0	152	2225451
Average	**1346**	**3.9**	**147**	**10116714**

Additional manufacturer costs of (PH)EVs compared to ICEVs

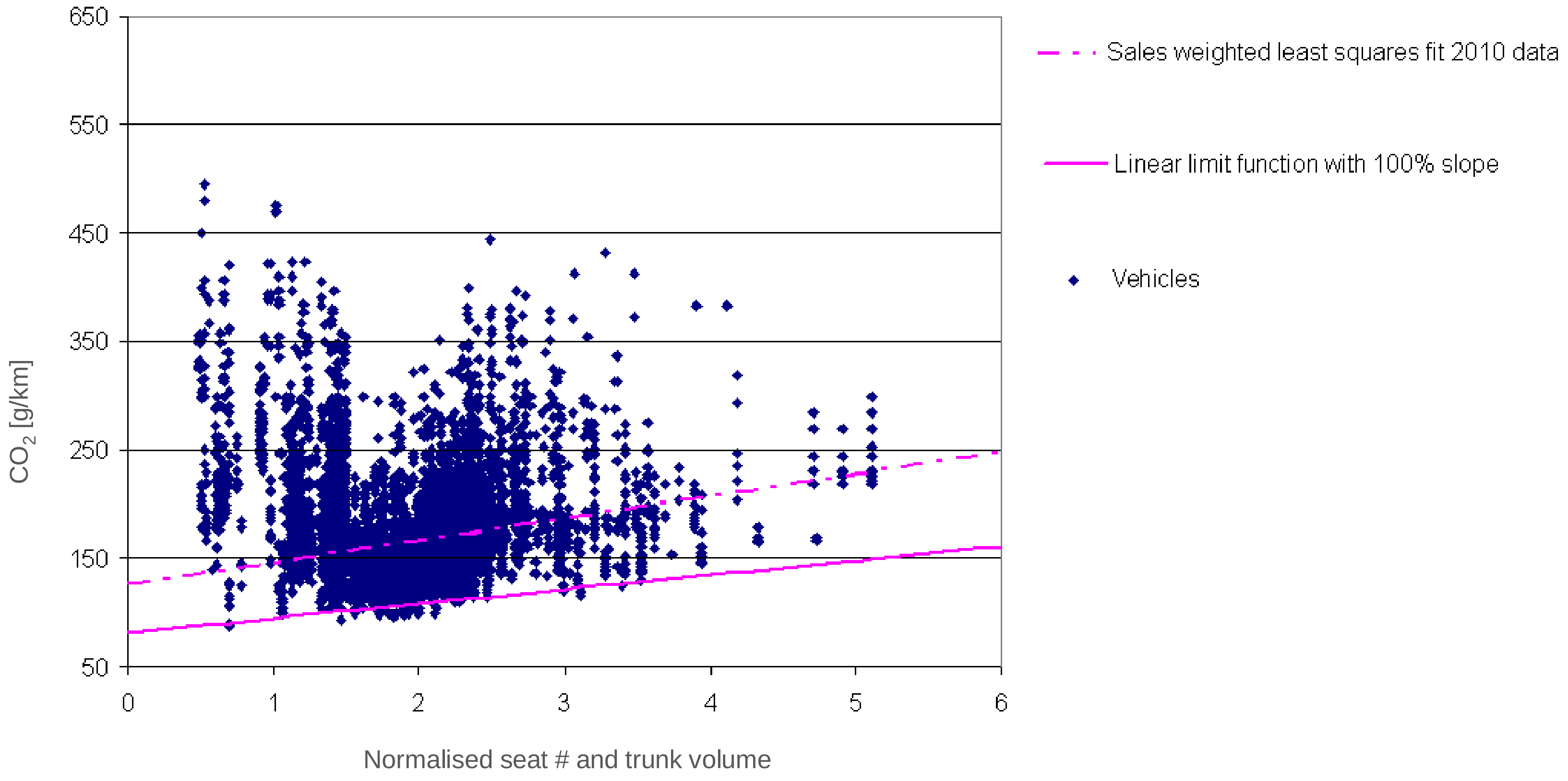
Additional manufacturer costs	**FEV**			**PHEV petrol**			**PHEV diesel**			**EREV petrol**			**EREV diesel**		
EV characteristics															
EV range [km]	150	175	200	50	50	50	50	50	50	50	50	50	50	50	50
Motor Power (peak) [kW]	62	80	85	28	30	30	28	30	30	66	80	84	67	81	85
Engine power [kW]	-	-	-	58	80	95	59	81	96	48	51	51	48	52	52
Battery capacity [kWh]	16.0	21.0	24.0	5.9	6.4	6.3	6.0	6.5	6.4	5.7	6.1	6.0	5.8	6.2	6.0
Cost electrification															
Battery [€]	6784	8747	9766	2579	2752	2711	2604	2787	2753	2493	2646	2585	2513	2667	2607
Motor [€]	435	551	582	208	222	220	210	224	223	464	552	580	470	558	586
Engine & Tranmission [€]	0	0	0	2000	2350	2450	2500	2800	2900	1000	1100	1100	1400	1600	1600
Generator [€]	0	0	0	0	0	0	0	0	0	432	463	462	436	467	466
Inverter & Boost converter [€]	690	878	929	337	359	356	341	364	361	1423	1615	1659	1439	1632	1677
Control unit & Harness [€]	240	270	300	240	270	300	240	270	300	360	390	420	360	390	420
Heat pump [€]	810	900	990	810	900	990	810	900	990	810	900	990	810	900	990
Avoided ICE costs															
ICE engine power [kW]	55	80	110	55	80	110	55	80	110	55	80	110	55	80	110
Engine & Tranmission [€]	1650	2400	3300	1650	2400	3300	1650	2400	3300	1650	2400	3300	1650	2400	3300
Total extra manufacturer costs [€]	**7309**	**8946**	**9267**	**4524**	**4453**	**3727**	**5055**	**4945**	**4227**	**5332**	**5266**	**4496**	**5778**	**5814**	**5046**

Footprint x height



- Better correlation with CO_2 than footprint
- Other pro's and con's are similar

Seats and trunk volume as utility parameter



- Theoretically a good measure of utility
- Poor correlation with CO_2

of seats (expressed in volume) + trunk volume

+ Very true utility parameter
+ This combined parameter might also be used for vans
o Possibilities for gaming depend on accuracy of assumed volume per seat
  - Whether or not increasing # of seats leads to more relaxed target depends on dimensions of car / seats compared to “average” car for which default value is defined
- Very poor correlation with CO_2
  - Increasing utility has limited impact on CO_2
  - Limit function based on fit leads to extremely stringent reduction goals for sports cars
- Based on assumption for default volume per seat that can be disputed

? Does expressing seats in volume solve the problem of defining what a seat is and possible problems with small seats, foldable or removable seats?

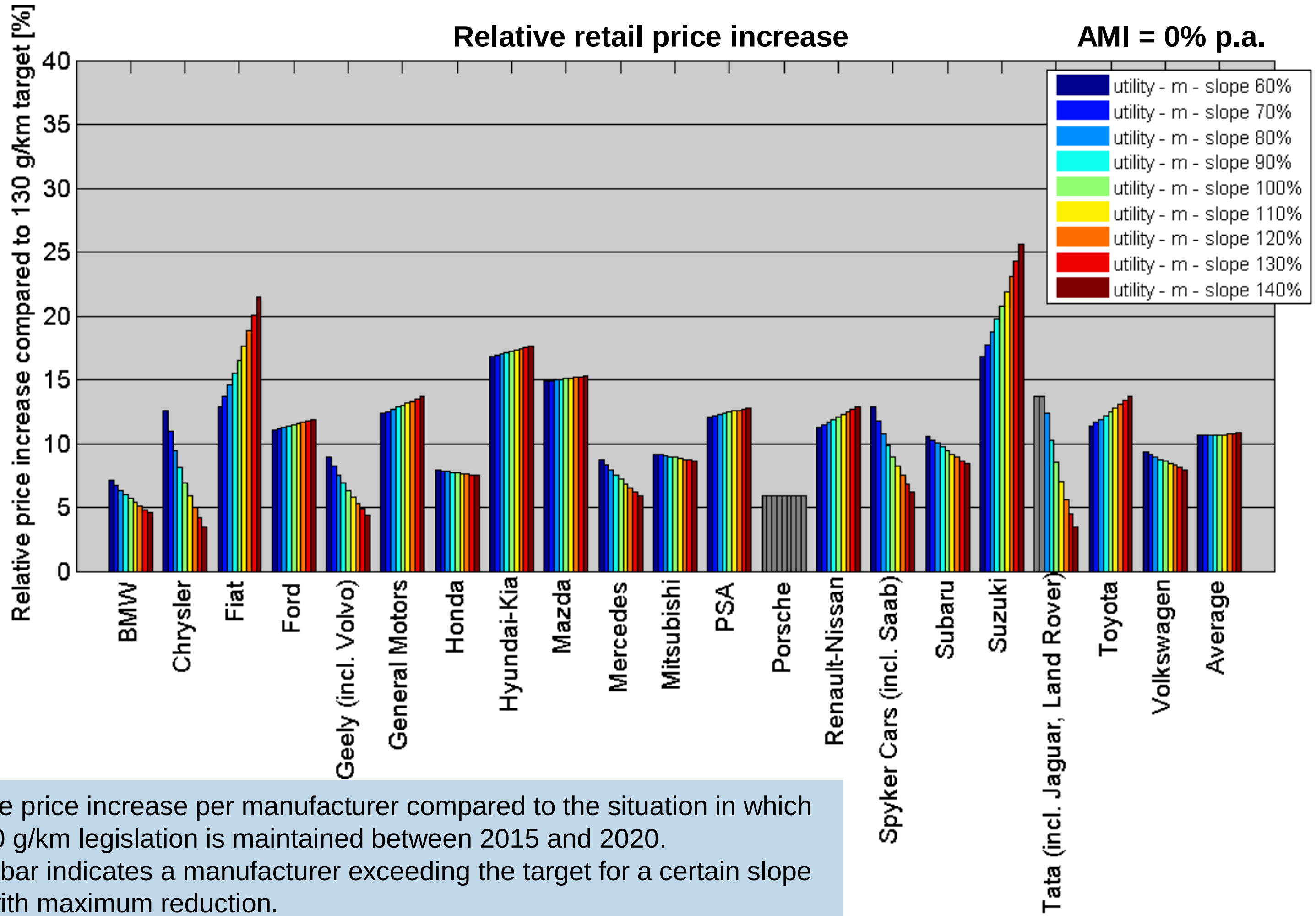
Conclusions on utility parameters

- Conclusion on main candidates
  - **mass, footprint, footprint x height**
- Other discarded options:
  - **pan area:** footprint is superior
  - **wheelbase:** footprint is superior
  - **# seats + trunk volume:** poor correlation with CO_2, questionable definition
  - **payload:** manufacturer declared value, poor correlation with CO_2
  - **normalised (payload + (# of seats + trunk volume)):** combination of disadvantages
  - **price:** not a measure of functional utility, very uneven distribution of vehicles around <U>, can not be objectively measured or verified, gives credit to performance (kW/ton ratio), promotes gaming

Footprint x height not further assessed as:
•it rewards higher vehicles such as SUVs
•decision was made to keep as much as possible the same for 2020 legislation

Distributional impacts – mass – 95 g/km in 2020

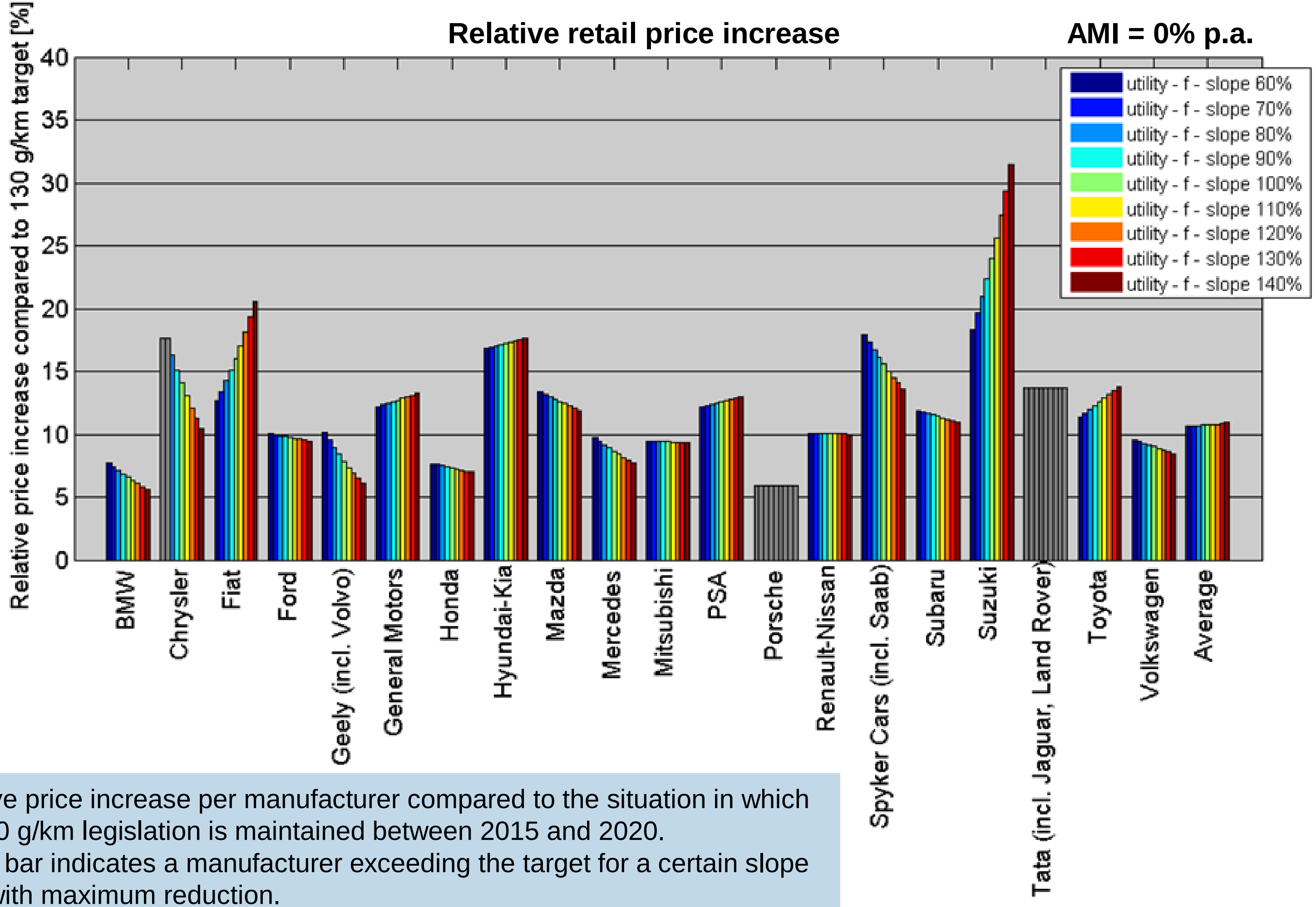
- Porsche not able to meet its 2020 target
- Problem for Tata with small slope values



- Relative price increase per manufacturer compared to the situation in which the 130 g/km legislation is maintained between 2015 and 2020.
- A grey bar indicates a manufacturer exceeding the target for a certain slope even with maximum reduction.

Distributional impacts – footprint – 95 g/km in 2020

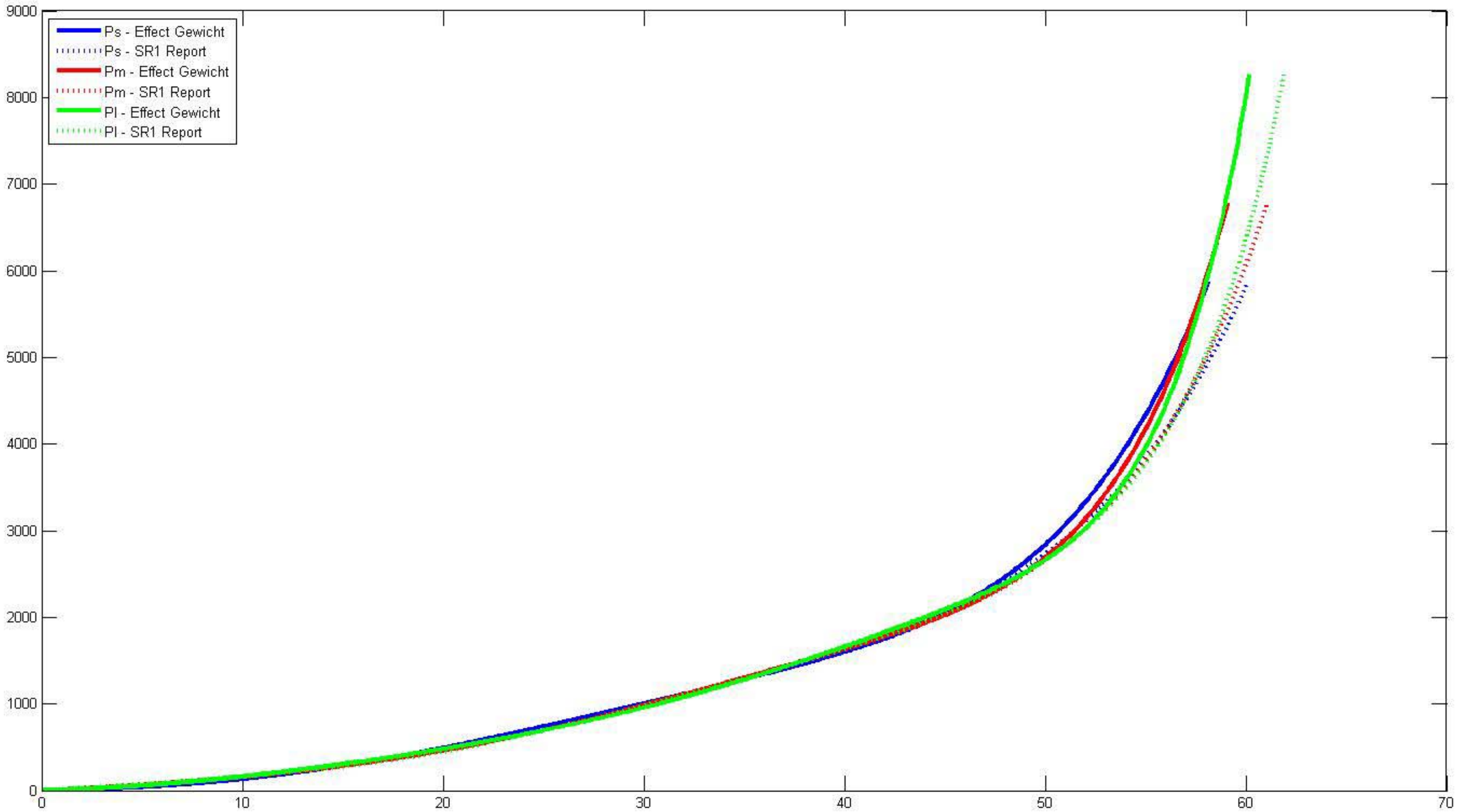
- Porsche + Tata not able to meet their 2020 targets
- Problem for Chrysler with small slope values



- Relative price increase per manufacturer compared to the situation in which the 130 g/km legislation is maintained between 2015 and 2020.
- A grey bar indicates a manufacturer exceeding the target for a certain slope even with maximum reduction.

Amended cost curves reflecting reduced effectiveness of weight reduction for U = mass

petrol



Amended cost curves reflecting reduced effectiveness of weight reduction for U = mass