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SERIES: CO_2 REDUCTION TECHNOLOGIES FOR THE EUROPEAN CAR AND VAN FLEET, A 2020-2025 ASSESSMENT

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Summary of Eastern EU labor rate impacts on EU cost curves

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1. Introduction

This paper discusses the impacts of Eastern EU labor rates on CO_2 benefit and cost curves for EU light-duty vehicles in the 2020-2025 timeframe. This paper is the fourth in a series, with the previous three papers describing the methodology and data used to generate CO_2 cost curves for EU vehicles. Those papers have been published as ICCT Working Papers 2012-4, 2012-5, and 2013-1.[1,2,3]

The previous EU studies assumed that all components were produced in Germany and thus all cost factors were based on the labor rates in Germany. In a cost sensitivity analysis, labor costs were estimated for six Eastern EU countries (Slovenia, Czech Republic, Hungary, Poland, Slovakia, and Romania)[4] and compared to labor costs in Germany (see Figure 1). As a result, an average scaling factor of 23% was determined for Eastern EU labor costs, i.e. labor costs were estimated to be 77% lower when compared to Western EU. Consequently, on average an hourly direct labor rate of 7.75 euros for suppliers and 10.29 euros for vehicle manufacturers were estimated for Eastern EU. The previously developed EU cost curves used the German labor rates, which on average were estimated at 33.28 euros per hour for suppliers and 44.16 euros for vehicle manufacturers. As a result, when compared to Western EU, the average costs of advanced technologies being produced in Eastern EU were estimated to be lower by 2.3% to 21.3%. This paper explains how the results of the Eastern EU labor cost sensitivity analysis affect the cost curves developed and explained in previous papers in this series.

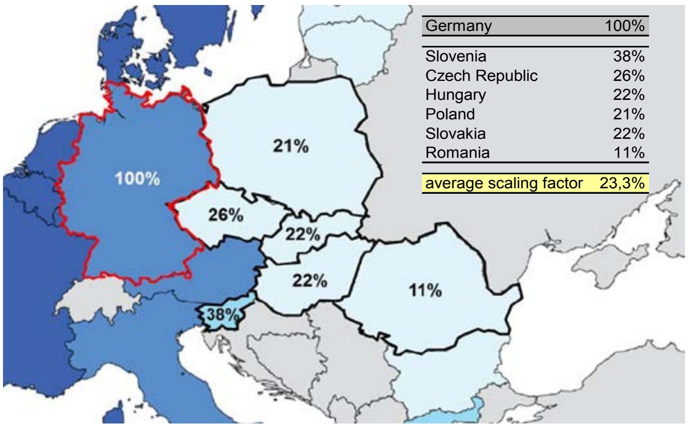

Figure 1. Labor rates of Six Eastern EU Countries Compared to Germany

Source: Figure B-4, FEV, "Light-Duty Vehicle Technology Cost Analysis European Vehicle Market Result Summary and Labor Rate Sensitivity Study," Revised Final Report, August 7, 2013.

1 ICCT, "CO_2 reduction technologies for the European car and van fleet, a 2020-2025 assessment: Initial processing of Ricardo vehicle simulation modeling CO_2 data," Working paper 2012-4, July 9, 2012.

2 ICCT, "CO_2 reduction technologies for the European car and van fleet, a 2020-2025 assessment: Summary of the EU cost curve development methodology," Working paper 2012-5, November 2, 2012.

3 ICCT, "CO_2 reduction technologies for the European car and van fleet, a 2020-2025 assessment: Summary of mass reduction impacts on EU cost curves," Working paper 2013-1, January 2013.

4 FEV, "Light-Duty Vehicle Technology Cost Analysis European Vehicle Market Result Summary and Labor Rate Sensitivity Study," Revised Final Report, August 7, 2013.

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ABOUT THIS SERIES The ICCT has compiled detailed data on the CO_2 reduction potential and associated costs of vehicle technologies for the European light duty vehicle market (passenger cars and light commercial vehicles). The analysis incorporates extensive vehicle simulation modeling as well as a detailed tear down cost assessment. Papers in this series summarize the underlying methodology, input data, and the results of the project.

As with the previous studies in this series, data are evaluated in terms of effects on five vehicle classes. CO_2 impacts for these classes, namely B, C, D, Small N1, and Large N1 class vehicles, are based on simulation modeling performed for the Toyota Yaris, Ford Focus, Toyota Camry, Ford Transit Connect, and Ford Transit respectively. All baseline modeling is for 2010-era vehicle design and technology.

To integrate the Eastern EU cost data into the EU vehicle cost curves, the FEV cost data employed in the previous studies in this series (hereafter referenced as the Western EU cost data) were replaced in their entirety with corresponding cost data for the Eastern EU. For most technologies, this represents a one-for-one data substitution. However, as was the case for the Western EU cost analysis, FEV-developed mass reduction cost data for the Eastern EU that were expressed in the form of a generalized function, so that the specific costs for a range of potential mass reductions could be evaluated. The first half of this paper summarizes the methodology employed and the resulting mass reduction cost curves. The interested reader can find greater detail on this methodology in Working Paper 2013-1. This paper primarily highlights the differences between the Western and Eastern EU mass reduction cost data. The second half of this paper presents the effects that accrue to the overall EU vehicle CO_2 compliance cost curves when the newly developed Eastern EU cost data are substituted for the previously used Western EU cost data. Whereas the previous papers in this series assumed 100 percent Western EU costs, this paper assumes 100 percent Eastern EU costs.

As with previous work in this series, the primary cost curves are strictly technology-based. The relative effectiveness of potential regulatory structures that might be imposed to drive CO_2 emission reductions—specifically with regard to associated influences on technology neutrality—are not considered in the primary cost curve analyses. This paper does, however, include a secondary set of cost curves designed to evaluate the potential impacts of regulatory structures that discount the value of vehicle mass reduction—either in whole or in part, through mechanisms such as adjusting CO_2 standards for changes in vehicle mass—on the cost of CO_2 standard compliance. This secondary evaluation is conducted through an analysis of compliance costs both with and without mass reduction technology. The scenario with mass reduction technology reflects the potential compliance costs of a regulatory structure that is fully technology neutral (e.g., a single standard or vehicle size-based regulatory structure), while the latter scenario reflects the potential compliance costs of a structure that *fully* discounts mass reduction as a compliance option (i.e., a regulatory structure that adjusts CO_2 standards to fully offset any CO_2 impacts associated with mass reduction). This is a bounding analysis, in that compliance costs for regulatory structures that *partially* discount the CO_2 effects of mass reduction will be between the two bounds evaluated in this paper.

As with previously presented cost curves, underlying cost data are primarily based on teardown studies of current technology conducted by FEV. The teardown approach adds an important element of validation with regard to cost estimates, but it also inherently ignores cost reductions due to any future advances in technology design. To the extent that design advances occur, the presented cost curves overstate CO_2 emission reduction costs in the years following such advances. Thus, while teardown cost estimates serve an important role in grounding future cost estimates, they generally reflect a relatively pessimistic view of advances beyond current technology capability, design, and manufacturing. Accordingly, the presented curves should be viewed as relatively conservative, in that aggregate future costs could be significantly lower than estimated.

The remaining sections of this paper detail the specific steps undertaken to integrate the newly released Eastern EU cost data into EU light-duty vehicle cost curves. Section 2 describes how the newly released Eastern EU cost data (excepting mass reduction cost data) were integrated into the analysis documented in this paper. Section 3 provides corresponding information for the newly released Eastern EU mass reduction cost data. Section 4 describes the methods used to develop mass reduction cost curves from the newly released Eastern EU mass reduction data. Section 5 discusses the methodology employed to integrate the Eastern EU mass reduction cost curves into the larger EU cost curve analysis (that includes other CO_2 reduction technologies). Section 6 presents the resulting cost curves and compliance cost comparison between applying Eastern EU vs. Western EU labor rates, Section 7 provides a series of closing remarks. Section 8 discusses data limitations and future work. At the end of the paper, the definitions for the various abbreviations and acronyms are provided.

2. Technology Cost Data Other Than Mass Reduction

For CO_2 reduction technologies other than mass reduction, the analysis summarized in this paper exactly follows the methodology described in Working Paper 2012-5 (the second paper in this series). FEV-estimated costs for the Eastern EU have been substituted on a one-for-one basis for corresponding FEV-estimated costs for the Western EU. Since these comparative costs are fully described in the referenced FEV report, they are not replicated herein.

Complexities only arise for technologies that were costed using non-FEV references.[5] Since such data sources provide no information on the differential cost impact of Western and Eastern EU labor rates, a generalized method was developed to estimate such impacts. As described in Working Paper 2012-5, a generalized method was previously developed to convert U.S.-based cost estimates to their Western EU equivalents. This method relied on a comparison of detailed and computationally consistent U.S. and Western EU cost estimates for an identical technology system conversion. Both cost estimates were prepared by FEV, with the U.S. market data being prepared for the U.S. Environmental Protection Agency and the corresponding EU market data being prepared for the ICCT. The specific technology package compared consisted of the conversion of a baseline 2.4 liter, I4, 16 valve, DOHC naturally aspirated petrol engine with discrete variable valve timing to a 1.6 liter, I4, 16 valve, DOHC turbocharged petrol direct injection with discrete variable valve timing. From this comparison, a scalar was developed to adjust costs for the U.S. market to their EU market equivalents.

This identical methodology was employed for the Eastern EU analysis, excepting that Eastern EU costs for the identical turbocharged direct injection technology conversion were substituted for those previously used for the Western EU analysis. As with the Western EU analysis, all cost data were developed by FEV so that the level of detail and computational consistency is maintained. The resulting U.S.-to-Eastern EU cost adjustment factor is calculated to be 0.692, as compared to 0.826 for the earlier Western EU analysis (i.e., the equivalent Western EU-to-Eastern EU scalar is 0.692/0.826, or 0.838).

3. Mass Reduction Cost Data

As described in detail in Working Paper 2013-1, the preceding paper in this series, EU-specific cost curves for mass reduction technology were developed from cost data developed by FEV. As with all other previous cost data, the mass reduction cost curves were based on Western EU labor rates. For the analysis underlying this current paper, the same cost curve development exercise was replicated using Eastern EU labor rate data. Since a detailed description of the cost curve development methodology is included in Working Paper 2013-1, this paper focuses primarily on those elements of the exercise that have changed during the substitution of Eastern EU cost data for the corresponding Western EU cost data used previously. All elements of the analysis that are not specifically described herein are unchanged from the analysis described in Working Paper 2013-1.

As discussed in Working Paper 2013-1, FEV evaluated nearly 250 vehicle components for mass reduction potential. The total base mass of the evaluated components was 1641.70 kg, from which FEV found weight reductions totaling 312.48 kg (or 19 percent) . With fluids and other minor components, the total base vehicle weight was 1711 kg, so the precise "implemented" mass reduction was 18.3 percent. Table 1 presents a summary of the 312.48 kg of mass reduction, with associated costs, sorted in order of increasing cost per kg of mass reduced.[6,7] It is important to note that the presented mass reduction and cost data include secondary (or compounded) benefits. Such benefits accrue due to the fact that mass reduction is synergistic. Since less energy is required to move reduced mass, the vehicle engine can be downsized. Similarly, components such as the vehicle suspension, brakes, and body can be made smaller or lighter since they need not support the same mass or dissipate the same energy. Of the 312.48 kg of mass reduction, 42.78 kg are associated with secondary mass reduction (so that secondary mass reduction represents 13.7 percent of total reductions, or 15.9 percent of primary mass reductions).[8]

5 In some cases, as described in detail in Working Paper 2012-5, the CO_2 technology packages modeled by Ricardo, Inc. (the consultant that performed the detailed CO_2 modeling that supports the analyses described in this and preceding papers) included individual technology components that were not analyzed by FEV with regard to cost. Cost data for such components were developed from alternative data sources; primarily data compiled by the U.S. Environmental Protection Agency as part of their 2017-2025 light duty vehicle greenhouse gas rulemaking. Such secondary data sources are described in detail in Working Paper 2012-5.

6 Unless otherwise indicated, all cost data in this paper are direct nominal costs to the vehicle manufacturer. Nominal indicates that learning factors derived by FEV for calendar years 2012-2025 are not applied to the direct costs, nor are indirect cost multipliers intended to reflect additional costs incurred during the distribution and sales of vehicles. Such factors are included, as appropriate, in the EU cost curve development process, but are excluded during comparative cost discussions to facilitate a consistent comparison metric.

7 For comparative purposes, both Western and Eastern EU cost data are included in Table 1. It is only possible to sort the data on the basis of one or the other set of data. For consistency with the corresponding table presented in Working Paper 2013-1, the data are sorted in accordance with Western EU data.

8 Such levels of secondary mass reduction are quite conservative based on estimates produced in other studies. For example, in a study conducted as part of the United States Automotive Materials Partnership (USAMP) Cooperative Research Program, Shaw (United States Steel Corporation) and Polewarczyk (General Motors Corporation) found secondary mass reductions ranging from 60-150 percent of primary mass reductions, equivalent to 38-60 percent of total mass reductions; with the range defined by whether or not the powertrain can be targeted for secondary mass reduction (see U.S. Department of Energy, "Lightweighting Material, 2010 Annual Progress Report," DOE/EE-0577, Objective ASP241, January 2011). In its 2011 study of fuel economy technology, the U.S. National Academy of Sciences (see "Assessment of Fuel Economy Technologies for Light-Duty Vehicles," The National Academies Press, Washington, D.C., 2011) cites two mass reduction studies. Both of these studies (one by Ibis Associates and one by Ricardo, Inc.) estimate potential secondary mass reductions equal to 30 percent of primary reductions, or 23 percent of total mass reductions. In the previously cited support document for its 2017-2025 light-duty vehicle greenhouse gas rulemaking, the U.S. EPA states that secondary mass reductions "in the two most recent mass reduction projects by EPA and NHTSA" equal 70 percent of primary mass reductions, or 41 percent of total mass reductions. Clearly, the secondary mass reduction estimates of the FEV study, at 16 percent of primary and 14 percent of total, are significantly more conservative than other estimates in the subject literature.

Table 1. Mass Reduction (kg) & Cost (€) as Reported by FEV

Vehicle Component(s)	kg	Western EU		Eastern EU	
		€	€/kg	€	€/kg
Cylinder Head Covers	0.052	-5.15	-99.67	-4.36	-84.43
Planetary Gears	0.263	-19.65	-74.59	-19.65	-74.59
Oil/Air Separator	0.219	-4.51	-20.57	-3.72	-16.99
Headliner Assembly	0.01	-0.18	-17.84	-0.08	-8.08
Brake Lines and Hoses	1.541	-25.91	-16.81	-21.93	-14.23
Exterior Mirrors	0.218	-3.58	-16.43	-1.86	-8.54
Fuel Rails	0.115	-1.88	-16.34	-1.47	-12.77
Parking Brake Cables and Attaching Components	2.117	-29	-13.7	-23.67	-11.18
Fender Seals	0.018	-0.22	-12.34	-0.15	-8.55
Infotainment Antennas and Cables	0.049	-0.51	-10.33	-0.35	-7.12
Electronic Climate Control Unit	0.009	-0.09	-10.06	-0.08	-9.29
Connect Rods (Connecting Rod & Cap)	0.596	-5.24	-8.79	-3.85	-6.45
Rear Side Door Dynamic Weatherstrip	0.356	-2.83	-7.94	-1.96	-5.5
Throttle Housing Assembly; including Supplies	0.245	-1.93	-7.9	-1.33	-5.44
Rear Spoiler Assembly	0.19	-1.5	-7.87	-1.48	-7.76
Seat Harness	0.009	-0.07	-7.51	-0.07	-7.72
Front Side Door Dynamic Weatherstrip	0.427	-3.17	-7.43	-2.2	-5.15
Rear Closure Finishers	0.145	-1.07	-7.41	-1.07	-7.37
Inlet Valves	0.015	-0.11	-7.41	-0.11	-7.41
Outlet Valves	0.015	-0.11	-7.41	-0.11	-7.41
Radiator Grill	0.155	-1.12	-7.23	-1.11	-7.17
Hood Dynamic Weatherstrip	0.03	-0.22	-7.12	-0.15	-4.93
Steering Column Assembly	1.148	-8.13	-7.08	-5	-4.35
Torque Converter Assembly	4.904	-34.13	-6.96	-27.59	-5.63
Parking Brake Shoes and Hardware	5.031	-32.75	-6.51	-27.94	-5.55
Rear Strut / Damper Assembly	4.785	-26.08	-5.45	-21.78	-4.55
Load Compartment Side Trim	3.842	-20.48	-5.33	-17.46	-4.55
Driver Information Center	0.027	-0.15	-5.32	-0.29	-10.7
Rear 60% Seat	13.551	-63.85	-4.71	-42.65	-3.15
Parking Brake Controls	2.487	-11.46	-4.61	-8.4	-3.38
Steering Wheel Trim	0.011	-0.05	-4.52	-0.04	-4.1
Static Sealing	1.198	-5.4	-4.51	-3.75	-3.13
Battery Cables	0.22	-0.91	-4.13	-0.93	-4.22
Front Window/Windshield Defrosting	0.393	-1.62	-4.12	-1.37	-3.48
Covers	1.276	-4.81	-3.77	-3.58	-2.81
Rear Closure Interior Trim Panel	0.027	-0.1	-3.65	-0.07	-2.44
Module - Front Bumper and Fascia	0.491	-1.69	-3.45	-1.66	-3.38
Module - Rear Bumper and Fascia	0.514	-1.76	-3.43	-1.72	-3.35
Carpet Support	0.021	-0.07	-3.29	-0.05	-2.24
Miscellaneous: Wipers and Washers Subsystem	0.1	-0.32	-3.21	-0.31	-3.09
Sun Visors	0.067	-0.21	-3.16	-0.19	-2.8
Air Distribution Duct Components	1.454	-4.35	-2.99	-4.06	-2.8
Main Floor Trim	0.075	-0.22	-2.95	-0.16	-2.07
Center Stack	0.728	-2.13	-2.92	-1.9	-2.6
Piston Cooling	0.124	-0.36	-2.92	-0.34	-2.73

Table 1. Mass Reduction (kg) & Cost (€) as Reported by FEV

Vehicle Component(s)	kg	Western EU		Eastern EU	
		€	€/kg	€	€/kg
Engine Down Size	10.365	-28.97	-2.8	-28.97	-2.8
Rear Caliper, Anchor and Attaching Components	5.025	-13.79	-2.74	-12.44	-2.47
Cargo Retention	0.161	-0.43	-2.67	-0.41	-2.58
Upper Exterior and Roof Finish	0.09	-0.24	-2.67	-0.23	-2.54
Front Drivers Seat	4.715	-11.53	-2.44	-4.6	-0.98
Cylinder Head	0.9	-2.11	-2.35	-2.11	-2.35
Front Strut / Damper Assembly	9.326	-19.77	-2.12	-16.69	-1.79
IP Cluster	0.049	-0.1	-2.08	-0.1	-2.01
HVAC Main Unit: Air Box/Core & Evaporator	0.478		-2.08	-0.88	-1.83
Cowl Vent Grill Assembly	0.104	-0.21	-2.02	-0.18	-1.77
Actuator Assemblies	1.443	-2.9	-2.01	-2.54	-1.76
Road Wheels and Tire Assembly	30.833	-59.2	-1.92	-52.14	-1.69
Floor Mats–OEM	0.809	-1.54	-1.91	-1.54	-1.91
Rear LH & RH Door Trim Panel	0.689	-1.28	-1.87	-1.03	-1.5
Front Caliper, Anchor and Attaching Components	7.5	-13.69	-1.83	-13.12	-1.75
Pillar Trim Upper	0.275	-0.49	-1.79	-0.36	-1.31
Rear Suspension Links/Arms Upper and Lower	0.995	-1.74	-1.75	-1.54	-1.55
Pistons (Including Ring Packs, Pins, Circlips)	0.092	-0.15	-1.68	-0.15	-1.68
Miscellaneous: Air Intake Subsystem	0.122	-0.2	-1.64	-0.14	-1.17
Tensioners	0.125	-0.2	-1.61	-0.05	-0.4
Front Left & Right Door Trim Panel	0.726	-1.15	-1.59	-1.02	-1.41
Water Pumps	1.601	-2.54	-1.59	-2.1	-1.31
Load Compartment Floor Trim	1.077	-1.61	-1.49	-1.48	-1.37
Pillar Trim Lower	0.289	-0.43	-1.48	-0.36	-1.25
Lower Exterior Finishers	0.463	-0.69	-1.48	-0.61	-1.31
Fuel Vapor Canister Assembly	0.497	-0.7	-1.41	-0.42	-0.85
Air Filter Box	0.144	-0.2	-1.4	-0.2	-1.38
Heat Exchangers	0.99	-1.38	-1.39	-1.13	-1.14
Rear Wheel Arch Liners	0.122	-0.16	-1.31	-0.14	-1.17
Crankcase Adaptor	1.924	-2.41	-1.25	-2.54	-1.32
Front Drive Unit	0.733	-0.91	-1.23	-0.91	-1.23
Vacuum Booster System Assembly	1.242	-1.48	-1.19	-1.09	-0.87
Guides	0.054	-0.06	-1.13	0.09	1.61
Front End and Engine Compartment Wiring	0.283	-0.29	-1.01	-0.27	-0.96
Load Compartment Transverse Trim	0.858	-0.87	-1.01	-0.79	-0.92
Engine Compartment Trim	0.268	-0.26	-0.98	-0.25	-0.94
Steering Gear	0.123	-0.11	-0.93	-0.11	-0.93
Fuel Filler	0.548	-0.47	-0.86	0.33	0.61
Under Eng. Closures/Air Dams	0.231	-0.2	-0.85	-0.19	-0.83
Transaxle Case	2.947	-2.46	-0.83	-2.46	-0.83
Engine Management & Electronic Systems	0.388	-0.32	-0.82	0.11	0.29
Enclosures	1.024	-0.84	-0.82	-0.44	-0.43
Covers	1.092	-0.87	-0.79	-0.87	-0.79
Steering Wheel	0.326	-0.25	-0.77	0.17	0.51
Fuel Tank Assembly	11.659	-8.76	-0.75	-4.82	-0.41

Table 1. Mass Reduction (kg) & Cost (€) as Reported by FEV

Vehicle Component(s)	kg	Western EU		Eastern EU	
		€	€/kg	€	€/kg
Transaxle Housing	3.706	-2.36	-0.64	-2.36	-0.64
Oil Pans (Oil Sump)	0.167	-0.08	-0.51	-0.08	-0.51
Roof	7.2	-3.47	-0.48	-3.41	-0.47
Engine and Transmission Wiring	0.143	-0.04	-0.27	-0.09	-0.62
Front Passenger Seat	3.638	-0.95	-0.26	3.15	0.87
Front Strut Frame	13.8	-3.16	-0.23	6.34	0.46
Front Rotor and Shield	5.023	-1.08	-0.22	-1.66	-0.33
Emission Control Components	4.729	-0.83	-0.17	-0.81	-0.17
Spare Wheel and Tire Assembly	2	-0.2	-0.1	-0.18	-0.09
Rear Stabilizer (Anti-Roll) Bar Assembly	1.56	-0.09	-0.06	0.52	0.33
Power Steering Electronic Controls	0.21	-0.01	-0.03	-0.09	-0.42
Other Parts for Cylinder Head	0.095	0	0	0	0
Miscellaneous: Rear View Mirror Subsystem	0	0	0	0	0
Miscellaneous: Front Brake Subsystem	0.124	0	0	0	0
Acoustic Control Components	2.789	0.1	0.03	0.1	0.04
Rear Suspension Knuckle Assembly	5.765	0.51	0.09	1.57	0.27
Ladder	12.1	1.59	0.13	1.56	0.13
Instrument Panel Harness	0.11	0.02	0.17	0.03	0.27
Rear 40% Seat	1.488	0.48	0.32	2.45	1.64
Oil Pump Assembly	1.034	0.39	0.38	0.39	0.38
Body and Rear End Wiring	0.123	0.05	0.38	0.05	0.38
Underbody	8.1	4.4	0.54	4.33	0.53
Front Stabilizer (Anti-Roll) Bar Assembly	2.879	1.85	0.64	1.92	0.67
Front Suspension Knuckle Assembly	6.759	4.41	0.65	3.68	0.54
Windshield and Front Quarter Window (Fixed)	1.559	1.21	0.77	1.41	0.9
Inflatable Knee Bolster or Active Leg Protection	0.377	0.34	0.9	0.39	1.03
Cross-Car Beam (IP)	3.975	3.69	0.93	2.9	0.73
Front Structure	5.7	5.38	0.94	5.29	0.93
Passenger Airbag / Cover Unit	0.483	0.5	1.04	1.03	2.13
Headlamp Cluster Assembly	0.531	0.55	1.04	1.24	2.33
Instrument Panel Main Molding	1.627	1.75	1.07	1.85	1.13
Rear Strut Frame	2.538	3.89	1.53	4.36	1.72
Engine Mountings	1.114	1.72	1.54	1.85	1.66
First Row Door Window Lift Assembly	0.939	1.6	1.7	1.6	1.7
Second Row Door, Quarter & Rear Window Lift	0.939	1.6	1.7	1.6	1.7
Front Half Shaft	0.77	1.31	1.7	1.05	1.37
Rear Rotor and Shield	1.216	2.13	1.75	1.35	1.11
Air Conditioning Compressors	0.709	1.42	2.01	1.18	1.67
Camshaft Phaser and/or Cam Sprockets	1.391	3.01	2.16	4.28	3.08
Front Suspension Links/Arms Upper and Lower	1.934	4.86	2.51	5.56	2.87
Back Window Assembly	1.218	3.19	2.62	3.34	2.75
Rear Side Door Glass	1.176	3.08	2.62	3.23	2.75
Back and Rear Quarter Windows (Fixed)	0.23	0.6	2.62	0.63	2.75
Rear Hatch	7.2	22.59	3.14	22.2	3.08
Cylinder Block	5.058	16.24	3.21	14.53	2.87

Table 1. Mass Reduction (kg) & Cost (€) as Reported by FEV

Vehicle Component(s)	kg	Western EU		Eastern EU	
		€	**€/kg**	**€**	**€/kg**
Hood	7.7	29.49	3.83	28.99	3.76
Bodyside	17.57	76.2	4.34	74.9	4.26
Miscellaneous: Lubrication Subsystem	0.067	0.3	4.54	0.3	4.43
Body Air Outlets	0.103	0.49	4.74	0.11	1.1
Valve Springs	0.154	0.8	5.22	0.72	4.68
Steering Wheel Airbag	0.2	1.45	7.26	1.07	5.36
Camshafts	2.133	16.51	7.74	12.93	6.06
Front Fenders	2	16.48	8.24	16.2	8.1
Shift Module Assembly	1.726	22.24	12.88	18.83	10.9
Front Bumper	0.4	8.08	20.19	7.94	19.85
Carrier Gears	3.227	110.64	34.29	109.96	34.08
Bolt on BIP Components	0	11.12	---	12.92	---
Vehicle Totals	**312.48**	**-142**	**-0.45**	**-39.6**	**-0.13**

Negative costs indicate cost savings.

As indicated in Table 1, FEV achieves, for Western EU labor rates, an 18.3 percent reduction in vehicle mass at a cost *savings* of 0.45 euros per kg reduced. For Eastern EU labor rates, the same mass reduction is achieved at a cost *savings* of 0.13 euros per kg reduced. That the cost savings per unit mass reduction are lower in the Eastern EU might seem counterintuitive given the generally lower labor costs in the region, but net mass reduction costs are driven by a combination of two primary influences. First, mass reduction options that generate improved "parts efficiency" can have components with significant labor savings. The cost magnitude of the labor savings increases with labor cost, so that savings in the Western EU are larger than corresponding savings in the Eastern EU. In other words, while Eastern EU labor is less costly, so is the savings that results when such costs are reduced by a given percentage relative to the savings in the higher labor cost Western EU. Second, mass reduction options that lead to material cost changes (generally cost increases) are less sensitive to labor rates. The net effect of these two influences is that options that generate cost savings tend to generate proportionally less savings in the Eastern EU and options that generate cost increases tend to generate similar increases in both the Eastern and Western EU.

As described in Working Paper 2013-1, the FEV-developed mass reduction options summarized in Table 1 were associated with (nominally) defining a 20 percent mass reduction package. Since the basic package achieved somewhat less than the 20 percent target, FEV performed a supplemental assessment wherein they identified up to 63.25 kg of additional mass reduction potential and associated costs. Based on discussions with FEV, the ICCT opted to include only a portion of these additional options (engine and transmission downsizing, and aluminum doors) as reasonable and feasible in the 2020 timeframe. The retained options reflect an additional 47.54 kg of mass reduction at a cost of 97.09 euros (2.04 euros per kg) in the Western EU, and 97.93 euros (2.06 euros per kg) in the Eastern EU.

FEV's nominal design mass reduction package (as summarized in Table 1 above) includes several mass reduction options with primary mass reduction costs in excess of four euros per kg. As described in Working Paper 2013-1, three of these options are related to the body-in-white (BIW) and are therefore integral to the structural integrity and safety of the reduced mass package. However, nine options are independent of the BIW and can be implemented (or not) based solely on their cost effectiveness. Given their unreasonably high cost, these nine options were removed from the FEV mass reduction package prior to the development of the mass reduction cost curves generated in this analysis. One of the nine dropped options (the front bumper) carries a secondary mass reduction benefit that was retained while the associated primary mass reduction was dropped.[9] In total, 9.8 kg of mass were added back to the reduced mass package at an aggregate cost savings of 18.2 euros per kg in the Western EU

9 Secondary reductions are facilitated by the cumulative primary mass reductions of all components that contribute to vehicle level mass reduction, not just the primary mass reductions of the component or system exhibiting the reduction. Thus, while secondary mass reductions should be (and are) adjusted for changes in cumulative primary mass reduction, they continue to apply across all components subject to secondary mass reduction whether or not those components themselves have a primary mass reduction.

and 17.2 euros per kg in the Eastern EU.[10] It should be recognized, however, that adding 9.8 kg of mass back into the reduced mass vehicle also had the effect of reducing the secondary mass benefits associated with the original FEV reduced mass package, resulting in a net mass increase of 11.4 kg.

As shown in Table 1 above, the original FEV reduced mass package delivered 312.48 kg of mass reduction (18.3 percent vehicle mass reduction) at a net savings of 0.13 euros per kg (in the Eastern EU). The reduced mass package with high cost options removed delivers 301.11 kg of mass reduction (17.6 percent vehicle mass reduction) at a net savings of 0.68 euros per kg. When the additional FEV mass reduction options discussed above—combined with an incremental secondary mass reduction impact of 7.5 kg—are implemented on top of the nominal reduced mass package with high cost options removed, the net package delivers 356.19 kg of mass reduction (20.8 percent vehicle mass reduction) at a net savings of 0.35 euros per kg. Table 2 presents a summary of these data.

Table 2. Summary of FEV Mass Reduction Benefits and Costs

			Western EU	Eastern EU
Mass Reduction Package	**Total Mass Reduction (kg)**	**Total Mass Reduction (percent)**	**Total Mass Reduction Cost (€/kg)**	**Total Mass Reduction Cost (€/kg)**
A. Mass Reduction Package as Described in FEV's Report	312.48	18.3	-0.45	-0.13
B. Package A with Nine High Cost Mass Reduction Options Removed	301.11	17.6	-1.05	-0.68
C. Package B with Three Additional Mass Reduction Options Added	356.19	20.8	-0.67	-0.35

As described above, FEV was tasked with defining mass reduction options capable of generating a 20 percent vehicle mass reduction. A similar study, but targeting a 30 percent vehicle mass reduction, was performed at approximately the same time by Lotus Engineering.[11] Both studies were based on the same baseline vehicle and both built off of and improved upon the analysis approach and data developed for an earlier study conducted by Lotus Engineering.[12] Thus, the analysis methods and baseline vehicle components evaluated by FEV and Lotus Engineering are consistent, so that the additional Lotus work targeting a 30 percent mass reduction package can be utilized to augment the work performed by FEV. Since the latest Lotus work is primarily limited to the detailed analysis of a BIW structure capable of promoting a 30 percent vehicle level mass reduction, the Lotus work is not a vehicle level substitute for the FEV data. It is possible, however, to replace the detailed FEV BIW with the similarly detailed Lotus BIW, while retaining the FEV non-BIW data. For the most part, this is a one-to-one replacement exercise, the only exception being that the added mass reductions associated with the more aggressive Lotus Engineering BIW also generate modestly larger secondary mass reduction benefits (2.8 kg) in the non-BIW components. For the Eastern EU analysis that underlies this paper, the Lotus BIW costs were adjusted according to the ratio of FEV Eastern EU-to-Western EU BIW costs (95.44/95.07, or 1.004). Table 3 presents a comparison of the FEV and Lotus Engineering BIW estimates, while Table 4 presents a summary of the various mass reduction package estimates.

4. Mass Reduction Cost Curves

The mass reduction package estimates summarized in Table 4 were developed into generalized cost curves through a detailed examination of the component mass reduction options. Two distinct curves were developed, one based on the adjusted mass reduction target data developed by FEV (package C in Table 4) and one based on these same data but with the Lotus reduced mass BIW substituted for the FEV reduced mass BIW (package D in Table 4). The former curve was taken as representative of mass reduction potential in 2020, while the latter was assumed to represent achievable reductions in the 2025 timeframe.

The specific methodology employed to generate the mass reduction cost curves is described in detail in Working Paper 2013-1. The exact same methodology was employed for the analysis underlying this paper, the only difference being the substitution of Eastern EU cost data for the previously employed Western EU data. The mass reduction cost curves are developed on the basis of system (or subsystem) level mass reductions and costs just as they were for Working Paper 2013-1. Secondary mass reductions were reallocated from those

10 It should be noted that one of the nine high cost mass reduction options that were removed from the Western EU analysis (see Working Paper 2013-1) had associated Eastern EU mass reduction costs below the four euros per kg selection criteria. For consistency across the Western and Eastern EU analyses, this option "Body Air Outlets," was eliminated from both analyses. Any effects due to such treatment are minor as this option contributes only 0.1 kg of the 9.8 kg total mass reduction of the nine high cost options.

11 Lotus Engineering Inc., "Evaluating the Structure and Crashworthiness of a 2020 Model-Year, Mass-Reduced Crossover Vehicle Using FEA Modeling," prepared for the California Air Resources Board (ARB) under Contract Number 09-621, August 31, 2012.

12 Lotus Engineering Inc., "An Assessment of Mass Reduction Opportunities for a 2017–2020 Model Year Vehicle Program," Revision 006A, prepared for the International Council on Clean Transportation (ICCT), March 2010.

components and systems that receive the secondary benefits to those components and systems that create them. Although this does not alter total mass reductions or costs in any way, it is absolutely necessary to properly account for the total mass impacts of both components and systems.

Table 3. Comparison of FEV and Lotus BIW Impact Estimates

Mass Reduction Package	Mass Reduction (kg)	Western EU		Eastern EU	
		Cost (€)	Cost (€/kg)	Cost (€)	Cost (€/kg)
1. BIW as Described in FEV's Report	50.79	95.07	1.87	95.44	1.88
2. FEV BIW after High Cost Options Removed & Additional Options Added	54.35	86.50	1.59	87.03	1.60
3. Lotus BIW	140.70	229.24	1.63	230.15	1.64
4. Differential Between Lotus BIW and FEV BIW (3 minus 2)	86.35	142.74	1.65	143.12	1.66

Note: The FEV BIW mass reductions change as adjustments are made to the base mass reduction package in accordance with the secondary mass impacts of those adjustments. The primary mass reductions associated with the FEV BIW are constant.

Table 4. Summary of Mass Reduction Package Benefits and Costs

Mass Reduction Package	Total Mass Reduction (kg)	Total Mass Reduction (percent)	Western EU	Eastern EU
			Total Mass Reduction Cost (€/kg)	Total Mass Reduction Cost (€/kg)
A. Mass Reduction Package as Described in FEV's Report	312.48	18.3	-0.45	-0.13
B. Package A with Nine High Cost Mass Reduction Options Removed	301.11	17.6	-1.05	-0.68
C. Package B with Three Additional Mass Reduction Options Added	356.19	20.8	-0.67	-0.35
D. Package C with FEV BIW Replaced with Lotus Engineering BIW	445.33	26.0	-0.23	+0.03

While secondary mass benefits accrue in only a subset of vehicle systems (and subsystems), these secondary reductions are facilitated by the cumulative primary mass reductions of *all* components that contribute to vehicle-level mass reduction. Thus, the benefits and costs of the secondary mass reductions are due to the cumulative effects of the contributing components, not the component or system exhibiting the reduction. To account for this, secondary benefits and costs are distributed across component mass reduction options in accordance with the share that each contributes to the total primary vehicle-level mass reduction.

Once secondary mass reduction impacts and costs are properly reallocated to contributing components, the next steps is to rank-order system level impacts in terms of cost per kilogram of mass reduced and plot the resulting cumulative impacts. This produces a series of data points ranging from near-zero mass reduction to the vehicle-level mass reduction package impacts summarized above in Table 4. Figure 2 depicts the data points for mass reductions of two percent and greater.[13] The depicted curves represent exponential regressions forced through the vehicle-level mass reduction package data point (the upper rightmost data point of each set of data points).

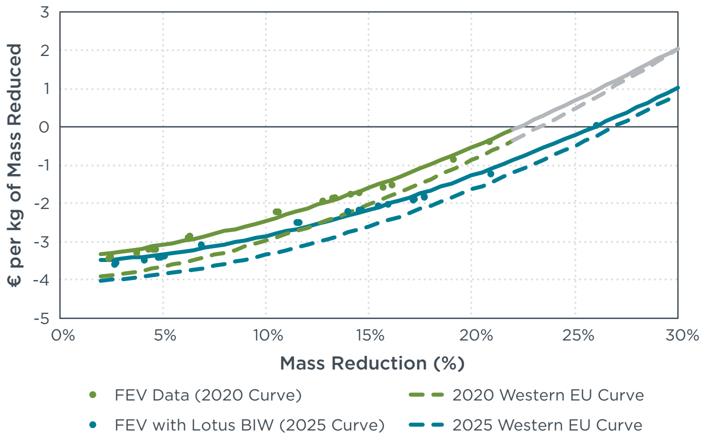

Figure 2. Nominal Mass Reduction Cost Curves for the Eastern EU

Costs are direct costs to the vehicle manufacturer (DMC).

The specific equations for each of the depicted curves are of the form:

$$€/kg\ cost = [a \times (percent\ mass\ reduction)^z] + b$$

and the evaluated parameters are:

Eastern EU Parameters	a	z	b	r^2
FEV BIW Curve (2020 Nominal)	36.94835	1.5900	-3.39719	0.99
Lotus BIW Curve (2025 Nominal)	37.13183	1.7444	-3.52257	0.99

Comparative Western EU Parameters	a	z	b	r^2
FEV BIW Curve (2020 Nominal)	42.57953	1.6276	-3.97684	0.99
Lotus BIW Curve (2025 Nominal)	40.35639	1.7487	-4.06337	0.99

As with the previously developed Western EU mass reduction cost curves, two characteristic features of the

13 Two percent is representative of an inflection point in the cost curve. There are four data points between zero and two percent that exhibit costs ranging from -15 to -5 euros per kilogram of mass reduced. These data points have been ignored in the cost curves generated for this paper. They contribute no useful information since the smallest non-zero mass reductions evaluated are five percent. By ignoring these data, the cost curves produced for this paper will *overestimate* the cost of mass reductions between zero and two percent. This does not affect the data presented in this paper in any way, but caution is advised in using the presented cost curves for other applications.

Eastern EU curves should be noted. First, the presented curves are cumulative cost curves as opposed to marginal cost curves. The independent parameter is the net (or cumulative) cost of any given mass reduction, incremental costs can be determined via the differential between the net costs of two given mass reductions. Expressing the curves in this manner denotes no special consideration, it is simply more convenient for the calculations associated with this work. Second, Figure 2 includes an extrapolation of both cost curves through mass reductions of 30 percent. The 2025 curve is actually used to estimate the cost of a 30 percent mass reduction in this paper, but the utility of the 2020 curve is limited to a 20 percent mass reduction (and thus the extrapolation is shown in gray and is intended solely to facilitate a visual comparison of the two curves over the depicted range of the x axis).[14]

All of the data depicted to this point have been expressed in terms of nominal costs. These data effectively represent the long term direct manufacturing cost differentials for competing technologies (generally alternative "new" technology versus baseline "old" technology) under an identical set of boundary conditions (including, for example, high production volumes, equivalent market maturity, and unchanged manufacturing cost structures). Learning factors, also developed by FEV as an integral component of their study, are applied to convert nominal cost data to data applicable to any given year. In the case of mass reduction, these learning factors can generally be thought of as "reverse" or "un" learning factors, since they increase cost differentials (relative to nominal cost estimates) in the period through at least 2025—i.e., that period evaluated in this paper.

Figure 3 presents the 2020 and 2025 mass reduction cost curves including the application of the learning factors for 2020 and 2025 respectively. These are the actual cost curves used for the direct manufacturing cost (DMC) evaluations presented in this paper (the dotted curves are the nominal cost curves presented previously in Figure 2). Also depicted in Figure 3, for comparative convenience, are the corresponding mass reduction cost curves (with learning) previously developed for the Western EU.

As was the case for the previously developed Western EU cost curves, it is helpful to note that there are two mass parameters in the depicted cost curves. The first is the percentage mass reduction depicted as movement along the x axis. The second results from the fact that y axis costs are presented per unit reduction in mass. As the magnitude of mass reduction increases, the cost per unit mass reduction also increases as expected. However, because the cost per unit mass is negative for a wide range of mass reductions, it may not be inherently obvious that net *savings* can increase as mass reductions increase even though the cost per unit mass reduction is increasing at the same time. In effect, higher mass reductions are offsetting the reduced per unit savings of those reductions. While it is not possible to generalize this relationship since it is dependent on the base mass of the affected vehicle, it is possible to depict the relationship for any given vehicle base mass. For example, Figure 4 shows the absolute cost of mass reduction for the curves depicted in Figure 3 for two base vehicle masses, 1200 and 2000 kilograms—base masses that roughly approximate the lightest and heaviest vehicles evaluated in this paper. As depicted, although cost savings per unit mass reduction decrease continuously with increasing mass reduction, net cost savings increase through about 11 percent mass reduction for the 2020 cost curve and through about 13.5 percent mass reduction for the 2025 cost curve—after which net cost savings decrease.[15] Recognizing this relationship can be helpful in understanding the effects of integrating the mass reduction cost curves into the more general cost curve analysis that follows.

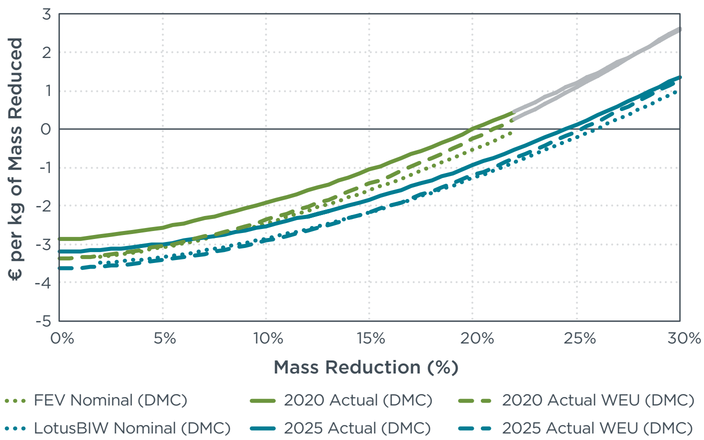

Figure 3. Actual Eastern EU Mass Reduction Cost Curves (with Learning)

Note: DMC means Direct Manufacturing Cost, WEU means Western EU.

14 The extrapolation of the 2025 curve is relatively modest, extending from 26 to 30 percent.

15 For comparative purposes, the corresponding minima for the Western EU data were 11.5 and 14 percent for the 2020 and 2025 cost curves respectively.

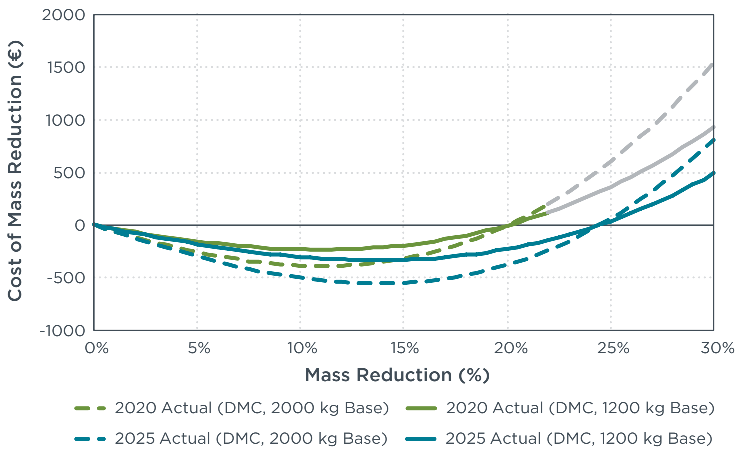

Figure 4. Eastern EU Mass Reduction Cost Curves in Net Cost Space

Note: DMC means Direct Manufacturing Cost.

Finally, FEV also developed indirect cost multipliers (ICMs) to convert direct manufacturing cost impacts to total cost (TC) impacts (reflecting the additional post-manufacturing cost impacts of vehicle distribution and sales). Figure 5 depicts the cost curves that result from the application of the FEV indirect cost multipliers. The methodology used to develop the curves is identical to that already described for the direct manufacturing cost curves. The reader is referred to the cited FEV report for additional discussion of ICM derivation and application.

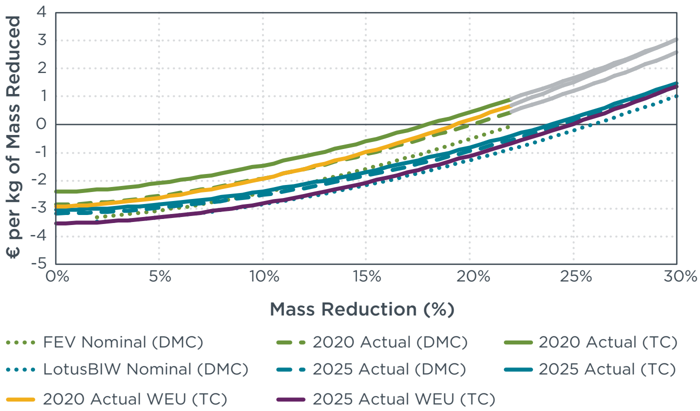

Figure 5. Eastern EU Mass Reduction Total Cost Curves

Note: DMC means Direct Manufacturing Cost, TC means Total Cost (TC = DMC × Indirect Cost Multiplier), WEU means Western EU.

5. Integration of the Mass Reduction Cost Curves Into the EU Cost Curve Analysis

As discussed in detail in Working Paper 2012-5, the basic methodology used to develop CO_2 cost curves for EU light-duty vehicles consists of combining CO_2 data resulting from vehicle simulation modeling performed by Ricardo Inc. with technology cost data developed through vehicle teardown studies by FEV, Inc. For the analysis underlying this paper, two primary modifications were implemented to the cost curve data previously reported in Working Paper 2013-1. First, the mass reduction cost curve data previously developed on the basis of Western EU labor costs were replaced with newly developed mass reduction cost curves for the Eastern EU, developed as described in the preceding sections of this paper. Second, similar substitutions of Eastern EU for Western EU discrete (non-mass reduction) technology costs were implemented to reflect Eastern EU labor rates. The specific discrete technology cost data are included in the referenced FEV report as well as discussed in general in Section 2 above. Since these modifications essentially entail one-for-one substitutions (i.e., Eastern EU for corresponding Western EU data), no additional discussion beyond that presented in the preceding sections of this paper is merited.

There is, however, one additional update to the previous work that was implemented for this paper. Previous FEV-developed costs for petrol vehicle cooled exhaust gas recirculation (EGR) technology were referenced to non-cooled EGR baseline systems. For the analysis underlying this paper, the cost baseline for petrol cooled EGR technology has been revised to reflect vehicles without EGR. This update results in a net increase in nominal direct manufacturing costs of 30.7 euros for the Western EU. Since Eastern EU cost data have not been previously analyzed, this update has no practical effect, but the equivalent cost increase for the Eastern EU for the same change in baseline EGR systems is 24.8 euros.

6. Resulting Eastern EU Cost Curves

Figures 6 and 7 depict an example of the resulting cost curves. Specifically, the figures depict the Eastern EU labor rate cost curves for C class petrol and diesel vehicles, respectively. Both figures present cost curves for 2020 and 2025, with and without mass reduction technology.[16] As indicated, the cost of CO_2 standard compliance is lower if mass reduction technology is credited by the compliance system.

16 The vehicle technology packages included in the figures provide examples of the types of technology packages included in the underlying analysis. To facilitate readability, not all evaluated technology packages are included.

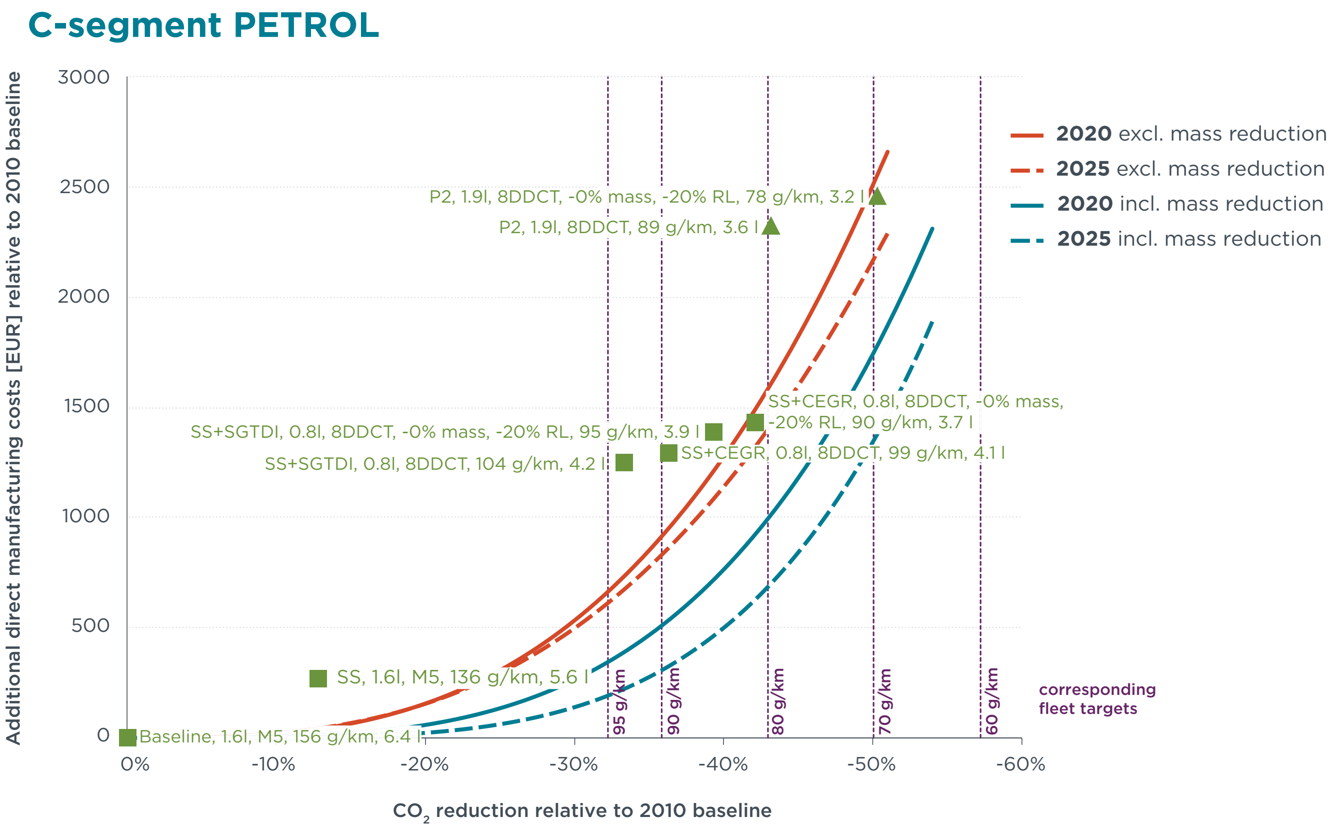

Figure 6. Cost Curves for Class C Petrol Vehicles with Eastern EU costs

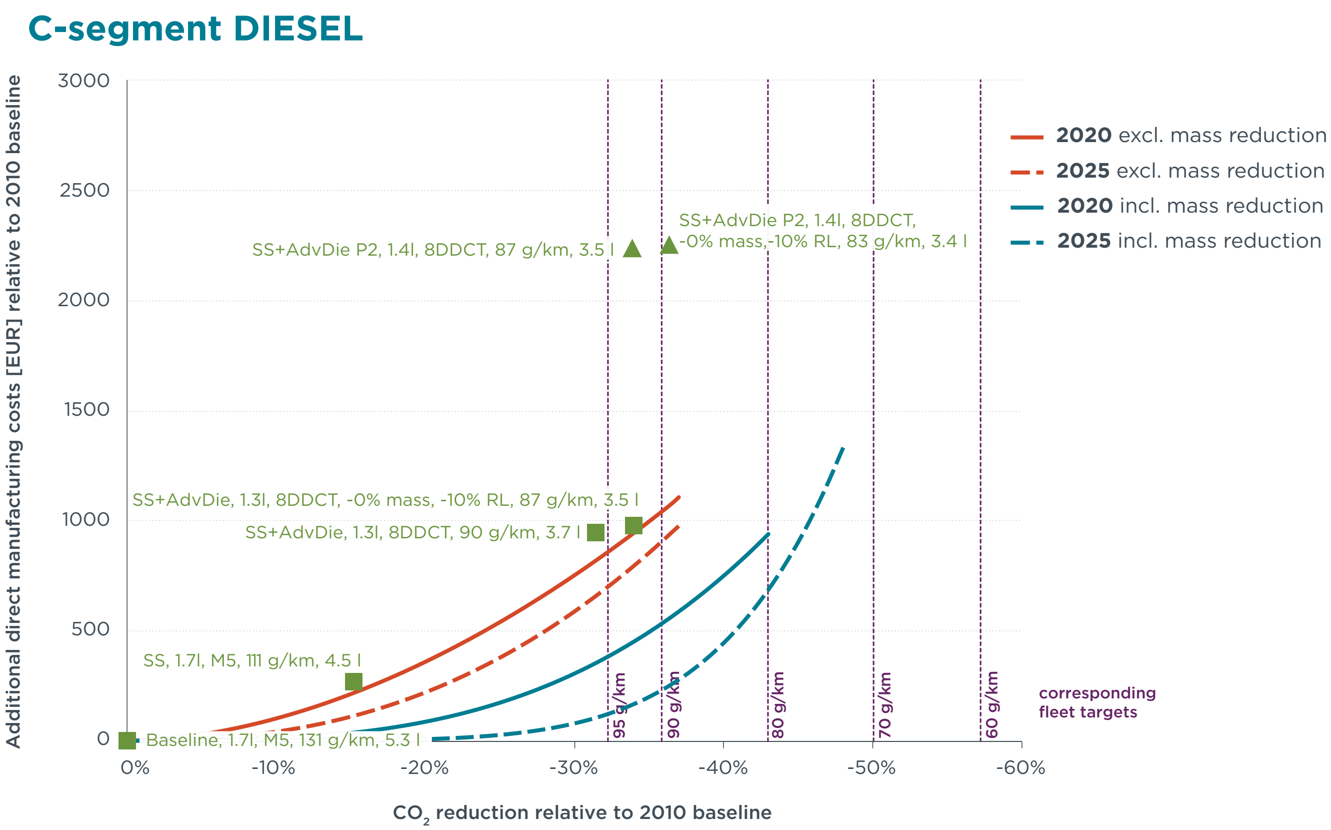

Figure 7. Cost Curves for Class C Diesel Vehicles with Eastern EU costs

When the CO_2 emission reduction benefit of mass reduction technology is not credited by the compliance system, or is *fully discounted*, the cost of compliance with a 95 g/km CO_2 standard in 2020 increases by about 300 euros for petrol vehicles and about 500 euros for diesel vehicles compared to a situation in which mass reduction technology is *fully creditable*.[17] Differences are even greater in 2025 as mass reduction options are assumed to expand beyond the 20 percent mass reduction cap assumed for 2020.[18]

Compared to the Western EU labor rate cost curves, compliance cost for C class vehicles in 2020 are lower by about 200 euros in the case of the Eastern EU labor rate cost curves.

Figures 8 and 9 depict corresponding curves for all passenger car classes evaluated for this paper with Eastern EU labor rates. The trends for the B Class and D class vehicles are similar to those of the C class vehicles, although there is variation between classes. The Eastern EU labor rate cost curves show a range of 200 to 400 euros lower compliance cost (95 g/km CO_2) across different classes in 2020 than those of the Western EU.

The endpoints of the cost curves depend on the technologies included in the cost curve. For example, for C class petrol vehicles, P2 hybrid technology was found to be a cost effective measure and was therefore included for the cost curve construction. The resulting maximum CO_2 reduction potential for C class petrol vehicles in 2020 is approximately 50 percent if mass reduction benefits are excluded, or 54 percent if mass reduction benefits are included (see Figure 6). For C class diesel vehicles, P2 hybrid technology was found to result only in marginally higher CO_2 reductions than advanced non-hybrid diesel technology, while carrying much higher costs. P2 technology is, therefore, not included in the C class diesel cost curve construction. Hence, the maximum CO_2 reduction potential—and the endpoint of the diesel cost curve—is approximately 36 percent if mass reduction benefits are excluded, or 43 percent if mass reduction benefits are included (see Figure 7).

To better depict a generalized relationship, Figures 10 and 11 depict characteristic cost curves for 2020 and 2025 constructed by weighting the individual cost curves for each of the vehicle segments by their respective market shares. For this it is assumed that market distributions across vehicle classes and fuel shares within vehicle classes do not change over time (i.e., the market share of petrol and diesel vehicles within each vehicle class and the market shares of B, C, and D class vehicles remain constant between 2010 and 2020/25).

The darker shaded areas in Figures 10 and 11 indicate the CO_2 reduction range where cost curve data for *all* vehicle segments are available (i.e., the area is constrained by the endpoint of the least ambitious cost curve, which is that of the B class diesel vehicle). The lower bound of the area is defined by a scenario in which mass reduction technology is *fully* credited by the compliance system, while the upper bound is defined by a scenario where mass reduction technology is *fully discounted*. For example, the additional direct manufacturing costs to achieve a CO_2 standard of 95 g/km, using the Eastern EU labor rate cost curves, in 2020 are between 400 and 1000 euros relative to the 2010 baseline. The 400 euros estimate assumes a technology neutral CO_2 regulatory structure wherein mass reduction technology is *fully* credited (e.g., a structure based on vehicle footprint), whereas the 1000 euros estimate is for a regulatory structure wherein mass reduction technology is *fully* discounted. The current EU vehicle weight-based structure *strongly*, but not *fully*, discounts mass reduction technology. The compliance costs under such a system are, therefore, assumed to be close to 800 euros for the Eastern EU labor rate cost curves. For the Western EU labor rates, the fleet-average compliance cost is estimated to be about 200-300 euros higher.

17 Note that the CO_2 target values indicated in the figures assume that all vehicle segments reduce CO_2 by an identical percentage. The C Class target itself is not 95 g/km per se, but the level of CO_2 that would result in a fleet average CO_2 level of 95 g/km.

18 Note that costs in 2020 and 2025 without mass reduction technology are not identical due to learning that is assumed to occur in the intervening five year period.

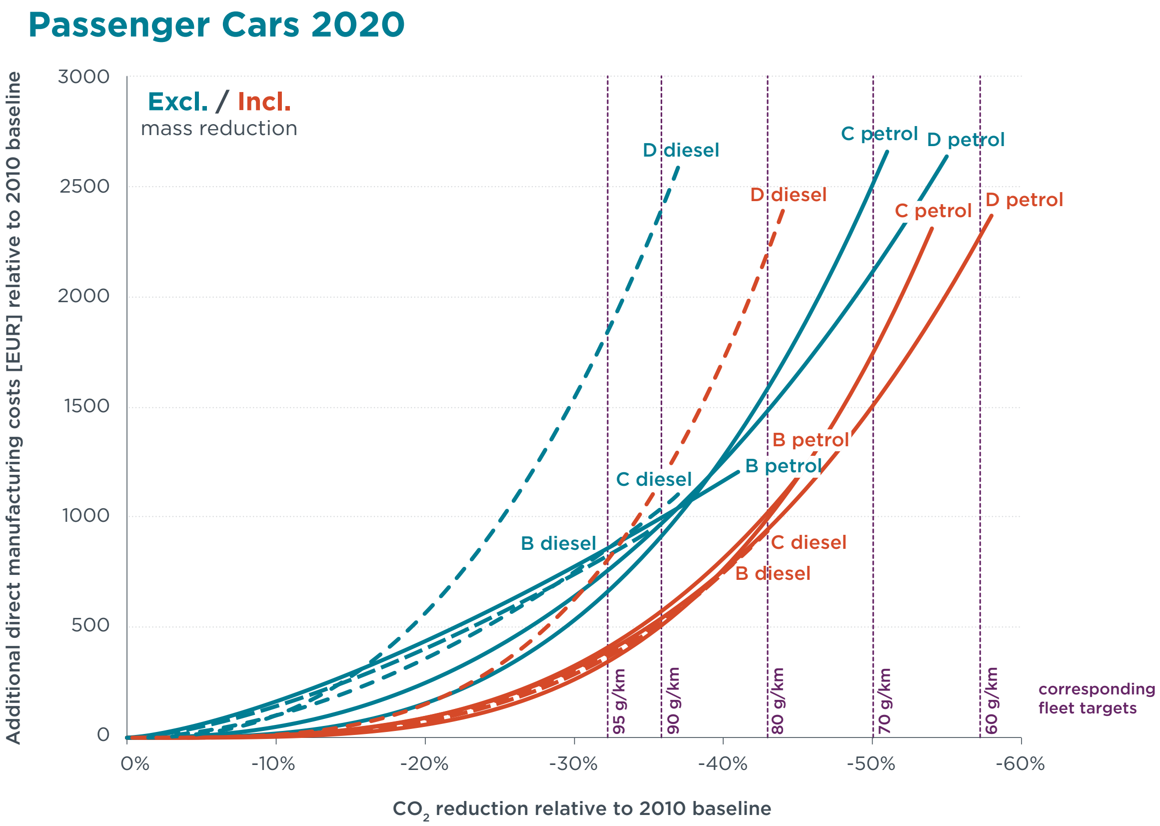

Figure 8. 2020 Class-Specific Cost Curves for Passenger Vehicles with Eastern EU costs

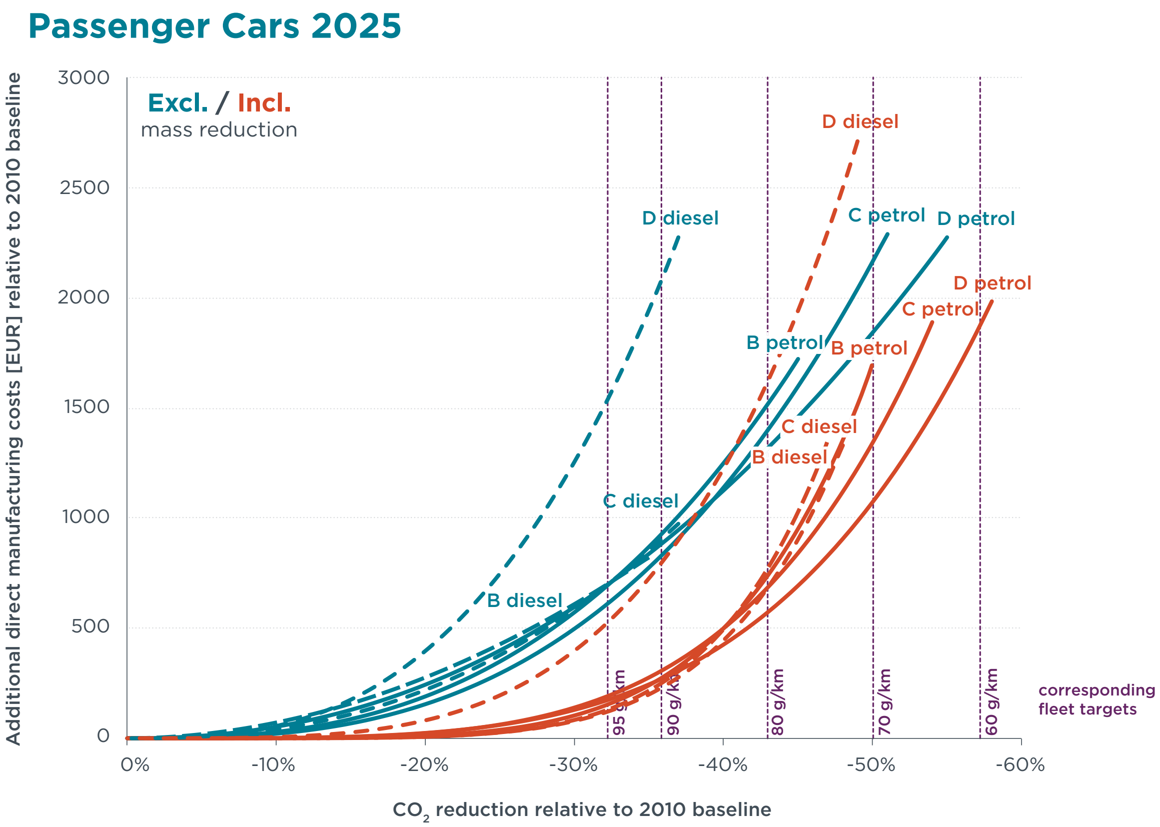

Figure 9. 2025 Class-Specific Cost Curves for Passenger Vehicles with Eastern EU costs

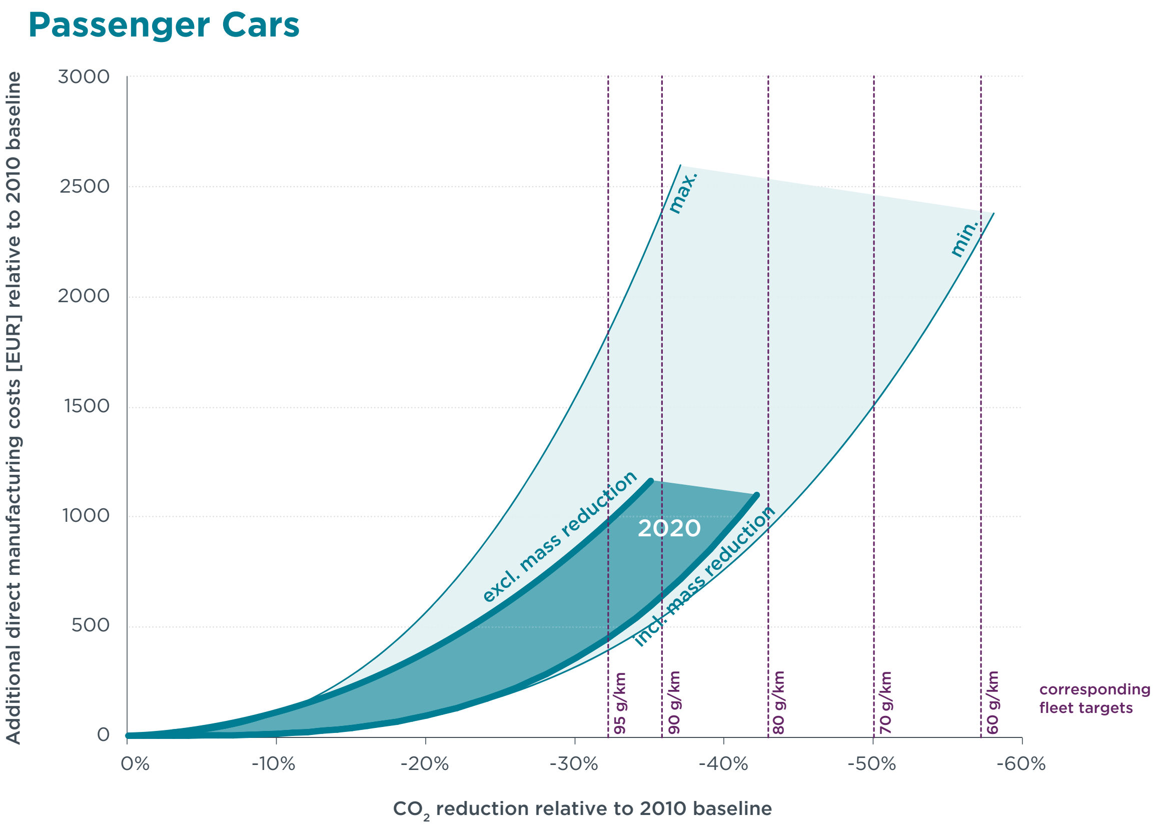

Figure 10. 2020 Passenger Vehicle Eastern EU Cost Curves Relative to 2010 Base

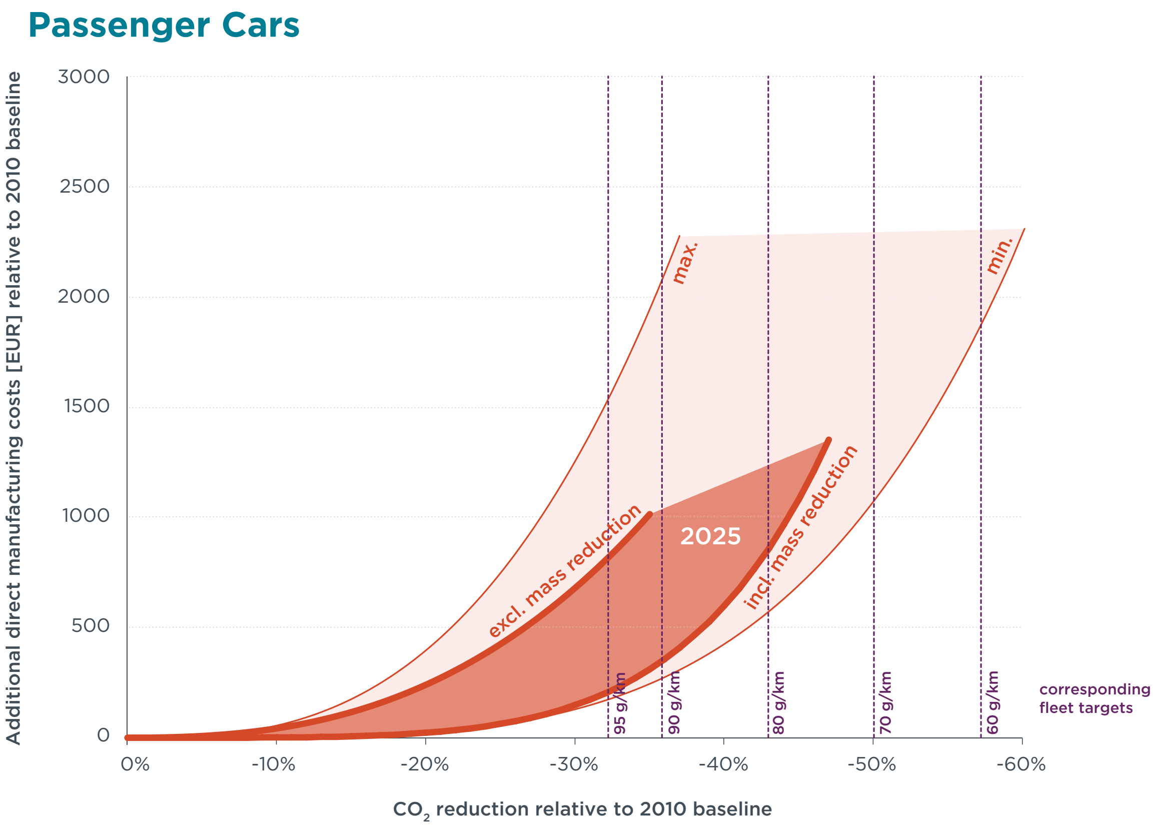

Figure 11. 2025 Passenger Vehicle Eastern EU Cost Curves Relative to 2010 Base

The lighter shaded areas in Figures 10 and 11 indicate the CO_2 reductions that are feasible in the most and least costly vehicle segments. The “maximum” curve indicates the most expensive cost curve (which reflects the D class diesel vehicle without mass reduction benefits), while the “minimum” curve indicates the least expensive cost curve (which reflects the D class petrol vehicle with mass reduction benefits). Meeting a CO_2 standard that is outside the darker shaded areas but within the lighter shaded areas requires either advances in technology beyond that considered in this analysis and/or shifts in vehicle class-specific of fuel-specific market shares.

Figures 12 and 13 depict similar characteristic curves, but expressed relative to the 2015 CO_2 standard of 130 g/km for passenger cars instead of 2010. Since the 130 g/km value is not far from the 2010 market average (140 g/km), the resulting cost curves are almost identical, and the compliance cost for a 95 g/km CO_2 standard in 2020 remains in the neighborhood of 400-900 euros relative to the 2015 baseline, while the Western EU labor rate compliance costs are estimated at 600-1200 euros incremental to the 2015 baseline.

Figures 14 through 17 depict corresponding cost curves for N1 (light-commercial) vehicles compared to a 2010 baseline. The costs for meeting the current 147 g/km CO_2 standard in 2020 are in the range of 200 to 350 euros per vehicle relative to the 2010 baseline using Eastern EU labor rates,[19, 20] while costs range from 260 to 500 euros using Western EU labor rates.

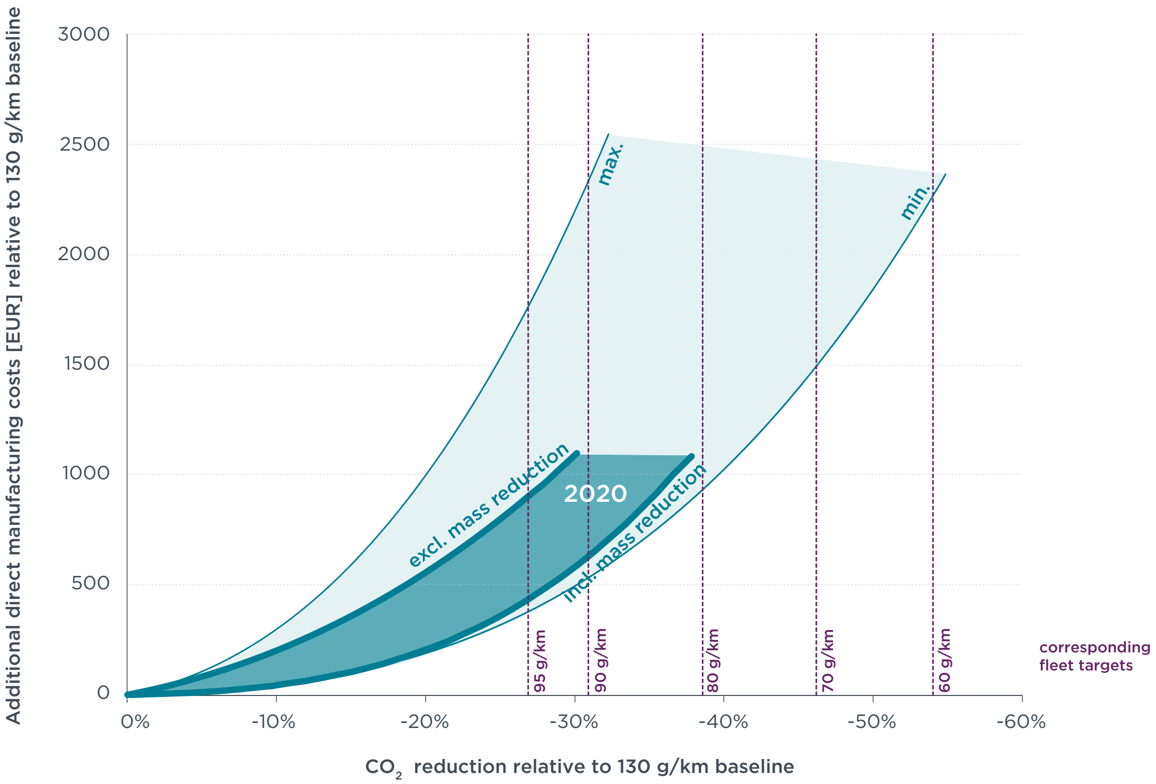

Figure 12. 2020 Passenger Vehicle Eastern EU Cost Curves Relative to 2015 Target

19 It should be noted that for N1 vehicles, the least expensive cost curves are for small and large N1 petrol vehicles. Since these vehicles currently account for only about 6 percent of the market, the respective cost curves were not used to determine the lighter shaded areas in Figures 16 and 17. Instead, only the small and large N1 diesel vehicle cost curves were used.

20 Similar to the passenger vehicles, 40% mass reduction benefits are used to estimate the high end of the compliance costs for N1 vehicles.

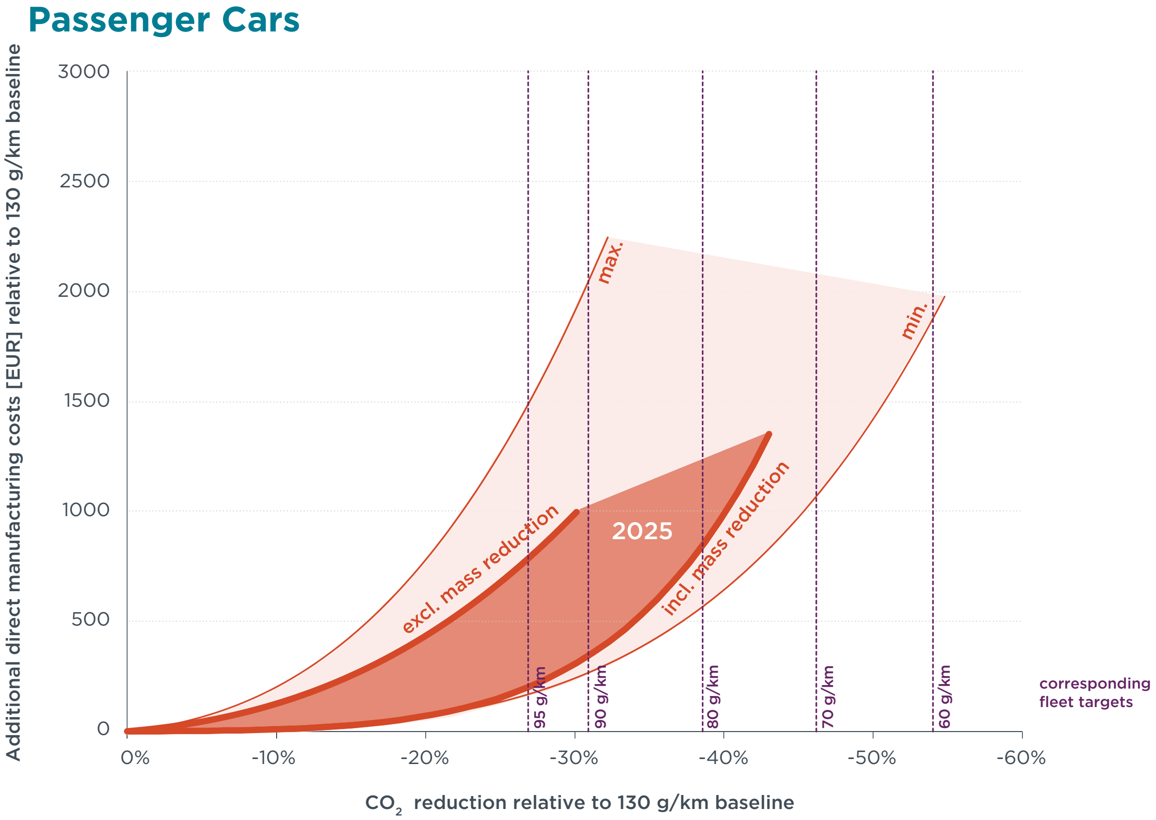

Figure 13. 2025 Passenger Vehicle Eastern EU Cost Curves Relative to 2015 Target

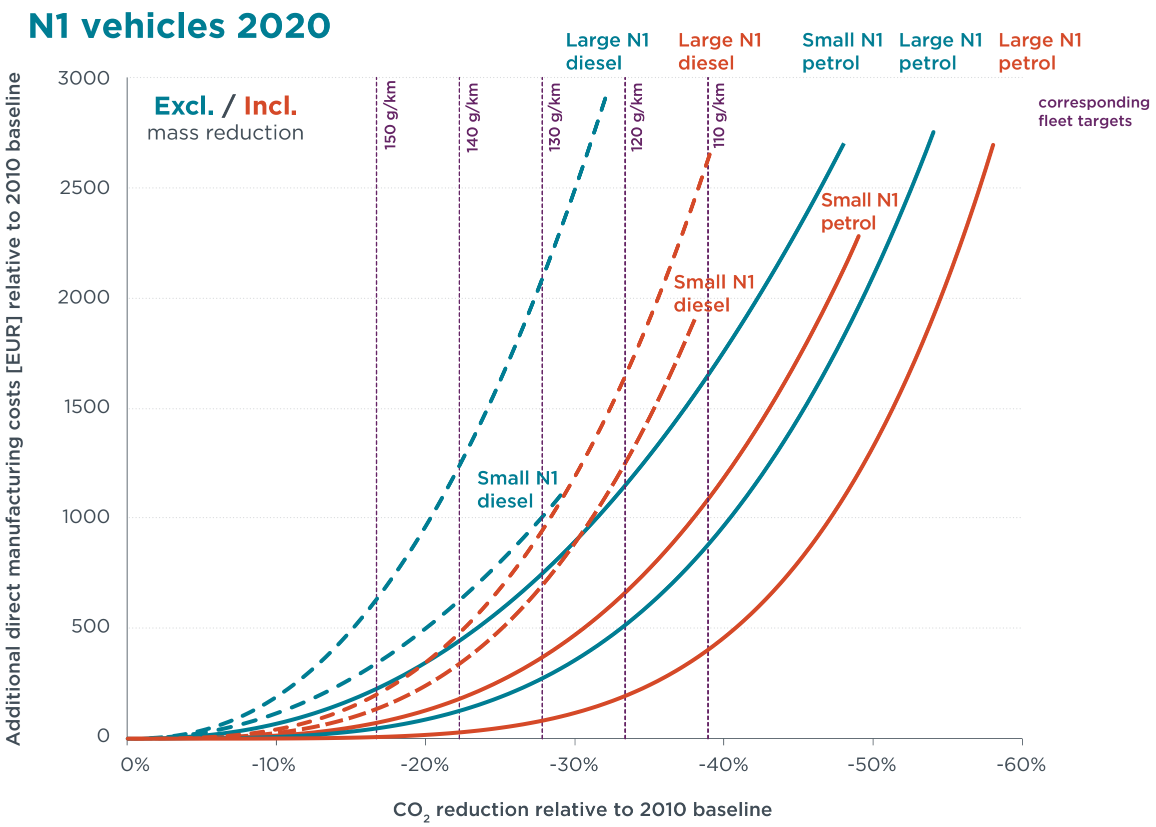

Figure 14. 2020 Eastern EU Cost Curves for N1 Class Vehicles Relative to 2010 Base

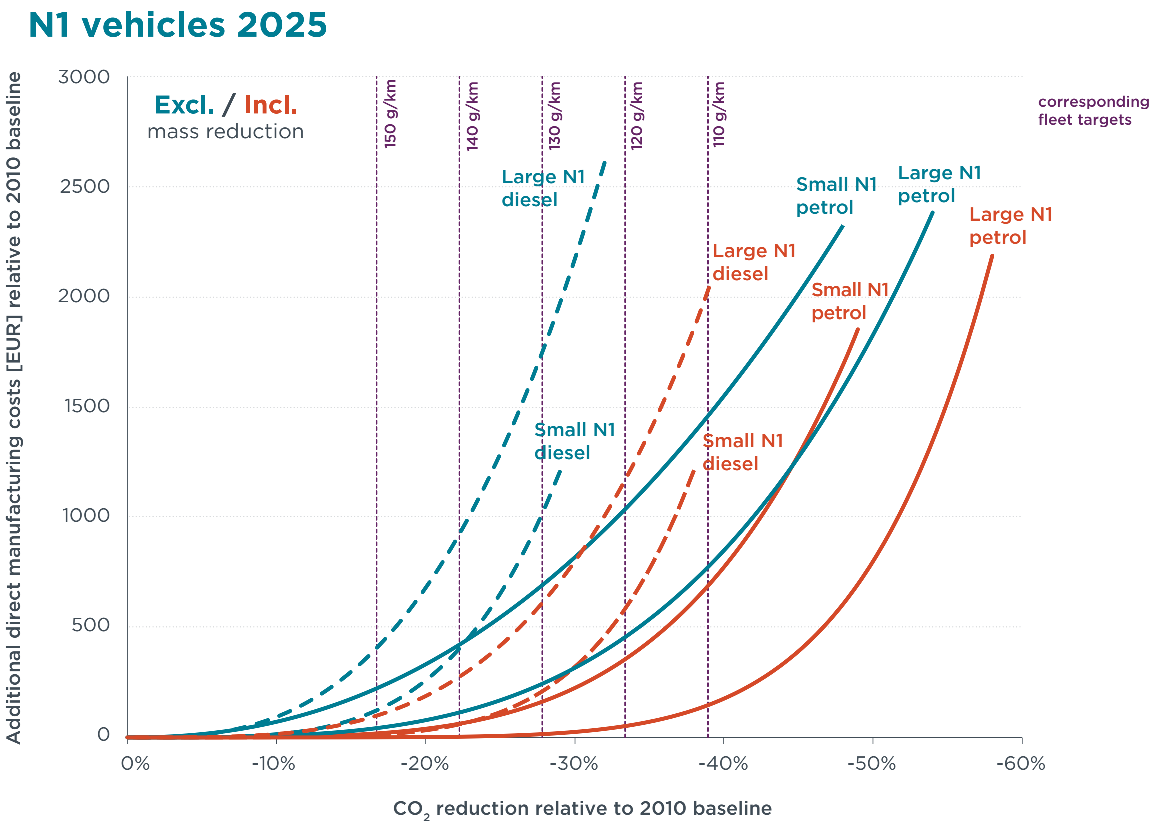

Figure 15. 2025 Eastern EU Cost Curves for N1 Class Vehicles Relative to 2010 Base

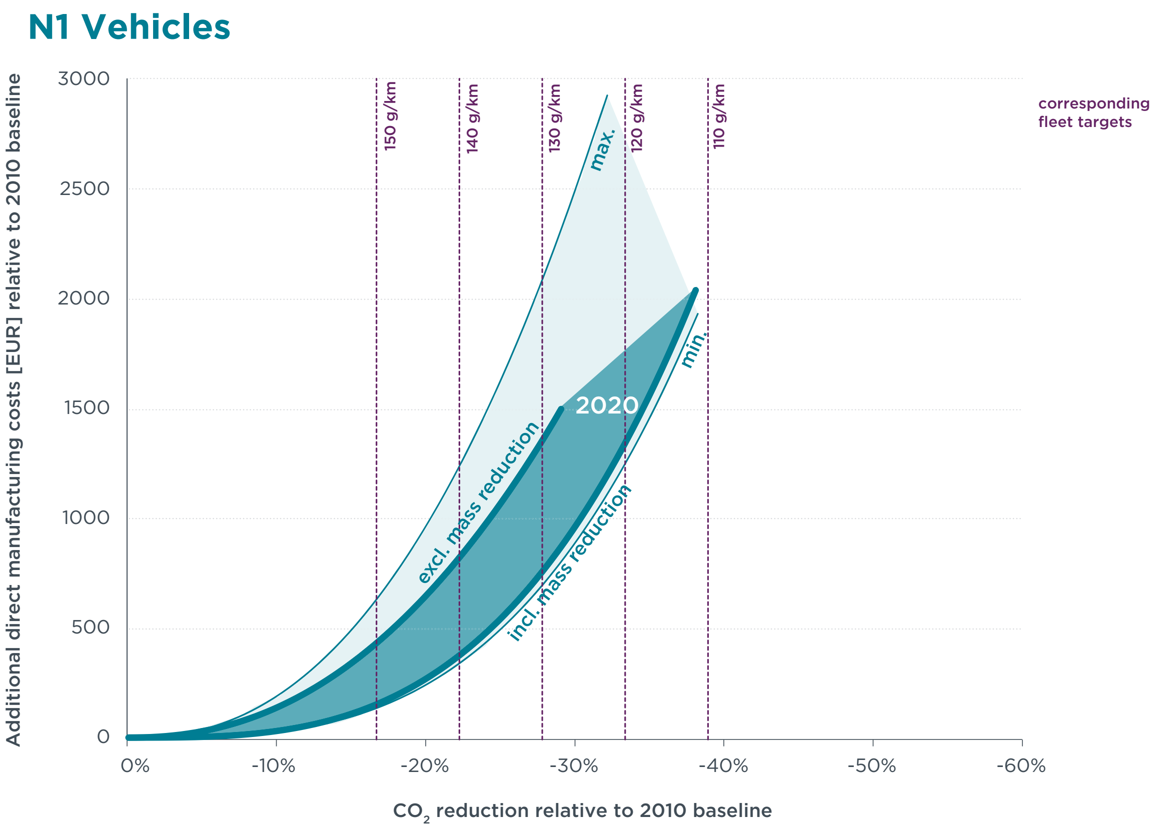

Figure 16. Characteristic 2020 N1 Eastern EU Cost Curves Relative to 2010 Base

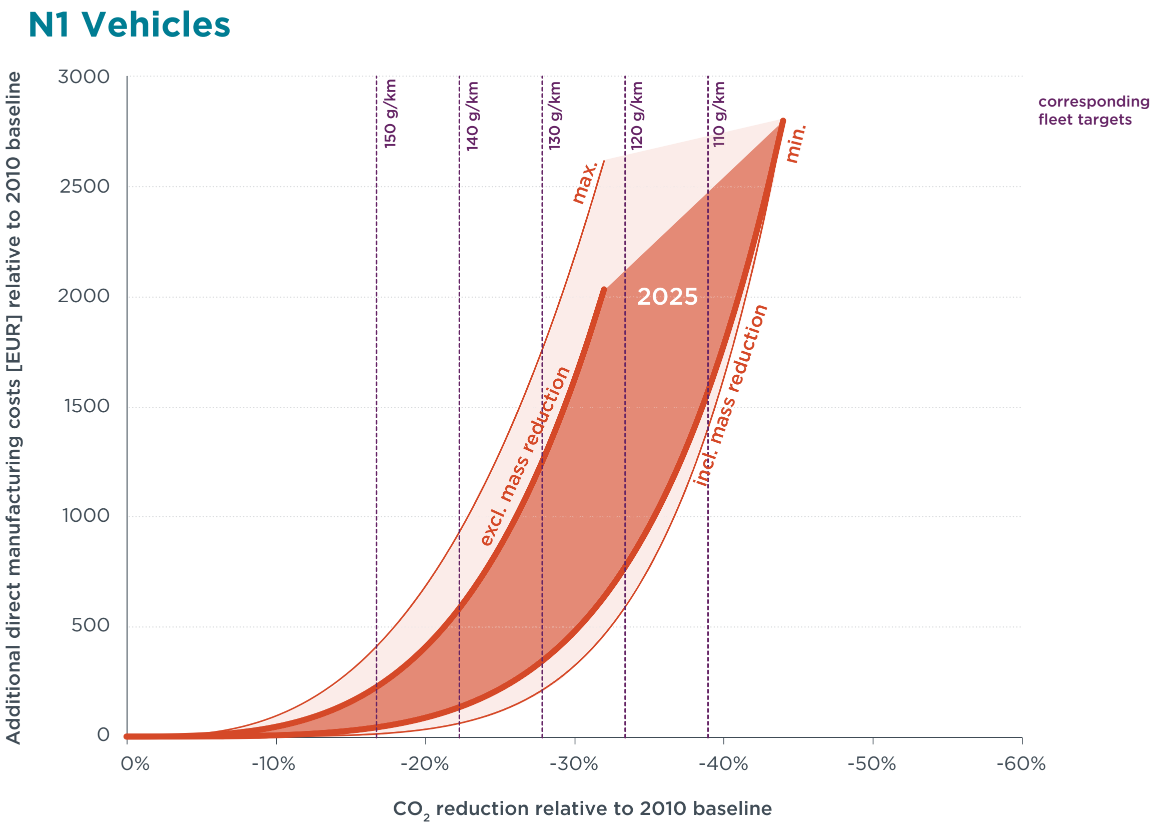

Figure 17. Characteristic 2025 Eastern EU N1 Cost Curves Relative to 2010 Base

7. Summary Remarks

This paper presents a set of revised cost curves, substituting Eastern EU labor costs for the previously-used Western EU labor costs. Based on the revised curves, the following conclusions can be drawn:

- Assuming Eastern EU labor rates, the estimated additional cost to attain a CO_2 standard of 95 g/km by 2020 is lower than 800 euros per vehicle relative to 2010 baseline, and as low as 400 euros per vehicle under a CO_2 regulatory structure that fully credits vehicle mass reduction. Assuming Western EU labor rates, on average the corresponding costs are estimated to be approximately 200-300 euros higher.
- For light-commercial vehicles, assuming Eastern EU labor rates, the estimated additional cost to attain a CO_2 standard of 147 g/km by 2020 is approximately 350 euros per vehicle relative to a 2010 baseline, and as low as 200 euros per vehicle under a CO_2 regulatory structure that fully credits vehicle mass reduction. Assuming Western EU labor rates, on average the compliance cost is estimated in a range of 260 to 500 euros.
- The 2020 targets can be attained by improvements to internal combustion engines and moderate mass reduction, with some degree of hybridization. It is expected that most manufacturers will be able to achieve compliance without introducing hybrids, but some manufacturers will likely need hybrid technology to offset atypical high-CO_2 fleet characteristics. Electric vehicles (either pure battery electric or plug-in hybrid electric) are not required to meet either fleet average CO_2 target. Note that manufacturers may still elect to introduce such vehicles to take advantage of the super-credits or for research, experience gathering, and other purposes.
- The cost to attain CO_2 standards below 95 g/km (passenger cars) and 147 g/km (light-commercial vehicles) depends on the specific standard and on the lead time allowed for compliance. Assuming that future market shares of fuels and vehicle classes remain as the same as current market shares, estimates can be derived from the cost curves presented in Figures 12-13 and 16-17.
- Compliance costs are much lower under a regulatory structure that fully credits the CO_2 emission reduction benefits of vehicle mass reduction than under a structure where mass reduction technologies are not fully creditable. In the extreme case of a regulatory structure that fully discounts vehicle

mass reduction, compliance costs are twice as high. A technology neutral (e.g., size-based) CO_2 regulatory structure is, therefore, expected to result in significantly greater benefits for society than the current EU weight-based structure.

As with previous work in this series, it is important to understand that the cost curves presented in this paper only apply to the average vehicle market. Costs for individual manufacturers will be different, as will the technology mix applied by individual manufacturers. Nevertheless, the presented cost curves are based on extensive vehicle simulation modeling and detailed teardown cost assessments, mirroring the industry approach of assessing the emission reduction potential and cost of future technologies. The analysis is expected to be a best practice example for the development of vehicle technology cost curves, and the results an accurate representation of current cost estimates for future CO_2 emission targets in the EU.

8. Data Limitations and Future Work

Limitations to the approach and the presented cost curves include:

- An underlying cost assessment assumption is that costs are based on high volume production, but no consideration is made for future changes in the design of a technology (as compared to today's state-of-the-science). This means that any potential redesign of a technology to optimize efficiency and reduce associated costs is not considered in the analysis. FEV calls this more conservative approach a "should-cost" assessment, in that it is based on what should be the cost of a technology *that already exists today* if it is mass produced in high volume, without any changes to a design that reflects current knowledge. This is different than a "could-cost" assessment that considers what could be the cost of a technology if it is optimized over time through product redesigns that take advantage of evolving knowledge. A good example of this differential approach is P2 hybrid electric vehicle technology. Currently, the P2 electric motor and transmission are produced as two separate units. With larger volumes, it is likely that manufacturers will invest in a redesign of the technology to integrate the electric motor and transmission into a single unit, which will reduce manufacturing costs. This likely redesign of the technology, as well as potential similar impacts for other evaluated technology, is not taken into account for the current cost assessment presented in this paper. Thus, while the "should cost" approach employed for this paper adds an important "ground truth" validation to the presented cost estimates, it also fully discounts future technology advances. To the extent that such design advances occur, the presented cost curves will overstate CO_2 emission reduction costs in the years following such advances.
- For the development of the cost curves in this paper it is assumed that market shares of fuels and vehicle segments will not change in the future. In particular, it is assumed that the market shares of petrol and diesel vehicles will remain constant over time. However, there is some likelihood that the market share of diesel vehicles will decrease in the EU in the future, should diesel and gasoline fuel taxes be harmonized. Such a shift could have an impact on fleet average compliance costs.
- All CO_2 emission reduction technology is evaluated on a constant performance basis. It is assumed that the zero to 96.6 kilometers per hour (60 miles per hour) acceleration time for reduced CO_2 vehicles is unchanged from that of associated baseline vehicles. CO_2 emission reduction costs for reduced performance vehicles would be lower than depicted in the presented cost curves.

Given these limitations, the cost curves presented in this paper are expected to be more reflective of upper range costs for vehicles manufactured in the Eastern EU, and that the real costs for meeting 95 g/km and other potential CO_2 emission targets is likely to be lower than indicated above. Subsequent working papers in this series will continue to investigate alternative cost curve scenarios.

Abbreviations and Acronyms

AdvDie	Advanced Diesel
ARB	California Air Resources Board
BIP	Body-in-Primer (Paint)
BIW	Body-in-White
CEGR	Cooled Exhaust Gas Recirculation
CO_2	Carbon Dioxide
DCT	Dual Clutch (Automated Manual) Transmission
DMC	Direct Manufacturing Costs
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EU	European Union
excl.	Excluding
g	Gram(s)
g/km	Grams per kilometer
HEV	Hybrid Electric Vehicle
ICCT	International Council on Clean Transportation
ICM	Indirect Cost Multiplier
incl.	Including
kg	Kilogram(s)
km	Kilometer(s)
l	Liter(s)
max.	Maximum
min.	Minimum
Misc.	Miscellaneous
M5	Five Speed Manual Transmission
M6	Six Speed Manual Transmission
NHTSA	U.S. National Highway Traffic Safety Administration
P2	P2 Design HEV
RL	Road Load
SGTDI	Stoichiometric Gasoline (Petrol) Turbocharged Direct Injection
SS	Start-Stop (Idle-Off) Technology
TC	Total Cost (DMC × ICM)
U.S.	United States
USAMP	U.S. Automotive Materials Partnership
6DDCT	Six Speed Dry Dual Clutch (Automated Manual) Transmission
8DDCT	Eight Speed Dry Dual Clutch (Automated Manual) Transmission
8WDCT	Eight Speed Wet Dual Clutch (Automated Manual) Transmission
€	Euro
$US2009	2009 U.S. Dollars
$US2010	2010 U.S. Dollars