IEA/SMP Model Documentation and Reference Case Projection

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1 INTRODUCTION AND MODEL OVERVIEW

Over the past two years, the IEA has worked with the WBCSD's Sustainable Mobility Project (SMP) to develop a global transport spreadsheet model that can serve both organisations in conducting projections and policy analysis. This report documents the model and describes the final reference case used in the SMP's Final Report, *Mobility 2030: Meeting the Challenges to Sustainability*.

1.1 Overview of the SMP Spreadsheet Model

The SMP transport spreadsheet model is designed to handle all transport modes and most vehicle types. It produces projections of vehicle stocks, travel, energy use and other indicators through 2050 for a reference case and for various policy cases and scenarios. It is designed to have some technology-oriented detail and to allow fairly detailed bottom-up modelling. The SMP spreadsheet model 1.60 is the most recent version and is available for a more detailed inspection (and use, though no user guide has been prepared and there are no plans, at this time, of providing on-going user-support for the model. A very basic outline of how to use the model is provided in the first sheet of the model spreadsheet).

The model does not include any representation of economic relationships (e.g., elasticities) nor does it track costs.[1] Rather, it is an "accounting" model, anchored by the "ASIF" identity:

Activity (passenger and freight travel) * ***S***tructure (travel shares by mode and vehicle type) * ***I***ntensity (fuel efficiency) * ***F***uel type = fuel use by fuel type (and CO_2 emissions per unit fuel use).

Various indicators are tracked and characterised by coefficients per unit travel, per vehicle or per unit fuel use as appropriate.

The modes, technologies, fuels, regions and basic variables included in the spreadsheet model are shown in the table below. Not all technologies or variables are covered for all modes. Apart from energy use, the model tracks emissions of CO_2, and CO_2-equivalent GHG emissions (from vehicles as well as upstream), PM, NOx, HC, CO and Pb. Projections of safety (fatalities and injuries) are also incorporated.

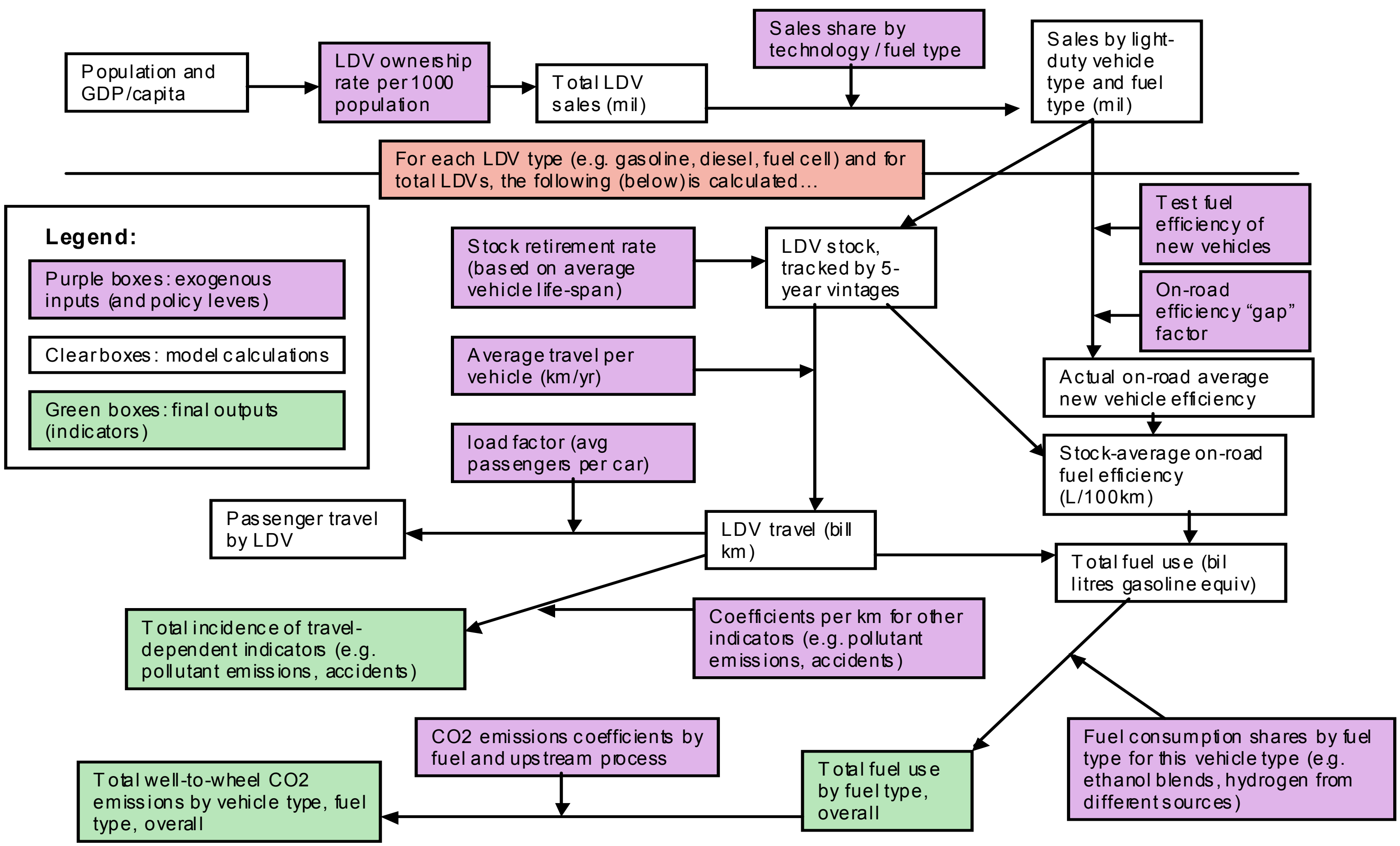
[1] The IEA has a cost-optimization model capable of this, the ETP model, but this model was not employed in the SMP's work due to its lack of transparency and its complexity.

Sectors, Fuels, Regions and Data Contained in the Spreadsheet Model

Sectors / Modes	**Vehicle Technologies/ Fuels**	**Regions**	**Variables**
• Light-duty vehicles (cars, minivans, SUVs) • Medium trucks • Heavy-duty (long-haul) trucks • Mini-buses ("paratransit") • Large buses • 2-3 wheelers • Aviation (Domestic + Int'l) • Rail freight • Rail passenger • National water-borne (Inland plus coastal) • Int'l shipping	• Internal combustion engine: ◊ Gasoline ◊ Diesel ◊ LPG-CNG ◊ Ethanol ◊ Biodiesel • Hybrid-Electric ICE (same fuels) • Fuel-cell vehicle ◊ Hydrogen (With feedstock differentiation for biofuels and hydrogen)	• OECD Europe • OECD North America • OECD Pacific (Japan, Korea, Australia, NZ) • Former Soviet Union (FSU) • Eastern Europe • Middle East • China • India • Other Asia • Latin America • Africa	• Passenger kilometres of travel • Vehicle sales (LDVs only) • Vehicle stocks • Average vehicle fuel-efficiency • Vehicle travel • Fuel use • CO_2 emissions • Pollutant emissions (PM, NOx, HC, CO, Pb) • Safety (road fatalities and injuries)

The most detailed segment of the model covers light-duty vehicles. The following flow chart provides an overview of the key linkages in the light-duty vehicle section of the model. For other passenger modes (such as buses, 2-wheelers), the approach is similar, however there is no stock model. Stocks are projected directly; vehicle sales needed to achieve these stocks is not currently tracked.

IEA/ETP Transport Spreadsheet Model Flowchart – Light-duty Vehicles



2 REFERENCE CASE HIGHLIGHTS

2.1 Definition of the Reference Case

The reference case projects one possible set of future conditions, based on recent trends in various important indicators and other variables. Adjustments are made for expected deviations from recent trends due to factors such as existing policies, population projections, income projections and expected availability of new technologies. Expectations for other future changes in trends, such as saturations in vehicle ownership, are also incorporated.

In general, no major new policies are assumed to be implemented beyond those already implemented in 2003. An exception to this is where there is clear evidence of what might be called "policy trajectories" – future policy actions that are either explicit or implicit in other trends. For example, a clear trend is emerging in the developing world to adopt vehicle emissions standards of a form similar to those already implemented in OECD countries. We assume this "policy trajectory" will continue in the future. In contrast, no such policy trajectory is evident for reduced light-duty vehicle (LDV) fuel consumption; we therefore only incorporate existing fuel consumption programmes through the year they currently end; we assume a return after that date to historical (non-policy-driven) trends in fuel consumption.

In general, we have tried to avoid introducing significant changes in trends after 2030. We run the trends assumed to exist in 2030 out to 2050 in order to see the net effects and directions in that latter year of actions and events that often occurred years earlier.

2.2 What is covered in the Reference Case?

The reference case covers the variables contained in the model, using the approach of the IEA "ASIF" structure: Activity, Structure, Intensity and Fuel composition. These variables together provide the basis for calculation of energy use by fuel type and of CO_2 and pollutant emissions.

The table below provides a simplified picture of what types of variables and the level of detail modelled for each major transport mode. As can be seen in the next table, there is a range of coverage by mode, as well as variations in the quality of the data available (indicated by x or i). In general, there is better data available for light-duty vehicles than for other modes, though for non-OECD regions most data is quite poor, except for aggregate estimates of transport energy consumption. New vehicle characteristics are only tracked for light-duty vehicles; existing stock is used as the basic vehicle indicator for all other modes.

The reference case includes the modes and variables identified in the table below:

Modes and Variables Covered in the Reference Case Projection

	LDV	Air	Truck	Frt Rail	Pass Rail	Bus	Mini-bus	2-3 wheel	Water
OECD regions									
Activity (passenger or tonne km)	●	●	●	●	●	●	i	i	
New vehicle characteristics (sales, fuel consumption)	●								
Stock-average energy intensity	●	●	●	●	●	●	i	i	
Calculation of energy use and vehicle CO_2 emissions	●	●	●	●	●	i	i	i	●
Non-OECD regions									
Activity (passenger or tonne km)	i	●	I	●	●	i	i	i	
New vehicle characteristics (sales, fuel consumption)	i								
Stock-average energy intensity	i	I	I	i	I	i	i	i	
Calculation of energy use and vehicle CO_2 emissions	i	●	I	●	●	i	i	i	●

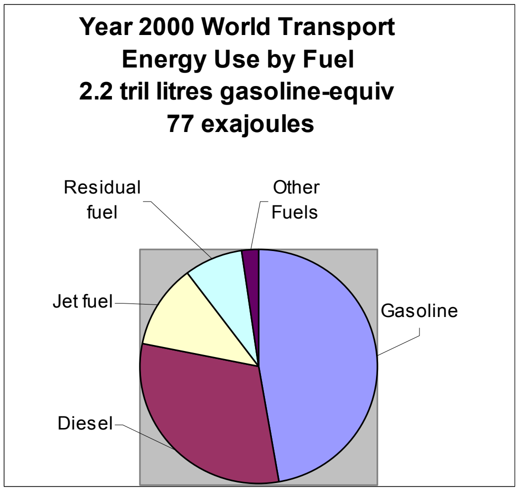
Note: ● = have data of fair to good reliability; i = have data but incomplete or of poor reliability; blank = have nothing or have not attempted to project. Note that data of fair reliability is available for energy use across all road vehicles in non-OECD countries, but breaking this out into various road modes (cars, trucks, buses, 2-wheelers) is difficult and relatively unreliable.

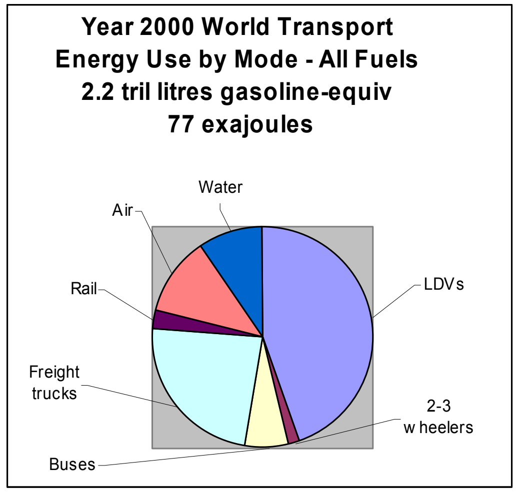
2.3 Key Results

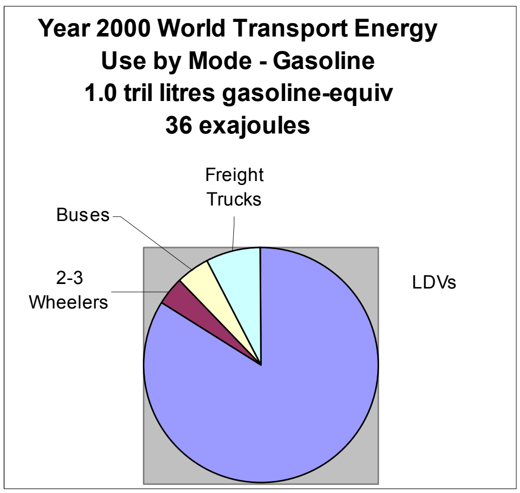
2.3.1 Fuel use projection

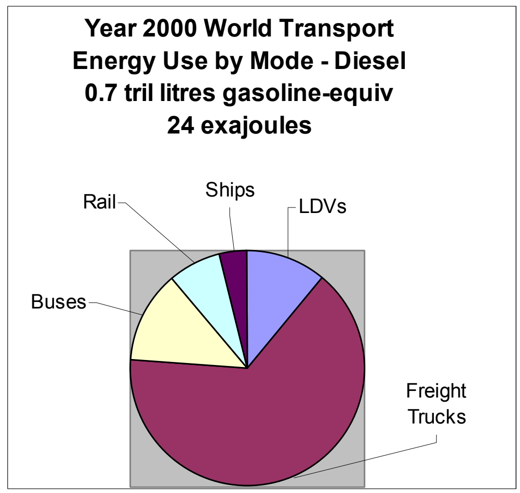
The fuel use projection results from projections of vehicle stocks, travel, intensity, and fuel types for each mode, from 2000 through 2050. Year 2000 fuel use breakout by mode shows that LDVs accounted for nearly half of transport energy use, and all road vehicles accounted for over three-fourths. The breakout by mode and fuel type shows that LDVs represented about 80% of total gasoline use and trucks about 75% of diesel fuel use. However, as discussed further in the more detailed sections that follow, some caveats are in order:

- IEA fuel use data is only for “all road vehicles” – breakouts here are based on our individual estimates for each mode.
- The breakout of LDV v. truck fuel consumption in most regions is based on weak assumptions
- Fuel consumption estimates for medium v. heavy-duty trucks is also uncertain

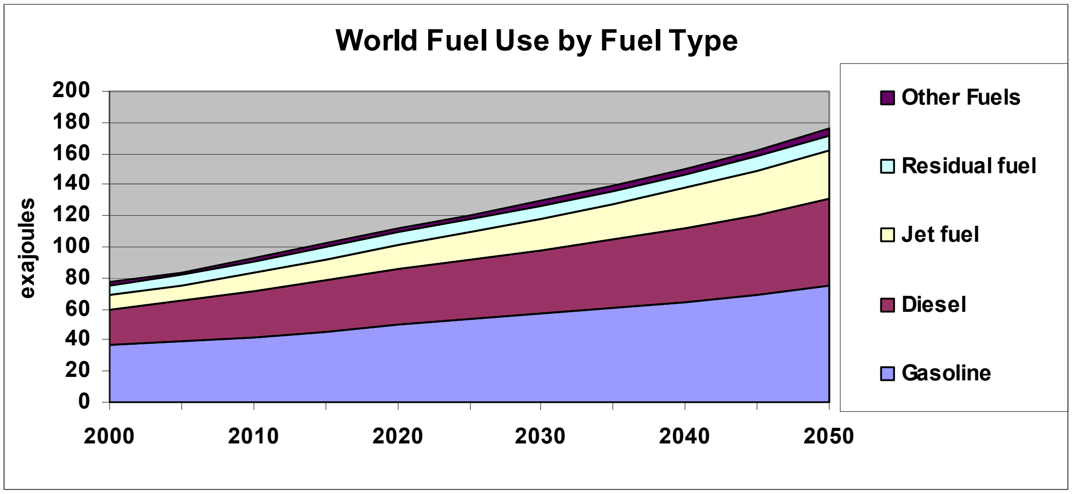




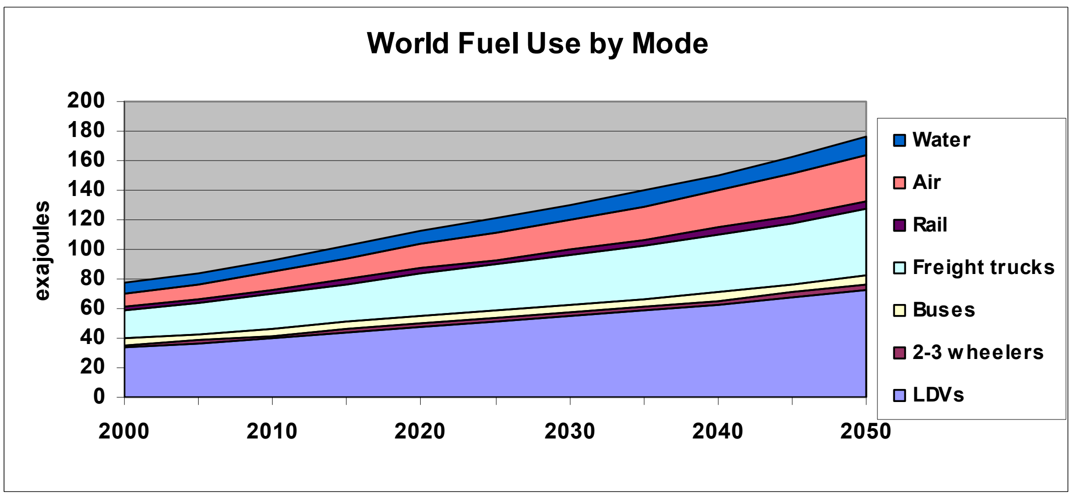




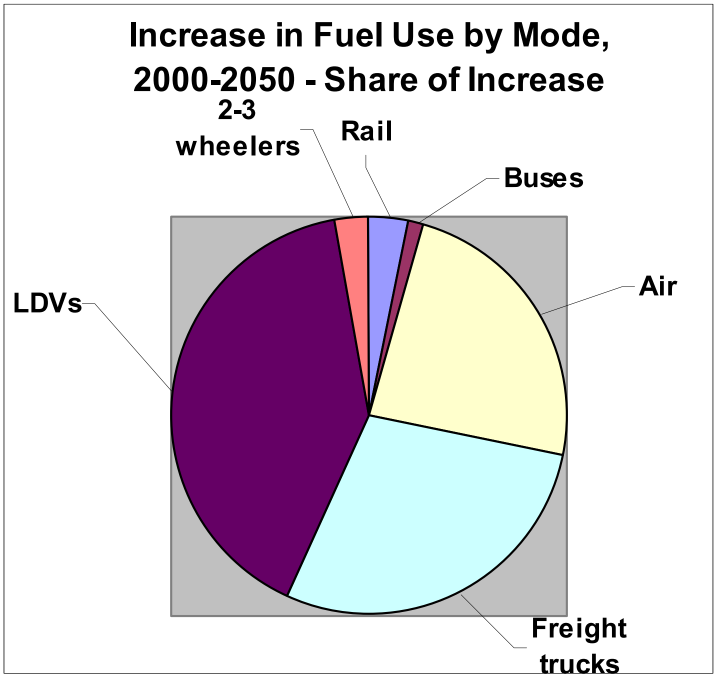
In the Reference Case projection, global transportation fuel use increases by a factor of nearly 2.5 between 2000 and 2050. Use of gasoline, diesel fuel, and jet fuel grows substantially, while other fuels retain a tiny share. Alternative fuels and vehicles do not penetrate significantly in the reference case. As shown in the second figure below, total fuel use by mode will grow significantly for all modes but buses, with the biggest growth occurring for light-duty vehicles, freight trucks, and air travel.



Note: “Other Fuels” include gaseous fuels, electricity and biofuels



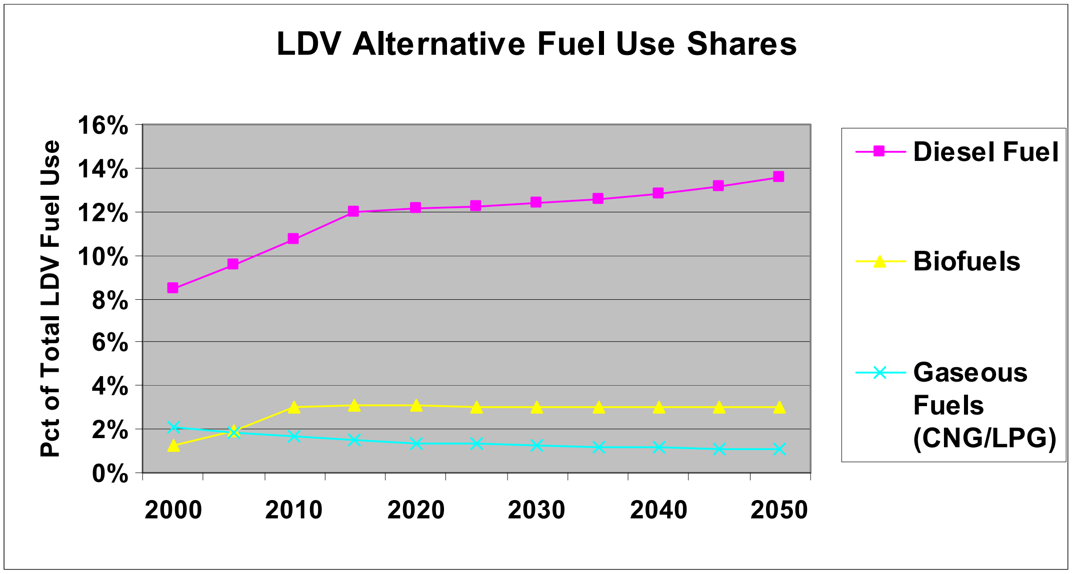
LDVs provide the biggest overall increase, accounting for nearly 40%of total increase of 99 exajoules. Though air has the highest growth rate and more than triples its fuel use between 2000 and 2050, its overall increase (22.6 exajoules) is significantly less than LDVs (38.5 exajoules), and somewhat less than freight trucks (26.8 exajoules). In terms of this increased energy use over the 50 years (year 2050 energy use minus year 2000 energy use), the following pie chart shows where most of the additional energy is being used.

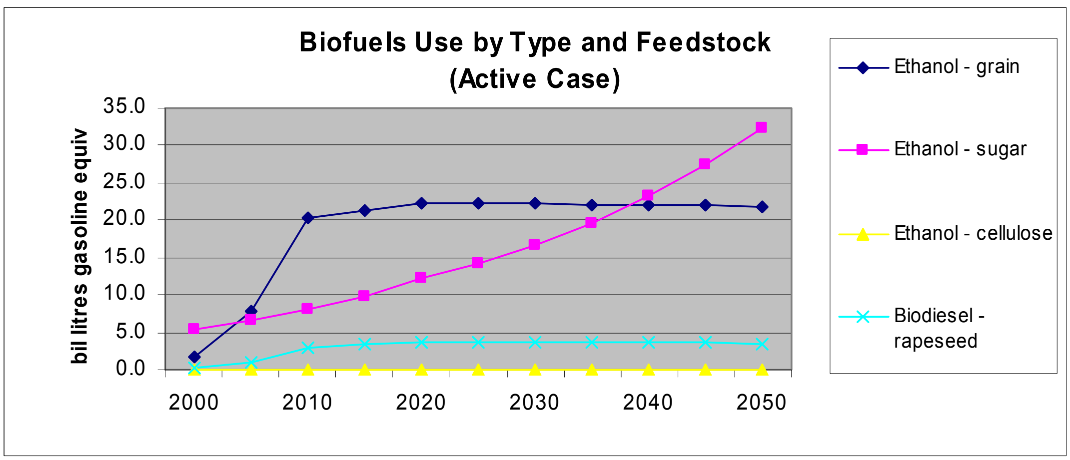


Light-duty vehicle alternative fuel use

In the reference case, road vehicles are assumed to use small, fairly constant amounts of most alternative fuels. The only fuels that show significant increases are diesel and biofuels. Key aspects include:

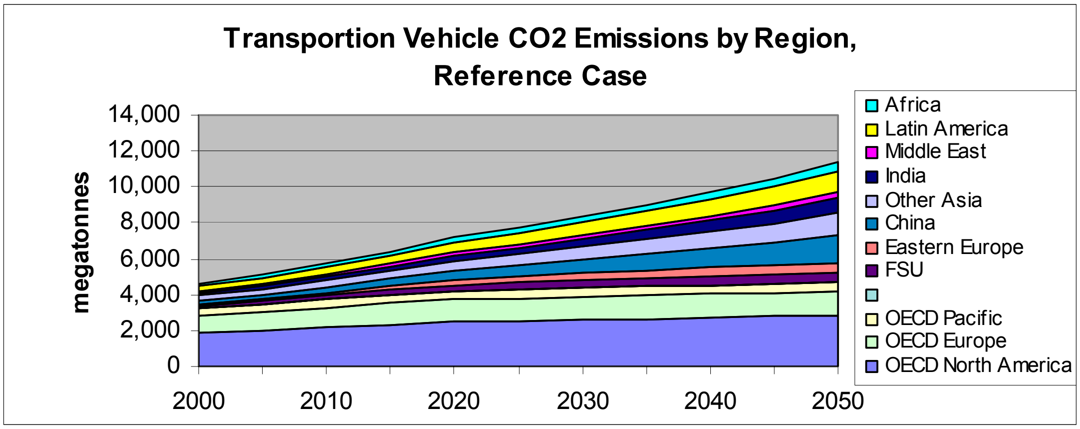
- Diesel fuel use share nearly doubles around the world (from 8% in 2000 to 14% in 2050), as LDV diesel vehicle sales increase. Diesel fuel share for trucks and buses remains fairly constant (at much higher shares than for light-duty).
- Ethanol in the US and Europe, and biodiesel in Europe, increase their share by several fold over the next 10 years, due to recent policy initiatives, then remain at a constant share after 2010 at around 3% of global LDV fuel use. In OECD regions, this is mainly ethanol from grains. In Latin America, the share of biofuels does not increase much, but production increases through 2050 along with total fuel use. This is mainly ethanol from sugar cane. Biofuels are also assumed to be blended into heavy-duty road vehicles but at lower levels.
- Gaseous fuels (CNG and LPG) are assumed to maintain a constant volume, and therefore declining share over the projection period (from 2% in 2000 down to about 1% by 2030). Hydrogen is barely used in the reference case (since fuel cell vehicles are not assumed to penetrate the market).



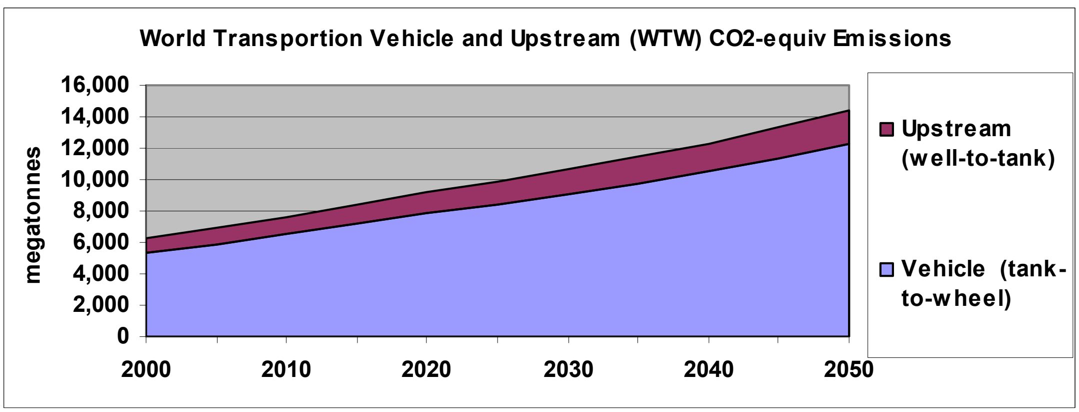


2.3.2 CO_2 Projections

Like fuel use, world transport CO_2 emissions from vehicles are projected to increase by a factor of 2.4 (i.e., by 140%), from about 4.6 gigatonnes in 2000 to 11.2 in 2050. Also, like fuel use (though not shown below), the vast majority of CO_2 increase will be in non-OECD (i.e., developing) regions.

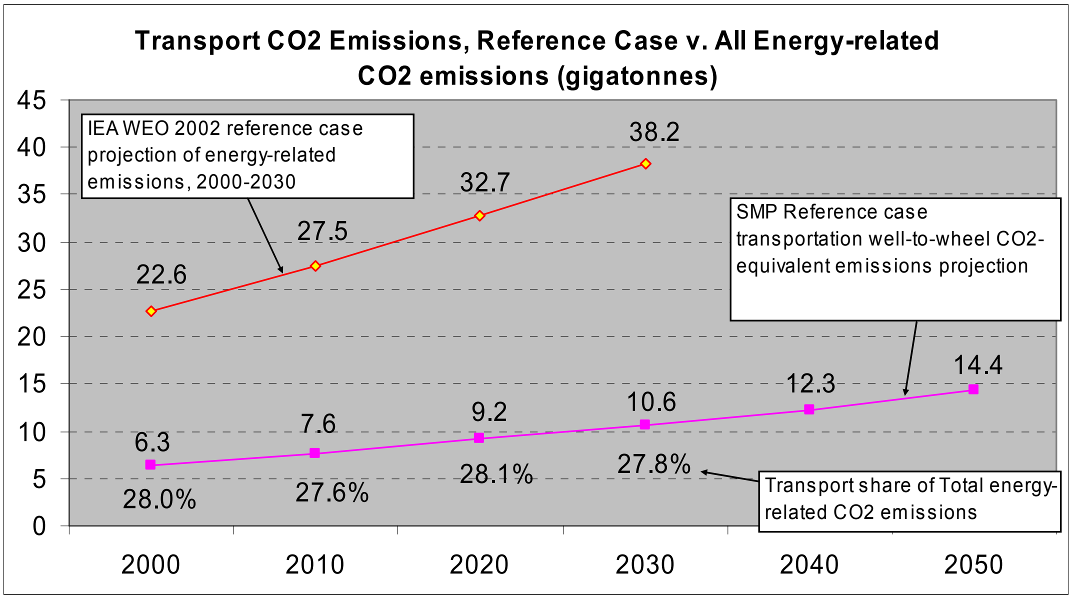


Accounting for upstream ("well-to-tank") adds an additional 12% to 16% CO_2-equivalent emissions. The upstream emissions factors vary by fuel/feedstock type and conversion process, but are assumed to be the same for all regions and all projected years.



In the current reference case, transport (well-to-wheels) CO_2 accounts for about 24% of all energy-related CO_2 emissions. This includes all transport modes except domestic and international shipping, which when added will increase the transport share by a couple of percentage points. (It also does not include energy used during pipeline transport, not included in this study). Compared to the IEA 2002 World Energy Outlook reference case projection across all energy-use sectors, our transport CO_2 projection of well-to-wheels CO_2-equivalent emissions is a fairly constant share through 2030, about 28%[2]. Note that this transport projection includes upstream emissions of N2O and CH4, whereas the IEA projection is for CO_2 only.

[2] This includes CO2 from ocean shipping, which the WEO keeps separate from other transport.



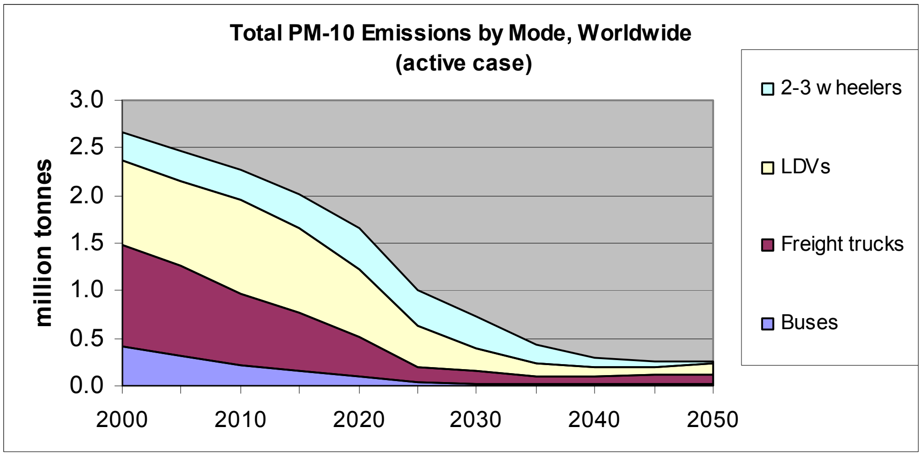
2.3.3 Pollutant Emissions

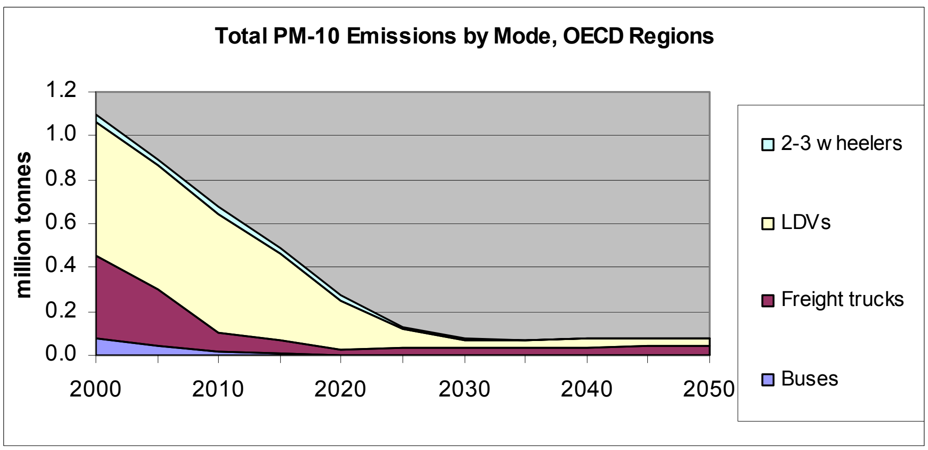
The SMP developed a reference case projection for five types of vehicle pollutant emissions: particulates (PM-10), nitrogen oxides (NOx), volatile organic compounds (VOC), carbon monoxide (CO) and lead (Pb). For all five of these pollutants, projected emissions declines dramatically in the future, in both OECD and non-OECD regions. These projections are shown in the figures below.

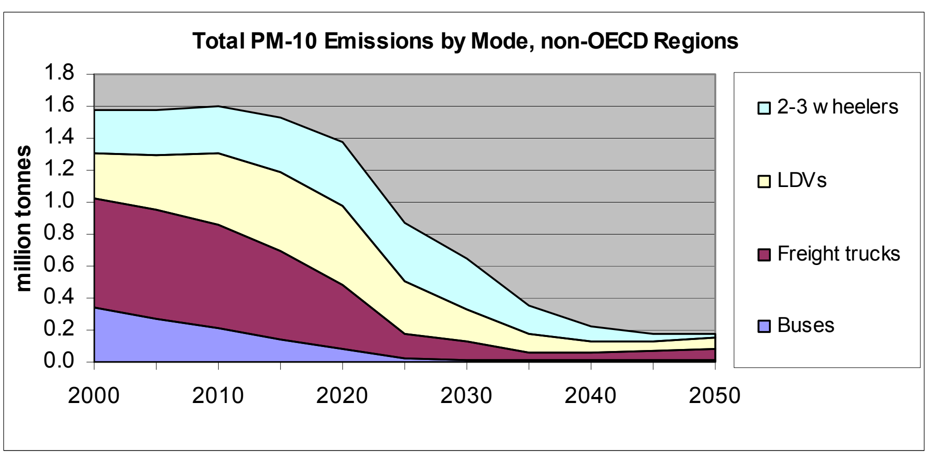
Except for lead (Pb), emissions are estimated as a simple function of vehicle kilometres of travel multiplied by average emissions per kilometre. Only for light-duty vehicles are emissions rates adjusted by vehicle age (as vehicles age, their in-use emissions increase). For other modes, only the average stock of vehicles is modelled, so only average emissions across all vehicles are tracked, with no vintaging or aging effect.

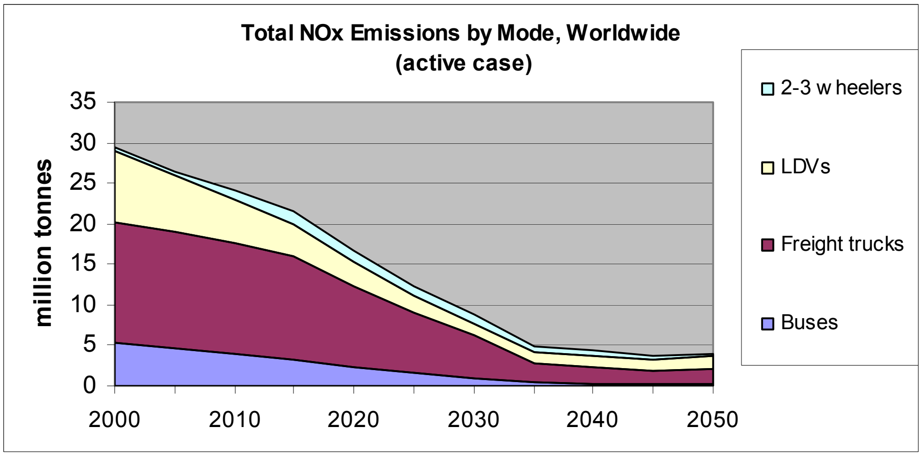
The projections for non-OECD regions are much less certain than for OECD regions and are dependant on two key assumptions: that all developing regions eventually adopt similar fuel and vehicle emissions standards as in the OECD, with a 10-15 year lag; and that vehicles are (eventually) maintained reasonably well in the developing world, though an assumption is maintained throughout the projection period that as vehicles age, emissions increase twice as much in non-OECD regions than in OECD regions.

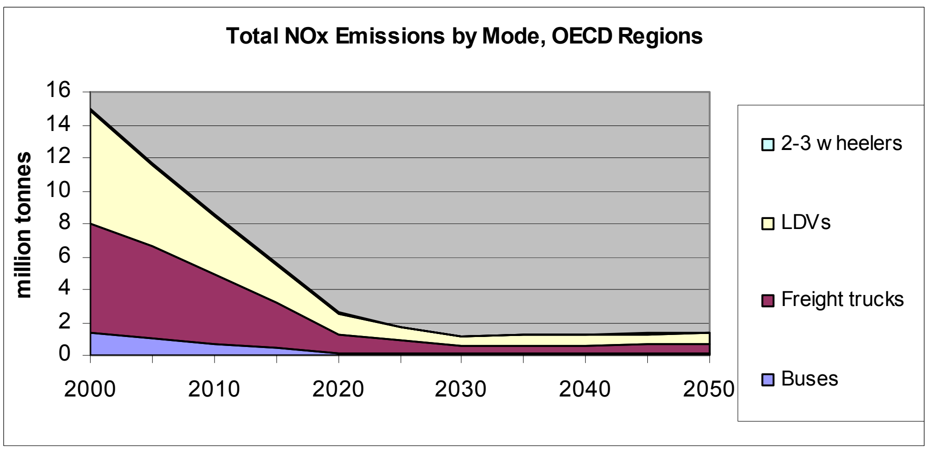
In short, total emissions drop over time because emissions per kilometre drop by a much greater amount that the increase in vehicle travel. Emissions of each pollutant drop by an order of magnitude or more between 2000 and 2030 around the world.

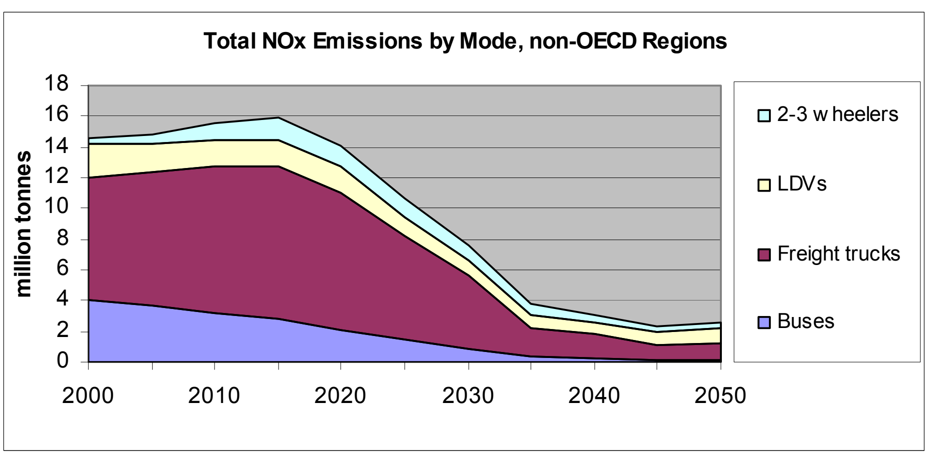

Total PM-10 Emissions by Mode, Worldwide
(active case)
million tonnes
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2000
2010
2020
2030
2040
2050
2-3 w heelers
LDVs
Freight trucks
Buses

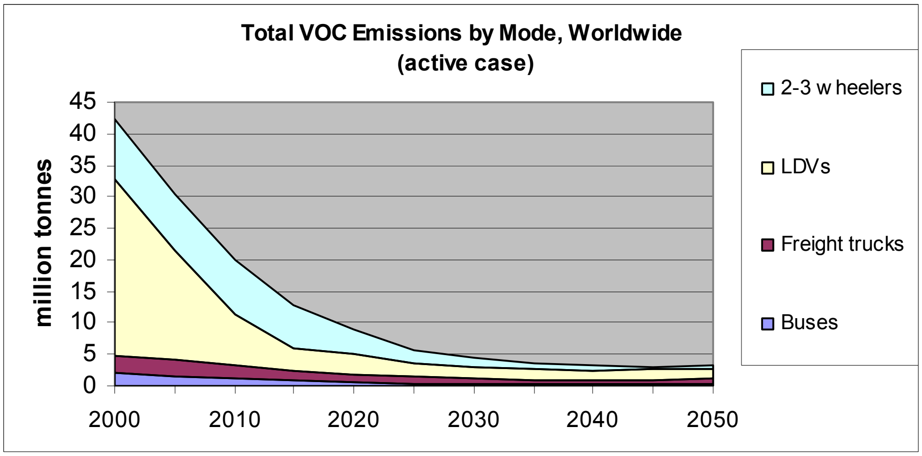

Total PM-10 Emissions by Mode, OECD Regions
million tonnes
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2000
2010
2020
2030
2040
2050
2-3 w heelers
LDVs
Freight trucks
Buses

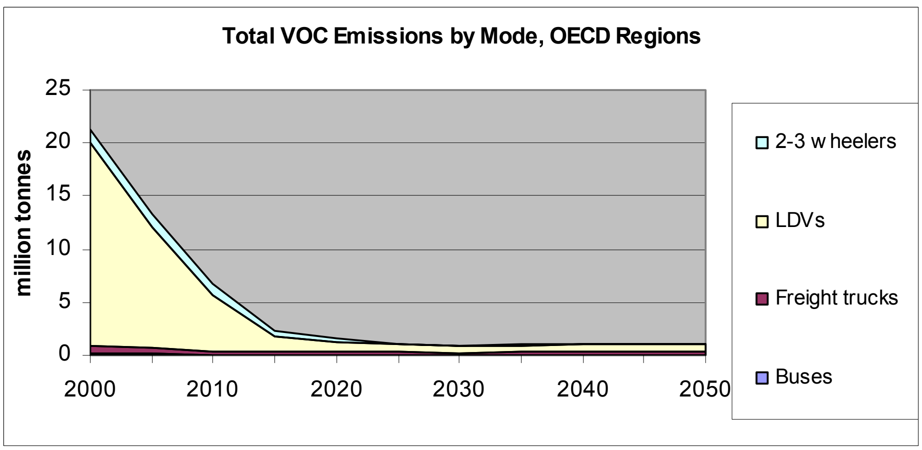

Total PM-10 Emissions by Mode, non-OECD Regions
million tonnes
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2000
2010
2020
2030
2040
2050
2-3 w heelers
LDVs
Freight trucks
Buses

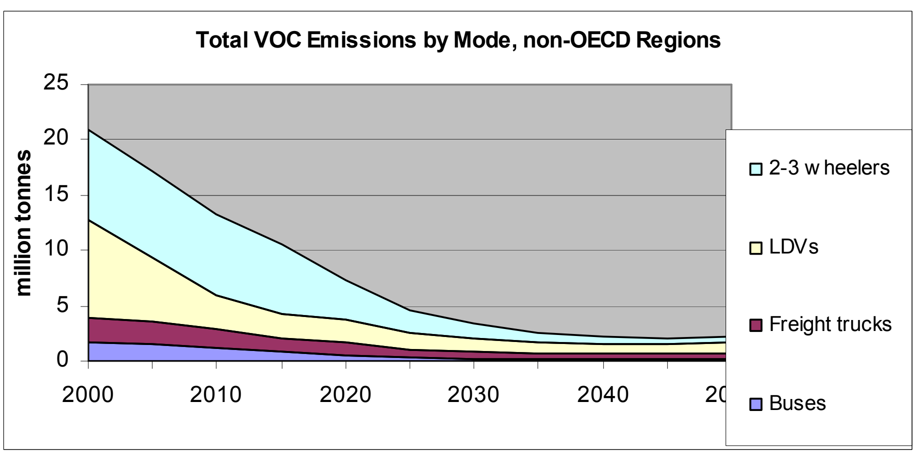

Total NOx Emissions by Mode, Worldwide
(active case)
million tonnes
35
30
25
20
15
10
5
0
2000
2010
2020
2030
2040
2050
2-3 w heelers
LDVs
Freight trucks
Buses

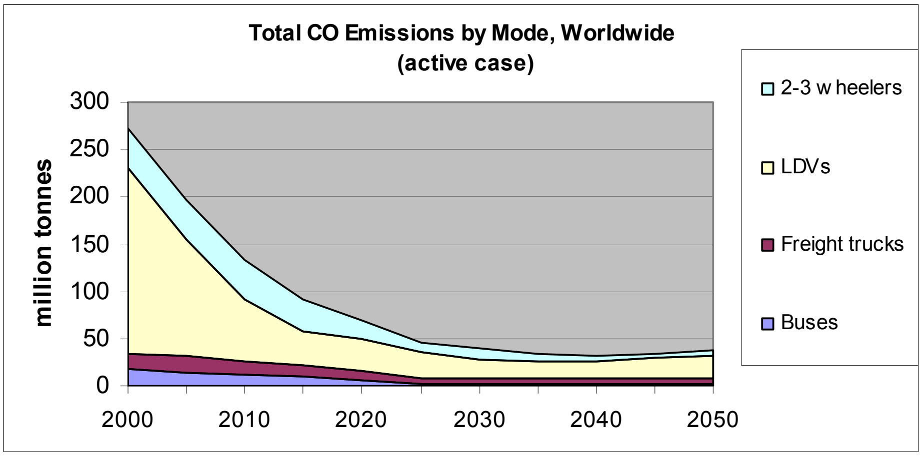

Total NOx Emissions by Mode, OECD Regions
million tonnes
16
14
12
10
8
6
4
2
0
2000
2010
2020
2030
2040
2050
2-3 w heelers
LDVs
Freight trucks
Buses

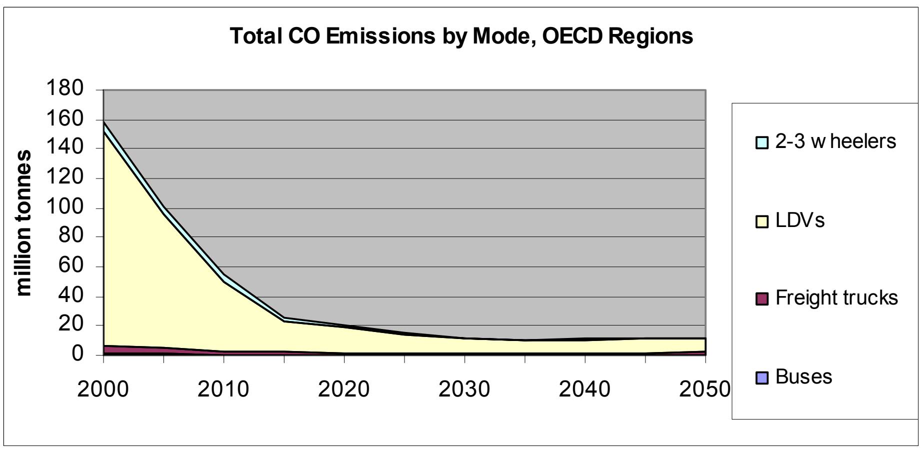

Total NOx Emissions by Mode, non-OECD Regions
million tonnes
18
16
14
12
10
8
6
4
2
0
2000
2010
2020
2030
2040
2050
2-3 w heelers
LDVs
Freight trucks
Buses

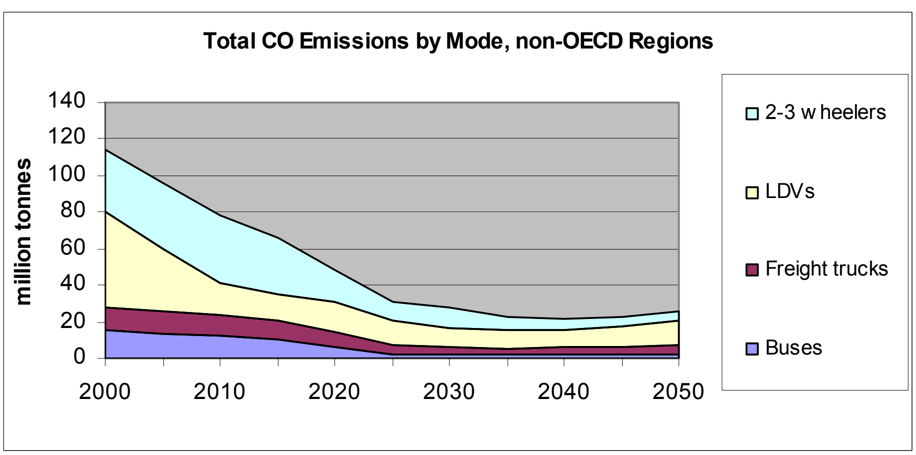

Total VOC Emissions by Mode, Worldwide
(active case)
million tonnes
45
40
35
30
25
20
15
10
5
0
2000
2010
2020
2030
2040
2050
2-3 w heelers
LDVs
Freight trucks
Buses


Total VOC Emissions by Mode, OECD Regions
million tonnes
25
20
15
10
5
0
2000
2010
2020
2030
2040
2050
2-3 w heelers
LDVs
Freight trucks
Buses

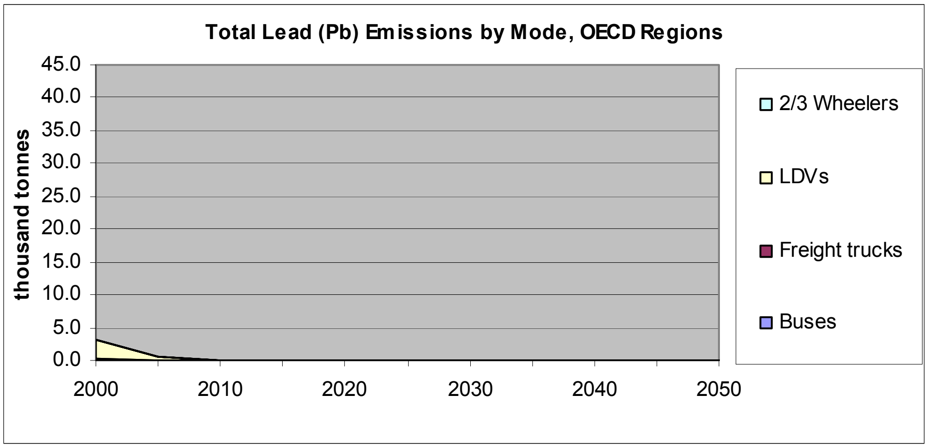

Total VOC Emissions by Mode, non-OECD Regions
million tonnes
25
20
15
10
5
0
2000
2010
2020
2030
2040
2-3 w heelers
LDVs
Freight trucks
Buses

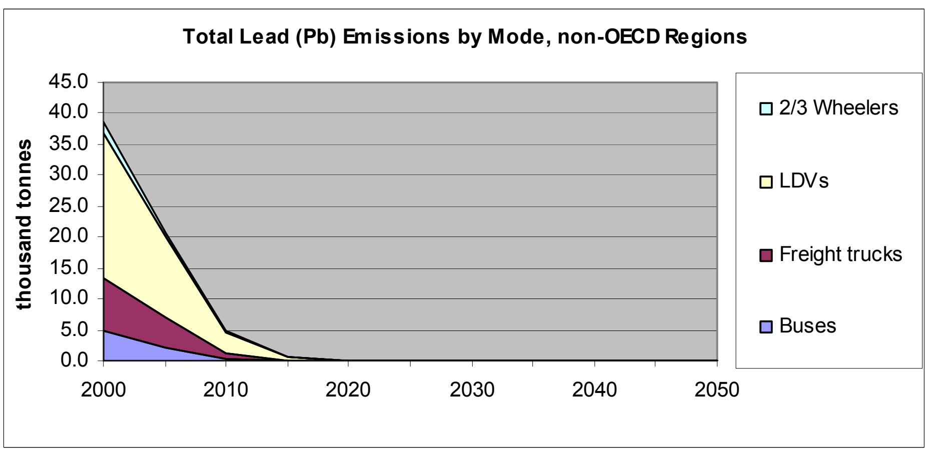

Total CO Emissions by Mode, Worldwide
(active case)
million tonnes
300
250
200
150
100
50
0
2000
2010
2020
2030
2040
2050
2-3 w heelers
LDVs
Freight trucks
Buses


Total CO Emissions by Mode, OECD Regions
million tonnes
180
160
140
120
100
80
60
40
20
0
2000
2010
2020
2030
2040
2050
2-3 w heelers
LDVs
Freight trucks
Buses


Total CO Emissions by Mode, non-OECD Regions
million tonnes
140
120
100
80
60
40
20
0
2000
2010
2020
2030
2040
2050
2-3 w heelers
LDVs
Freight trucks
Buses

Projections of lead (Pb) emissions differ from the others in that lead is projected on the basis of fuel use and lead content of fuel (rather than on driving levels and emissions per kilometre). As discussed further below (in the more detailed section outlining assumptions for pollutant emissions), leaded fuel is expected to be fully, or almost fully, phased out in nearly every country in the world by 2015. This results in the steep decline in lead emissions shown in the figures below (which are already, in 2000, much lower then lead emissions were during the 1990s).

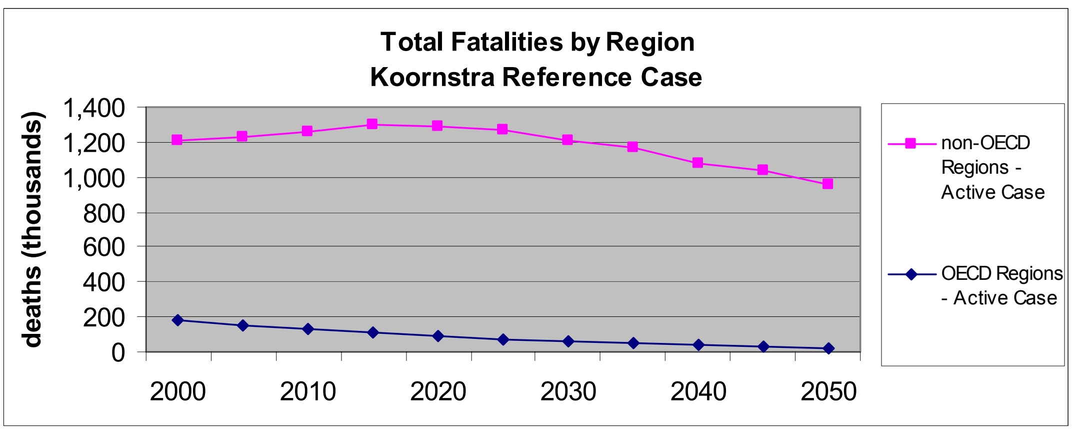


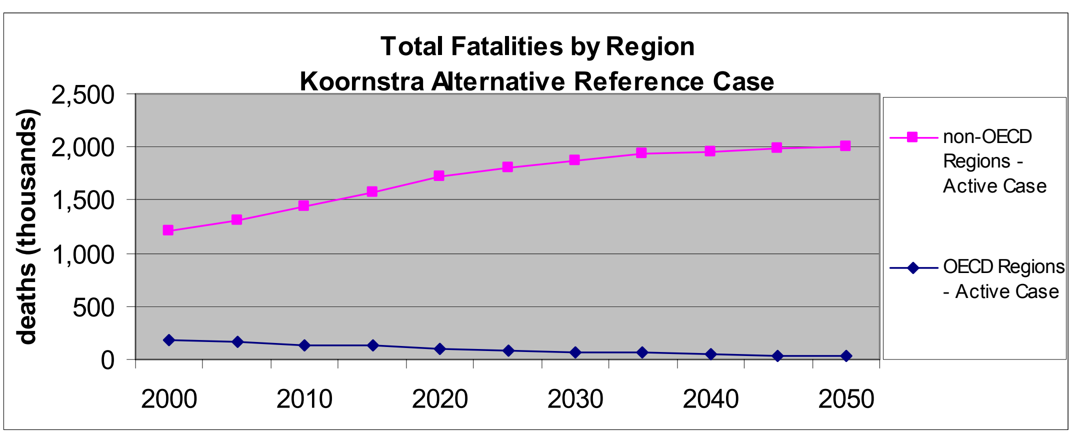


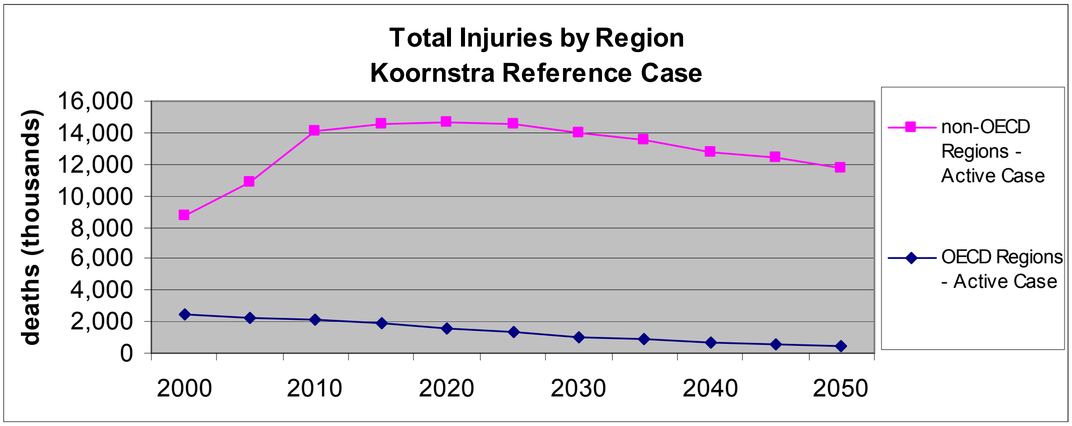
2.3.4 Safety

The SMP commissioned three separate studies on safety, the results of which are incorporated in the *Mobility 2030* report's discussion of safety issues. One of these studies, by M. Koornstra, also provided various detailed scenarios of future vehicle-related deaths and injuries around the world. Two of Koornstra's projections have been included in the SMP model to show two possible "reference case" futures. Total fatalities and injuries for these two scenarios are shown in the figures below.

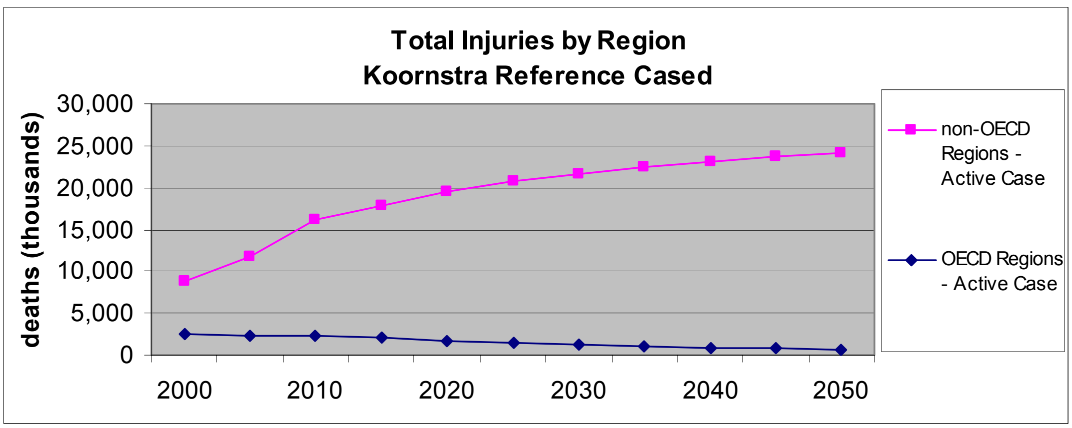
In 2000, average traffic fatality rates were about 10 times higher in the developing world than developed world, and total fatalities 6 times higher. In both Koornstra's "Reference Case I" and "Reference Case II", rates in both regions are projected to drop substantially by 2050, but will remain several times higher in developing than developed regions. These two cases vary by assumptions regarding the rate of uptake of safety measures in developing countries, both as a function of income growth and through "autonomous" learning over time, for example through lessons learned in OECD countries. Thus, although these are "reference" cases, they do incorporate assumptions regarding an on-going trend toward greater safety in terms of safer vehicles. Better road and surrounding infrastructure, increased awareness and safety-conscious behaviour, etc.







Total Injuries by Region
Koornstra Reference Case
deaths (thousands)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
2000
2010
2020
2030
2040
2050
non-OECD Regions - Active Case
OECD Regions - Active Case



Total Injuries by Region
Koornstra Reference Cased
deaths (thousands)
30,000
25,000
20,000
15,000
10,000
5,000
0
2000
2010
2020
2030
2040
2050
non-OECD Regions - Active Case
OECD Regions - Active Case

3 DOCUMENTATION OF THE REFERENCE CASE

3.1 Light-duty Vehicle (LDV) Fuel Consumption

Light-duty vehicles are defined as 4-wheel vehicles used primarily for personal passenger road travel. The exact definition depends somewhat on the region and data used, but these are typically cars, SUVs, small passenger vans (up to 8 seats) and personal pickup trucks.

The term "fuel consumption" is used here to refer to vehicle fuel consumption per unit travel, generally measured in litres per 100 kilometres. This could alternatively be referred to as "fuel economy" although this term is more common in North America and typically refers to the measure of miles per gallon[3].

3.1.1 Year 2000 Average Fuel Consumption Rates by Region

Although it would be best to have solid fuel data for each region for 2000, data for most regions (weighted average across all vehicles sold in the region) is not available (or non-existent), at least for non-OECD regions. Some data points are available, and some estimates have been made by previous studies. Also, for each region, it is important to ensure that the values used for new LDV fuel consumption, on-road "gap" factor, and stock average on-road fuel consumption are reasonable in relation to each other (e.g. multiplying the new care fuel consumption number by the on-road gap factor should yield a value close to the stock on-road average, unless one believes that new LDVs have much different fuel consumption, on-road, than the stock average.) It is also necessary to ensure that stock on-road fuel consumption, when multiplied by total vehicle travel, results in a number for fuel consumption consistent with the (generally much better) data available for this.

For OECD regions, we started with estimates of new car fuel efficiency from the WEO 2002 and EIA's Annual Energy Outlook 2002. Stock on-road average comes from IEA's indicators data and the AEO. These data include all LDVs, i.e. gasoline and diesel and in most countries a very small number of other fuel types like LPG or CNG. For non-OECD regions, we started with estimates from the WEC 1999 study. We were able to update or improve certain estimates as shown in the table below. In many cases the numbers were selected to fit the constraints in ASIF identities outlined above. All estimates in the table are for average light-duty vehicles (e.g. they include gasoline and diesel vehicles, with diesels important mainly in Europe).

[3] Fuel consumption in litres per 100km is equal to 235.24 / MPG.

Year 2000 Fuel Consumption Data and Assumptions

Region	New Car Tested Fuel Consumption L/100km	Source	On-road gap factor (percent worse than tested)	Source	Stock-average on-road fuel consumption (L/100km)	Source
OECD North America	9.6	US EIA/AEO 2002	22%	US EPA	11.5	US EIA/AEO 2002
OECD Europe	6.6	IEA WEO 2002	18%	best fit	8.0	IEA Indicators database
OECD Pacific	8.4	IEA WEO 2002	18%	best fit	10.6	IEA Indicators database
FSU	8.4	Russia (Donchenko)	25%	best fit	10.5	WEC 1999, adjusted[1]
Eastern Europe	8.0	best fit	22%	best fit	9.5	WEC 1999
China	9.4	China (D. He)	25%	best fit	11.4	WEC 1999
Other Asia	8.8	best fit	25%	best fit	11.9	WEC 1999
India	8.7	best fit	25%	best fit	11.8	WEC 1999
Middle East	8.7	best fit	25%	best fit	12.0	WEC 1999
Latin America	8.7	best fit	25%	best fit	11.8	WEC 1999
Africa	10.3	best fit	25%	best fit	13.9	WEC 1999

[1] WEC 1999 estimates adjusted (generally improved slightly) to account for later year and to give best fit with other data.

3.1.2 LDV Fuel Consumption: Technical Potential

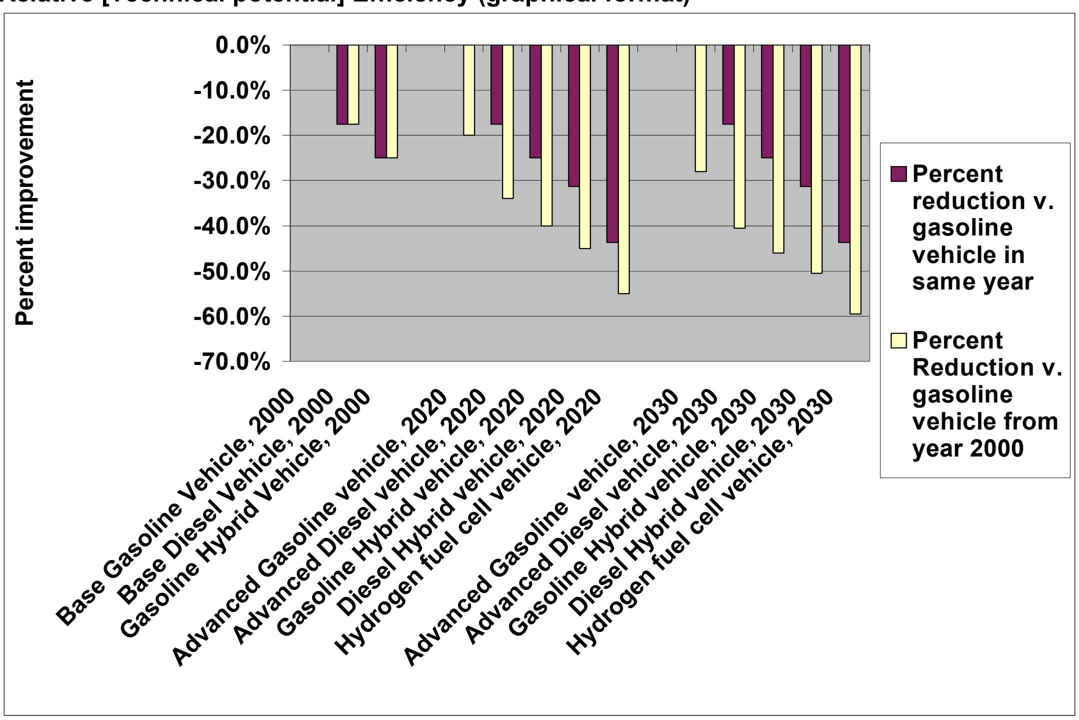
Estimates of technical potential for fuel consumption improvement (reductions in fuel consumption per kilometre) were provided by Workstream 2 of the SMP. This section outlines how light-duty vehicle fuel consumption has been modelled in the SMP reference case, based on these estimates..

The following summary table of relative efficiency for gasoline and other vehicle technologies shows both conventional gasoline vehicle fuel consumption improvement over time and also gasoline vehicles compared to other technologies and propulsion systems (including hybridized gasoline vehicles). These technologies are not discussed further here, but are covered in the main SMP report.

Relative Efficiency Improvement (technical potential, fuel consumption per kilometre) for different LDV technology / fuel types in different years

	Ratio to year 2000 gasoline	Percent reduction v. gasoline vehicle in same year	Percent Reduction v. gasoline vehicle from year 2000
Base Gasoline Vehicle, 2000	1.00	0%	0%
Base Diesel Vehicle, 2000	0.83	-18%	-18%
Gasoline Hybrid Vehicle, 2000	0.75	-25%	-25%
Advanced Gasoline vehicle, 2020	0.80	0%	-20%
Advanced Diesel vehicle, 2020	0.66	-18%	-34%
Gasoline Hybrid vehicle, 2020	0.60	-25%	-40%
Diesel Hybrid vehicle, 2020	0.55	-31%	-45%
Hydrogen fuel cell vehicle, 2020	0.45	-44%	-55%
Advanced Gasoline vehicle, 2030	0.72	0%	-28%
Advanced Diesel vehicle, 2030	0.59	-18%	-41%
Gasoline Hybrid vehicle, 2030	0.54	-25%	-46%
Diesel Hybrid vehicle, 2030	0.50	-31%	-51%
Hydrogen fuel cell vehicle, 2030	0.41	-44%	-60%

Relative [Technical potential] Efficiency (graphical format)



As shown in the table and figure, by 2020 a 20% reduction in fuel consumption (relative to 2000 levels) for conventional gasoline vehicles is considered (by companies in the SMP) technically achievable. By 2030, the potential is 28%. To repeat, this reflects *technical* potential, but in our modelling work, we have not assumed that all of this improvement occurs in the reference case; thus our projections of average actual fuel consumption improvement are lower. The reference case projection (discussed next) was developed taking into account recent trends and expected future policy and market developments in addition to technical efficiency potential.

Average values for fuel consumption per kilometre in 2000, shown earlier, were broken out into averages for different vehicle technologies and fuels in 2000 using the fuel consumption differences across technology and fuel, combined with the sales share for each type. These two aspects are shown in the tables below. Sales share data was not easily available outside of the OECD, so simple assumptions were used. Europe is the only region with more than 10% of vehicle sales other than gasoline, so in most cases the gasoline fuel consumption number is very close to the average number shown above. Most developing country regions are simply assumed to have 5% sales share of diesel vehicles, a weak assumption. Very few gasoline hybrids, and no diesel hybrids or fuel cells, were sold in any region in 2000. Gaseous-fuel vehicle shares are based on reported road transport consumption of natural gas and LPG in countries in each region.

Year 2000 New LDV fuel consumption estimates by technology/fuel type and region, L/100km

	Gasoline	Gasoline hybrid	Diesel	Diesel hybrid	LPG/CNG	Fuel cell / hydrogen
OECD North America	9.6	6.7	7.9	6.1	10.1	5.3
OECD Europe	7.1	4.9	5.8	4.5	7.5	3.9
OECD Pacific	8.4	5.9	6.9	5.4	8.9	4.6
FSU	8.5	5.9	6.9	5.4	8.9	4.7
Eastern Europe	8.1	5.6	6.6	5.1	8.5	4.4
China	9.5	6.6	7.8	6.1	10.0	5.2
Other Asia	8.9	6.2	7.3	5.7	9.3	4.9
India	8.8	6.1	7.2	5.6	9.2	4.8
Middle East	8.7	6.1	7.2	5.6	9.2	4.8
Latin America	8.8	6.1	7.2	5.6	9.2	4.8
Africa	10.4	7.2	8.5	6.6	10.9	5.7

Year 2000 estimated sales shares by technology/fuel type

	Gasoline	Gasoline hybrid	Diesel	Diesel hybrid	LPG/CNG	Fuel cell / hydrogen
OECD North America	97.6%	0.1%	2.0%	0.0%	0.3%	0.0%
OECD Europe	58.4%	0.0%	40.0%	0.0%	1.5%	0.0%
OECD Pacific	86.6%	0.4%	6.0%	0.0%	7.0%	0.0%
FSU	94.0%	0.0%	5.0%	0.0%	1.0%	0.0%
Eastern Europe	78.0%	0.0%	20.0%	0.0%	2.0%	0.0%
China	94.9%	0.0%	5.0%	0.0%	0.1%	0.0%
Other Asia	94.8%	0.0%	5.0%	0.0%	0.2%	0.0%
India	90.0%	0.0%	10.0%	0.0%	0.0%	0.0%
Middle East	93.0%	0.0%	5.0%	0.0%	2.0%	0.0%
Latin America	94.0%	0.0%	5.0%	0.0%	1.0%	0.0%
Africa	94.6%	0.0%	5.0%	0.0%	0.4%	0.0%

3.1.3 LDV Fuel Consumption: Reference Case Projection

In projecting new light-duty vehicle (tested) fuel consumption, as with other aspects of the reference case projection, the primary target was to stay close to the IEA/WEO 2002. Another consideration was that car markets around the world are likely to become more similar in the coming 50 years, and by 2050 we assume that average fuel consumption will be fairly similar across regions (at least more similar than now), though differences due to differential fuel prices and taxes may still exist. Using the IEA indicators database to establish past trends for IEA countries, we estimate that average fuel consumption improvement, in the absence of policies to promote improvement, is about 0.4% per year reduction in L/100km. The major exception is that in the past ten years in the US, the improvement has actually been close to 0.0%; it is projected to improve at 0.2% per year through 2010[4]. Also, in the two regions with strong fuel consumption improvement policies (EU and Japan) improvements have occurred at or in excess of 1.0% per year. We assume that this will continue until 2010, then revert to historical trends (i.e. the EU VA or Japanese Top Runner are not assumed to go beyond 2010, though they could).

We were unable to find any trend data for fuel efficiency for vehicles in any developing country or region, so we have selected improvement rates in line with the averages in OECD Europe before the VA, but accelerated slightly to reflect that non-OECD regions may improve faster as the technologies used in vehicles around the world "catch up" with technology in the OECD regions, and a general convergence occurs. The resulting set of assumptions for annual percentage change in fuel consumption per kilometre for new LDVs, by region and time period, is shown in the table below.

Annual percentage change in fuel consumption per kilometre for new LDVs, by region and time period

Region	2000-2010	2010-2030	2030-2050
OECD North America	-0.2%	-0.4%	-0.4%
OECD Europe	-1.2%	-0.4%	-0.4%
OECD Pacific	-1.2%	-0.4%	-0.4%
FSU	-0.4%	-0.4%	-0.4%
Eastern Europe	-0.4%	-0.4%	-0.4%
China	-0.8%	-0.8%	-0.6%
Other Asia	-0.6%	-0.6%	-0.6%
India	-0.6%	-0.6%	-0.6%
Middle East	-0.6%	-0.6%	-0.6%
Latin America	-0.6%	-0.6%	-0.6%
Africa	-0.8%	-0.8%	-0.8%

Fuel consumption for all non-gasoline technologies in all future years is determined using the relative efficiency table shown above. Thus, there is a general assumption that as gasoline vehicle fuel consumption changes, other technology fuel consumption changes by a similar percentage and the relative fuel consumption levels across technologies and fuel types is preserved.

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[4] See EPA, 2004, "Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2004", available at http://www.epa.gov/otaq/fetrends.htm.

Sales shares of alternative fuel vehicles (and gasoline hybrids) also impacts the overall average fuel consumption of LDVs. Several general assumptions were made regarding sales and market share for alternative-fuel vehicles in the future:

- Diesel share rises slowly over time in most regions, reaching slightly more then 10% sales share by 2030. However, in OECD Europe and Eastern Europe, diesel market shares rise to 50% over time – by 2010 in Western Europe and by 2030 in Eastern Europe. Diesel sales are assumed to increase due to their fuel savings characteristics and increased availability of light-duty vehicle diesel models.
- Gasoline hybrids achieve sales of 1 million units per year world-wide by 2030; about 1% market share.
- CNG/LPG vehicles retain current market shares – small in most regions.
- Diesel hybrids and fuel cells do not penetrate significantly over the projection period.

The sales shares for diesel and gasoline hybrid vehicles are shown in the table below.

Sales share projections for gasoline hybrids and diesel LDVs.

	2000	2010	2020	2030	2040	2050
Gasoline Hybrid						
OECD North America	0.1%	0.5%	0.9%	1.1%	1.3%	1.5%
OECD Europe	0.0%	0.4%	0.8%	1.0%	1.2%	1.4%
OECD Pacific	0.4%	0.8%	1.2%	1.4%	1.6%	1.8%
FSU	0.0%	0.1%	0.5%	0.9%	1.1%	1.3%
Eastern Europe	0.0%	0.1%	0.5%	0.9%	1.1%	1.3%
China	0.0%	0.1%	0.5%	0.9%	1.1%	1.3%
Other Asia	0.0%	0.1%	0.5%	0.9%	1.1%	1.3%
India	0.0%	0.1%	0.5%	0.9%	1.1%	1.3%
Middle East	0.0%	0.1%	0.5%	0.9%	1.1%	1.3%
Latin America	0.0%	0.1%	0.5%	0.9%	1.1%	1.3%
Africa	0.0%	0.1%	0.5%	0.9%	1.1%	1.3%
Diesel						
OECD North America	2.0%	2.4%	2.9%	3.5%	4.3%	5.2%
OECD Europe	40.0%	50.0%	50.0%	50.0%	50.0%	50.0%
OECD Pacific	6.0%	7.3%	8.8%	10.6%	12.9%	15.6%
FSU	5.0%	6.1%	7.3%	8.9%	10.7%	13.0%
Eastern Europe	20.0%	28.8%	41.5%	50.0%	50.0%	50.0%
China	5.0%	6.1%	7.3%	8.9%	10.7%	13.0%
Other Asia	5.0%	6.1%	7.3%	8.9%	10.7%	13.0%
India	10.0%	11.0%	12.2%	13.4%	14.8%	16.3%
Middle East	5.0%	6.1%	7.3%	8.9%	10.7%	13.0%
Latin America	5.0%	6.1%	7.3%	8.9%	10.7%	13.0%
Africa	5.0%	6.1%	7.3%	8.9%	10.7%	13.0%

The combination of starting points (year 2000 estimates) and projection of percentage change over time results in the following average new light-duty vehicle fuel consumption projection in litres per 100 kilometres, and percentage changes by time period. This is also presented in MPG terms below. In L/100km, gasoline vehicles improve by about 15%, on average, around the world between 2000 and 2030.

New LDV Fuel Consumption (L/100km)

							Annual Percentage Change			Total [Cumulative] Percent Change		
	2000	2010	2020	2030	2040	2050	2000-2010	2010-2030	2030-2050	2000-2010	2000-2030	2000-2050
OECD North America	9.6	9.4	9.0	8.7	8.3	8.0	-0.2%	-0.4%	-0.4%	-2.0%	-9.6%	-16.6%
OECD Europe	6.6	5.9	5.6	5.4	5.2	5.0	-1.2%	-0.4%	-0.4%	-11.4%	-18.3%	-24.6%
OECD Pacific	8.4	7.4	7.1	6.8	6.6	6.3	-1.2%	-0.4%	-0.4%	-11.6%	-18.5%	-24.8%
FSU	8.4	8.1	7.7	7.4	7.1	6.9	-0.4%	-0.4%	-0.4%	-4.0%	-11.4%	-18.3%
Eastern Europe	8.0	7.7	7.4	7.1	6.8	6.5	-0.4%	-0.4%	-0.4%	-4.0%	-11.4%	-18.3%
China	9.4	8.7	8.0	7.4	7.0	6.5	-0.8%	-0.8%	-0.6%	-7.8%	-21.7%	-30.7%
Other Asia	8.8	8.3	7.8	7.3	6.9	6.5	-0.6%	-0.6%	-0.6%	-5.9%	-16.7%	-26.3%
India	8.7	8.2	7.7	7.3	6.8	6.4	-0.6%	-0.6%	-0.6%	-5.9%	-16.7%	-26.3%
Middle East	8.7	8.2	7.7	7.2	6.8	6.4	-0.6%	-0.6%	-0.6%	-5.9%	-16.7%	-26.3%
Latin America	8.7	8.2	7.7	7.3	6.8	6.4	-0.6%	-0.6%	-0.6%	-5.9%	-16.7%	-26.3%
Africa	10.3	9.5	8.8	8.1	7.4	6.8	-0.8%	-0.8%	-0.8%	-7.8%	-21.7%	-33.5%

New LDV Fuel Consumption (Miles per Gallon)

							Annual Percentage Change			Total Percent Change		
	2000	2010	2020	2030	2040	2050	2000-2010	2010-2030	2030-2050	2000-2010	2000-2030	2000-2050
OECD North America	24.6	25.1	26.1	27.2	28.3	29.5	0.2%	0.4%	0.4%	2.0%	10.6%	19.9%
OECD Europe	35.6	40.1	41.8	43.5	45.3	47.2	1.2%	0.4%	0.4%	12.8%	22.3%	32.6%
OECD Pacific	28.1	31.8	33.1	34.5	35.9	37.4	1.2%	0.4%	0.4%	13.1%	22.6%	33.0%
FSU	28.0	29.2	30.4	31.6	32.9	34.3	0.4%	0.4%	0.4%	4.1%	12.9%	22.4%
Eastern Europe	29.4	30.6	31.9	33.2	34.6	36.0	0.4%	0.4%	0.4%	4.1%	12.9%	22.4%
China	24.9	27.0	29.3	31.8	33.8	36.0	0.8%	0.8%	0.6%	8.5%	27.8%	44.3%
Other Asia	26.7	28.4	30.2	32.1	34.1	36.2	0.6%	0.6%	0.6%	6.3%	20.1%	35.6%
India	27.0	28.7	30.5	32.4	34.5	36.6	0.6%	0.6%	0.6%	6.3%	20.1%	35.6%
Middle East	27.1	28.8	30.7	32.6	34.6	36.8	0.6%	0.6%	0.6%	6.3%	20.1%	35.6%
Latin America	27.0	28.7	30.5	32.4	34.5	36.6	0.6%	0.6%	0.6%	6.3%	20.1%	35.6%
Africa	22.8	24.8	26.9	29.2	31.7	34.3	0.8%	0.8%	0.8%	8.5%	27.8%	50.4%

If one compares this reference case set of projections to the estimated technical potential discussed above, one can see that some technical potential for fuel consumption improvement remains unrealized in the reference case. This is because the estimated potential for *technical efficiency* improvement of new, conventional gasoline light-duty vehicles (non-hybridized), based on available technology, is not equivalent to what occurs in practice, both because some technologies are not implemented (or not implemented on all vehicles) and because vehicles may change in size, weight, power, and other attributes that affect *fuel consumption*[5] and fuel consumption.

The 15% average fuel consumption improvement, world-wide, in the reference case is 13 percentage points less than the estimated technical potential (28%) in 2030. This difference can be attributed both to mix shifting and to lower-than-maximum possible uptake of technologies. No attempt has been made to separate these, though a mix shifting analysis was conducted for North America. This shows that if present trends continue, in terms of changes in the relative market share of different size classes (e.g. large vehicles gaining share at the expense of smaller vehicles), then about half of the potential fuel consumption improvement from technical change will be lost to this "mix shifting" (this is a cross-class estimate; shifting to bigger, more powerful vehicles within

[5] The term "fuel consumption" is used here to denote energy use per kilometre of vehicle travel, as opposed to "efficiency", which relates to the technical efficiency of a vehicle, e.g. energy use per unit vehicle travel, but taking into account vehicle size, weight, power, accessory load, etc. Thus, fuel consumption could be constant while technical efficiency improves, if, for example, vehicle weight or power increases. [note: this is indeed what has happened in the United States over the last decade or so. Do we want to cite EPA data showing this?]

market classes could increase this effect further). Since other regions can also be expected to experience significant mix shifting, it appears that much of the 13 percentage point difference for the world average can also be related to mix shifting (i.e. the trend-based projection would be close to the 28% maximum potential improvement in 2030 if size-mix were held at year 2000 levels). Put another way, if the world experiences similar amounts of mix shifting in the future as has occurred in North America, then it will require the full implementation of available technology in order for our reference case fuel consumption improvements to occur.

3.1.4 On-road Fuel Consumption

The "gap" between tested fuel consumption and actual on-road fuel consumption is set between 18% and 25% (in L/100km terms) depending on the region, then held constant over time. This relates to different test cycles and driving conditions in the different regions.

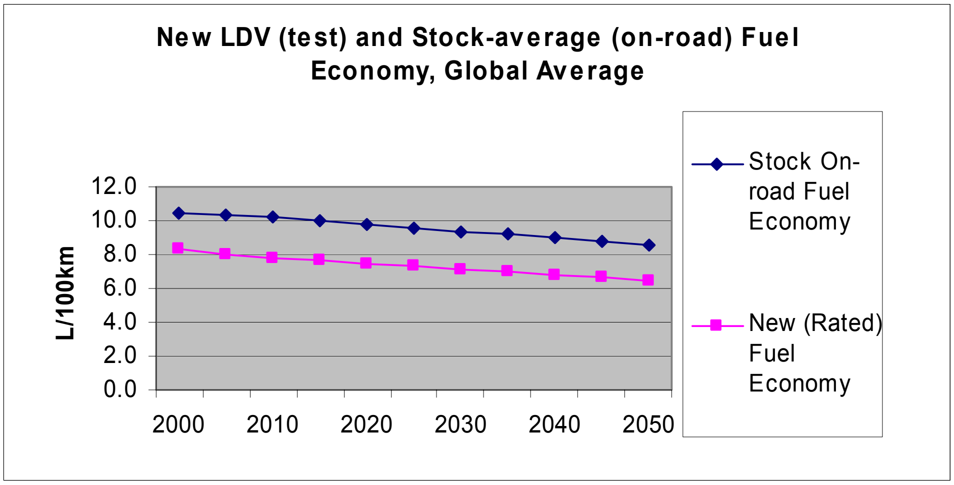
- The gap factors are set based both on direct data on this gap as well as data on new car fuel consumption and average fuel intensity.
- There is also a calibration aspect – it is necessary to ensure that new car fuel consumption, when adjusted to on-road, results in a reasonable projection of stock average on-road fuel intensity, in line with country data and the travel/efficiency/fuel use ASIF identity.
- Given poor data availability for non-OECD countries, similar gap factors are used, that are assumed to be somewhat higher than in OECD (due to worse road conditions and poor vehicle maintenance).

These assumptions result in the estimates of the table below.

Fuel Consumption "Gap" Factors by Region

	Increase in fuel consumption per kilometre	**Decrease in MPG**
OECD North America	22%	-18%
OECD Europe	18%	-15%
OECD Pacific	20%	-17%
FSU	25%	-20%
Eastern Europe	25%	-20%
China	25%	-20%
Other Asia	25%	-20%
India	25%	-20%
Middle East	25%	-20%
Latin America	25%	-20%
Africa	25%	-20%

The resulting projection of stock average on-road fuel consumption improves at about the same rate as new LDVs, though it lags this improvement by a number of years, and the gap between them is fairly constant.



3.1.5 Year 2000 Vehicle Stock and Sales

One of the more available types of data is for vehicle stocks by region, including non-OECD regions. For the year 2000, the IEA has data on stocks for OECD regions, and this is reflected in the WEO. This was combined with data from several other sources in order to obtain reasonable estimates for non-OECD regions. These sources include: IRTAD 2001, IRF, 2000, Koornstra, 2003, and CCFA, 2001. These data sources differ significantly in their estimates (and in some cases only 1999, not 2000 data were available). To some extent, this variation may be due to varying definitions of light-duty vehicle (for example, some distinguish between cars and other LDVs and some do not.) Koornstra 2003 made a detailed effort to resolve many of these differences from the other sources, though he only estimates total road vehicles. A combination of these data were used, adjusted for certain regions as part of our general effort to produce numbers that when multiplied through, hit the IEA data for fuel consumption. The results are shown below.

Sales data are based on both the WEO 2002 and the WEC 1999 study, but adjusted for non-OECD regions in order to align with the stock numbers, as these grow in the future. For example, in some cases sales would have to decline in order to hit future (targeted) stock numbers, which seems unreasonable, and probably indicates that the sales estimates is out of line with the stock estimate. Thus, some (generally minor) adjustments were made to align these better.

Year 2000 LDV Sales and Stocks

	Sales (millions)	Stocks (millions)	LDVs per 1000 people
OECD North America	15.5	250.4	618
OECD Europe	16.0	200.5	390
OECD Pacific	6.0	86.4	438
FSU	2.1	25.4	100
Eastern Europe	1.2	20.0	201
China	1.8	16.5	13
Other Asia	1.6	18.7	21
India	1.0	10.1	10
Middle East	0.5	7.0	42
Latin America	3.0	32.4	78
Africa	1.1	15.9	20
World Total	49.8	683.4	

3.1.6 Projections of vehicle ownership, stocks, average vehicle life, and sales

The main driver for the projection of vehicle sales and stock was car ownership rates. Several projections of car ownership rates in the future are available in the literature. We chose to adopt the approach taken by Dargay and Gately, 1999[6], which fits a logistic function to car ownership by region on the basis of income and projected income growth. Their curve was adapted to the present context, including adjusting for the somewhat different OECD income projections used here. In some cases growth rates were slowed somewhat to reflect the possible difficulties in keeping up with demand growth implied by the initial projections, and to take into account growth in 2-wheelers that, in some regions, could slow the growth in 4-wheelers (the total of 2 and 4 wheelers per capita were also tracked, to ensure that the combined total stayed within a reasonable range, well below 1 per person). As a rough guide, the following table indicates the approximate rate of change in car ownership with change in income (as an elasticity). Until the regional average income reaches $5k per year, ownership growth is very slow, but takes off at this point. It then has a very high elasticity of 1.3% change in car ownership for each 1% increase in average income until the regions reaches 300 cars per capita. It then slows, reflecting an inflection in the logistic curve and the beginning of asymptotic (saturation) behaviour.

LDV ownership growth rates at different income and car ownership levels.

	Ownership growth elasticity relative to income growth (pct basis)	Maximum ownership level for this growth rate
until $5k income	0.30	no maximum
>$5k	1.30	300 cars per cap
>$5k	0.60	500 cars per cap
>$5k	0.25	600 cars per cap
>$5k	0.10	700 cars per cap

The following table and figure show how these growth rates translate into ownership estimates. The colour coding in the table matches that in the previous table, in order to indicate the situation different regions are in at different times.

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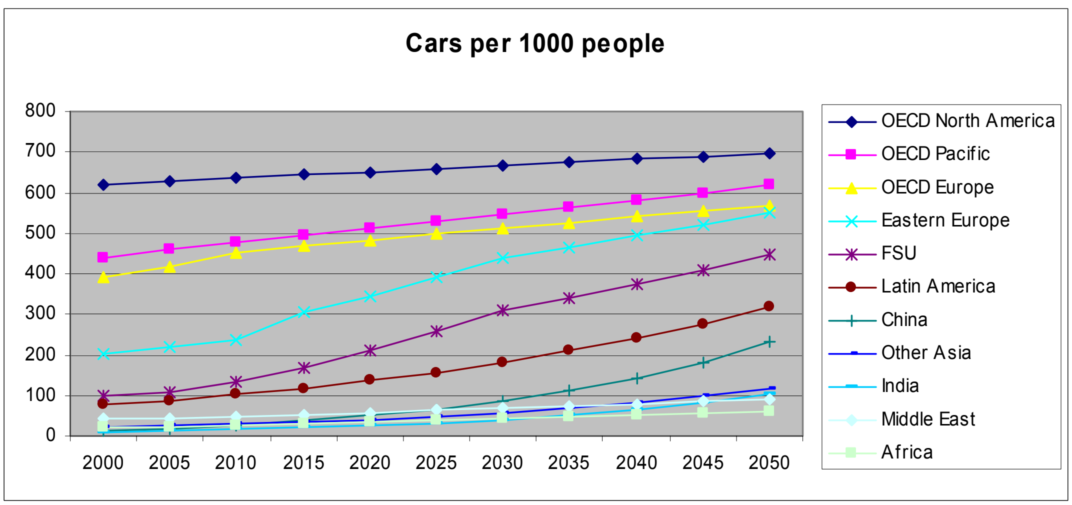
[6] Dargay, J. and D. Gately, “Income's effect on car and vehicle ownership, worldwide: 1960–2015” Transportation Research Part A: Policy and Practice, V.33:2 , February 1999, Pages 101-138.

LDV Car ownership rate (per 1000 population)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
OECD North America	618	626	636	644	651	659	667	674	682	690	698
OECD Europe	390	417	451	468	483	497	511	525	540	555	570
OECD Pacific	438	459	477	494	510	527	545	562	581	599	618
FSU	100	108	133	168	212	258	310	340	373	408	447
Eastern Europe	201	218	235	304	345	391	440	466	493	522	551
China	13	17	26	37	50	66	86	111	142	181	231
Other Asia	21	25	29	33	37	46	56	68	82	98	117
India	10	14	17	21	26	30	40	51	66	83	105
Middle East	42	45	47	51	57	63	68	74	79	85	91
Latin America	78	87	101	118	136	157	181	209	240	276	317
Africa	20	23	27	31	34	38	42	46	50	54	58

See table above for definition of colour codes.



Note: colour of lines in figure does not match colour-coding of tables above.

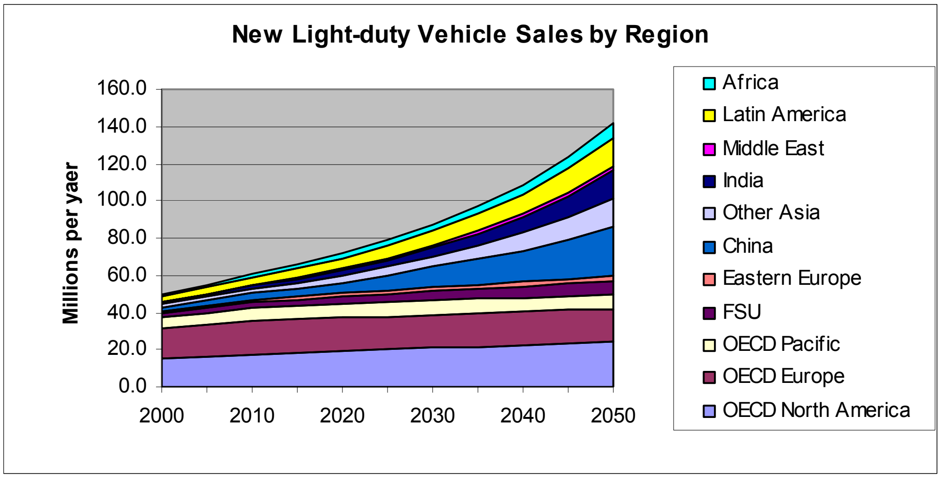
Once LDV ownership rates are established, these are simply multiplied by the population projection (from the UN) to derive projections of total LDV stocks. Sales are then derived based on expected lifetimes of vehicles and the stock-turnover algorithm in order to produce the right number of new vehicles each year to hit the stock projection. Thus, assumptions about vehicle lifetime and turnover rates are important in determining the relationship between sales and stocks. These are shown below. Estimates for IEA regions are based on IEA data. Unfortunately, no good data could be found for any developing countries, so (as can be seen) simple assumptions were made. In reality, vehicles in most developing countries probably stay on the road for more than 20 years. However, this data is also used to capture the fact that newer cars drive much more than older vehicles, which is not otherwise reflected in the ETP model. An approximation of this effect was achieved by shortening the estimated average vehicle life in all regions. In addition, average vehicle life was assumed to drop slightly over time in the developing world, to reach a level similar to North America by 2050. The resulting projection of sales is shown separately.

Average vehicle life, years, for vehicles sold in the five years up to and including that year

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
OECD North America	n/a	18	18	18	18	18	18	18	18	18	18
OECD Europe	n/a	15	15	15	15	15	15	15	15	15	15
OECD Pacific	n/a	15	15	15	15	15	15	15	15	15	15
OECD average		16.2	16.2	16.3	16.3	16.3	16.3	16.4	16.4	16.4	16.4
FSU	n/a	20	19.8	19.6	19.4	19.2	19.0	18.8	18.6	18.5	18.3
Eastern Europe	n/a	20	19.8	19.6	19.4	19.2	19.0	18.8	18.6	18.5	18.3
China	n/a	20	19.8	19.6	19.4	19.2	19.0	18.8	18.6	18.5	18.3
Other Asia	n/a	20	19.8	19.6	19.4	19.2	19.0	18.8	18.6	18.5	18.3
India	n/a	20	19.8	19.6	19.4	19.2	19.0	18.8	18.6	18.5	18.3
Middle East	n/a	20	19.8	19.6	19.4	19.2	19.0	18.8	18.6	18.5	18.3
Latin America	n/a	20	19.8	19.6	19.4	19.2	19.0	18.8	18.6	18.5	18.3
Africa	n/a	25	24.8	24.5	24.3	24.0	23.8	23.5	23.3	23.1	22.8
non-OECD average		20.5	20.3	20.1	19.9	19.7	19.4	19.2	19.0	18.8	18.7
World Average		17.3	17.4	17.5	17.6	17.7	17.7	17.8	17.8	17.8	17.8

LDV annual sales (millions)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
OECD North America	15.5	16.5	17.6	18.4	19.3	20.1	20.9	21.6	22.4	23.2	24.0
OECD Europe	16.0	16.8	17.7	17.8	17.9	17.9	17.9	17.9	17.9	17.9	17.9
OECD Pacific	6.0	6.6	7.3	7.3	7.3	7.4	7.5	7.7	7.8	8.0	8.2
FSU	2.1	2.4	2.7	3.2	3.9	4.4	5.0	5.4	5.9	6.3	6.8
Eastern Europe	1.2	1.3	1.5	1.6	1.8	2.0	2.2	2.3	2.5	2.6	2.8
China	1.8	2.5	3.4	4.5	6.1	8.1	10.8	13.6	17.0	21.3	26.6
Other Asia	1.6	1.9	2.4	2.9	3.6	4.6	5.8	7.4	9.5	12.1	15.4
India	1.0	1.3	1.6	2.1	2.7	3.5	4.5	6.0	8.0	10.8	14.4
Middle East	0.5	0.6	0.8	0.9	1.1	1.3	1.6	1.8	2.0	2.3	2.6
Latin America	3.0	3.4	3.9	4.5	5.1	6.2	7.6	9.0	10.7	12.7	15.1
Africa	1.1	1.5	2.0	2.4	2.8	3.1	3.4	4.1	5.1	6.3	7.7
World Total	49.8	54.9	60.9	65.7	71.5	78.5	87.2	96.9	108.7	123.3	141.4



The growth rate in vehicle sales reflected in this projection follows:

LDV sales growth rates (average annual percentage growth during each period)

	2000-10	**2010-20**	**2020-30**	**2030-50**
OECD North America	1.3%	0.9%	0.8%	0.7%
OECD Europe	1.0%	0.1%	0.0%	0.0%
OECD Pacific	2.0%	0.0%	0.3%	0.4%
FSU	2.6%	3.6%	2.7%	1.5%
Eastern Europe	2.2%	2.0%	2.0%	1.1%
China	6.5%	6.0%	6.0%	4.6%
Other Asia	4.0%	4.2%	5.0%	5.0%
India	5.1%	5.1%	5.2%	6.0%
Middle East	4.4%	3.9%	3.5%	2.5%
Latin America	2.7%	2.7%	4.0%	3.5%
Africa	35.0%	18.0%	10.0%	4.2%

Vehicle travel is estimated as the product of vehicle stocks and average travel per vehicle. For OECD regions, average travel per vehicle was taken from IEA data, with a check that the total LDV travel was in line with external estimates of this (mainly the EIA estimates for the US). For other regions, the WEC 99 study estimates were used. One thing that is quite clear from the IEA indicator trend data is that average travel per vehicle is very stable across time in almost every IEA country (i.e., increases in car travel track very closely to increases in vehicle stocks). We therefore made a similar assumption for non-OECD regions, though it is a weak assumption. Particularly in regions with low travel per vehicle, like India, it may be the case that average travel increases as average speeds increase, which could occur as road infrastructure improves. On the other hand, average travel per vehicle could decline in some regions as vehicle ownership increases and sharing of vehicles among multiple drivers becomes less frequent. The resulting projection of total travel is provided in the following table.

Average travel per vehicle per year (kilometres)

	2000	**2010**	**2020**	**2030**	**2040**	**2050**
OECD North America	17,600	17,600	17,600	17,600	17,600	17,600
OECD Europe	12,500	12,500	12,500	12,500	12,500	12,500
OECD Pacific	10,000	10,000	10,000	10,000	10,000	10,000

FSU	13,000	13,000	13,000	13,000	13,000	13,000
Eastern Europe	11,000	11,000	11,000	11,000	11,000	11,000
China	10,000	10,000	10,000	10,000	10,000	10,000
Other Asia	10,000	10,000	10,000	10,000	10,000	10,000
India	8,000	8,000	8,000	8,000	8,000	8,000
Middle East	13,000	13,000	13,000	13,000	13,000	13,000
Latin America	12,000	12,000	12,000	12,000	12,000	12,000
Africa	10,000	10,000	10,000	10,000	10,000	10,000
World Average	13,755	13,505	13,194	12,914	12,564	12,160

Total vehicle travel per year (trillion kilometres) and annual percentage growth

							Annual Percentage Growth		
	2000	**2010**	**2020**	**2030**	**2040**	**2050**	**2000-2010**	**2010-2030**	**2030-2050**
OECD North America	4.4	4.9	5.6	6.1	6.6	7.1	1.0%	1.2%	0.8%
OECD Europe	2.5	2.9	3.3	3.3	3.3	3.3	1.6%	0.6%	0.0%
OECD Pacific	0.9	1.0	1.1	1.1	1.1	1.2	1.0%	0.8%	0.4%
FSU	0.3	0.5	0.7	1.0	1.2	1.4	3.7%	3.7%	1.9%
Eastern Europe	0.2	0.3	0.3	0.4	0.5	0.5	1.6%	2.2%	1.3%
China	0.2	0.3	0.7	1.3	2.1	3.4	7.3%	6.9%	5.0%
Other Asia	0.2	0.3	0.5	0.7	1.2	1.9	4.5%	4.8%	4.8%
India	0.1	0.1	0.3	0.4	0.8	1.3	6.0%	5.8%	5.5%
Middle East	0.1	0.1	0.2	0.3	0.4	0.5	3.4%	4.3%	2.8%
Latin America	0.4	0.6	1.0	1.3	1.8	2.5	4.6%	3.8%	3.4%
Africa	0.2	0.2	0.4	0.6	0.8	1.2	4.5%	4.7%	3.2%

A projection of total passenger travel in light-duty vehicles was also made, although this projection was not used for calculating energy consumption (since energy consumption is based on vehicle kilometres of travel). Passenger travel is derived from vehicle kilometres of travel, multiplied by average vehicle occupancy. IEA estimates are available for average vehicle occupancy in OECD regions, but no reliable data was found for non-OECD regions, apart from a few estimates for particular cities like Delhi and Mexico City, which suggested that average rates are higher than in the OECD but not that much higher (perhaps around 2 people per vehicle). As a general approximation, occupancy rates were assumed to be 10% higher, with Pacific regions set to be 10% higher than OECD Pacific, and the rest of the world set to be 10% higher than OECD Europe. (Note that these estimates are for all travel, not just commuting trips, which in general have much lower average occupancy rates).

For the project, a simple assumption of 2% reduction in average occupancy every five years was used. This is a slower decline than recent trends in OECD countries, but the decline in occupancy rates has been slowing very recently. In addition, declines greater than this would result in an unreasonably low estimate of occupancy in 2050. The resulting projection of passenger travel (derived by multiplying vehicle travel by occupancy rates) is also shown below.

Average LDV occupancy (number of persons per trip)

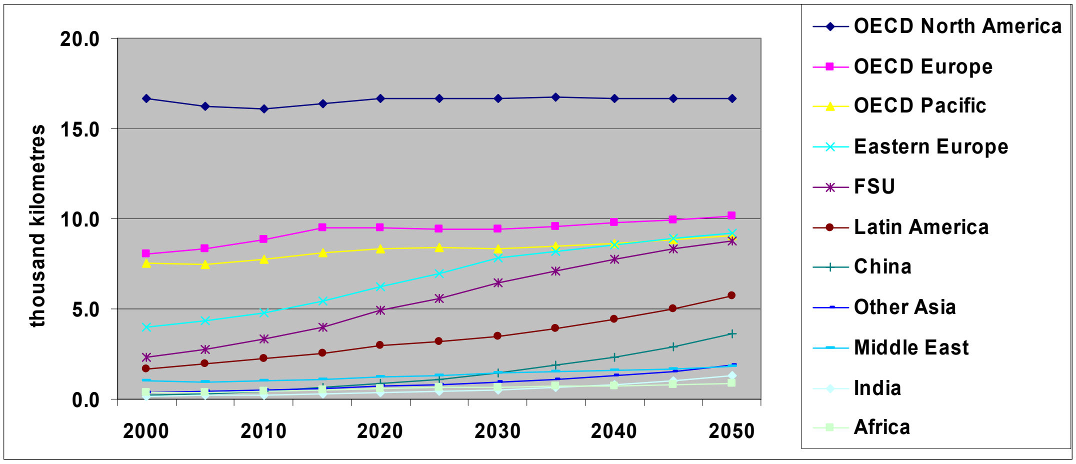
	2000	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
OECD North America	1.53	1.50	1.47	1.46	1.44	1.43	1.42	1.40	1.39	1.37	1.36
OECD Europe	1.64	1.61	1.58	1.55	1.52	1.49	1.47	1.46	1.44	1.43	1.41
OECD Pacific	1.72	1.69	1.65	1.62	1.59	1.55	1.52	1.51	1.49	1.48	1.46
FSU	1.81	1.77	1.74	1.70	1.67	1.63	1.60	1.57	1.54	1.52	1.51
Eastern Europe	1.81	1.77	1.74	1.70	1.67	1.63	1.60	1.57	1.54	1.52	1.51
China	1.89	1.85	1.82	1.78	1.75	1.71	1.68	1.64	1.61	1.59	1.58
Other Asia	1.89	1.85	1.82	1.78	1.75	1.71	1.68	1.64	1.61	1.59	1.58
India	1.89	1.85	1.82	1.78	1.75	1.71	1.68	1.64	1.61	1.59	1.58
Middle East	1.81	1.77	1.74	1.70	1.67	1.63	1.60	1.57	1.54	1.52	1.51
Latin America	1.81	1.77	1.74	1.70	1.67	1.63	1.60	1.57	1.54	1.52	1.51
Africa	1.81	1.77	1.74	1.70	1.67	1.63	1.60	1.57	1.54	1.52	1.51

Total Annual Passenger Travel in LDVs, trillion kilometres and annual Pct Growth

							Annual Percentage Growth		
	2000	**2010**	**2020**	**2030**	**2040**	**2050**	**2000-2010**	**2010-2030**	**2030-2050**
OECD North America	6.8	7.2	8.1	8.7	9.2	9.7	0.6%	1.0%	0.6%
OECD Europe	4.1	4.6	5.0	4.9	4.8	4.7	1.2%	0.3%	-0.2%
OECD Pacific	1.5	1.6	1.7	1.7	1.7	1.7	0.6%	0.4%	0.1%
FSU	0.6	0.8	1.2	1.6	1.9	2.2	3.3%	3.3%	1.6%
Eastern Europe	0.4	0.4	0.5	0.6	0.7	0.8	1.2%	1.8%	1.0%
China	0.3	0.6	1.2	2.1	3.5	5.3	6.9%	6.5%	4.7%
Other Asia	0.4	0.5	0.9	1.3	1.9	3.0	4.1%	4.4%	4.5%
India	0.2	0.3	0.5	0.8	1.2	2.1	5.5%	5.4%	5.2%
Middle East	0.2	0.2	0.3	0.5	0.6	0.8	2.9%	3.8%	2.5%
Latin America	0.7	1.1	1.6	2.0	2.7	3.8	4.1%	3.3%	3.1%
Africa	0.3	0.4	0.7	1.0	1.3	1.8	4.1%	4.3%	2.9%
World Total	15.3	17.8	21.8	25.2	29.6	35.9	1.5%	1.8%	1.8%

As a “reality check”, passenger travel per person per year (in LDVs) was calculated. The increases in LDV travel per capita are near zero in OECD countries (i.e. overall growth in passenger travel is about at the rate of population growth). Though growth is substantial in some non-OECD regions, it is still relatively low in 2050 compared to OECD regions especially the US). In non-OECD regions, a key determinant whether these types of travel increases are surely reasonable given that they mostly reflect increasing shares of the population with access to motor vehicle travel, which is much faster than non-motorised travel. Thus, the average time spent travelling by individuals would not necessarily rise due to the increases shown here.

Projected average travel per person per year in light-duty vehicles



3.1.7 Projected LDV Fuel Consumption

Finally, to derive total LDV fuel consumption, we multiply together the vehicle stock, travel rates, and on-road per vehicle fuel consumption projections described above

LDV Total Fuel Consumption (bil litres gasoline equiv)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
OECD North America	507	530	562	601	635	655	671	684	696	706	716
OECD Europe	200	210	219	227	223	219	215	211	207	202	198
OECD Pacific	92	91	92	93	94	93	91	90	90	90	89
FSU	35	41	49	60	74	84	95	105	114	121	127
Eastern Europe	20	22	24	26	29	31	33	35	37	38	39
China	19	26	38	54	76	98	125	157	195	238	287
Other Asia	22	26	32	40	50	60	72	87	107	131	160
India	9	12	15	21	28	34	42	53	66	85	109
Middle East	11	12	14	17	21	24	28	32	35	39	42
Latin America	46	55	66	80	97	107	121	138	159	183	209
Africa	22	26	32	40	50	61	69	76	84	95	108
Total	982	1,052	1,145	1,260	1,377	1,466	1,562	1,669	1,790	1,927	2,086

LDV Total Fuel Consumption (exajoules)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
OECD North America	17.7	18.5	19.6	20.9	22.1	22.8	23.4	23.8	24.2	24.6	25.0
OECD Europe	7.0	7.3	7.6	7.9	7.8	7.6	7.5	7.3	7.2	7.1	6.9
OECD Pacific	3.2	3.2	3.2	3.2	3.3	3.2	3.2	3.2	3.1	3.1	3.1
FSU	1.2	1.4	1.7	2.1	2.6	2.9	3.3	3.7	4.0	4.2	4.4
Eastern Europe	0.7	0.8	0.8	0.9	1.0	1.1	1.2	1.2	1.3	1.3	1.4
China	0.7	0.9	1.3	1.9	2.7	3.4	4.4	5.5	6.8	8.3	10.0
Other Asia	0.8	0.9	1.1	1.4	1.8	2.1	2.5	3.0	3.7	4.6	5.6
India	0.3	0.4	0.5	0.7	1.0	1.2	1.5	1.8	2.3	3.0	3.8
Middle East	0.4	0.4	0.5	0.6	0.7	0.8	1.0	1.1	1.2	1.4	1.5
Latin America	1.6	1.9	2.3	2.8	3.4	3.7	4.2	4.8	5.5	6.4	7.3
Africa	0.8	0.9	1.1	1.4	1.7	2.1	2.4	2.7	2.9	3.3	3.8
Total	34.2	36.7	39.9	43.9	48.0	51.1	54.4	58.1	62.4	67.1	72.7

LDV Total Gasoline Consumption (bil litres)

OECD North America	495	514	539	576	607	625	639	650	659	667	674
OECD Europe	150	145	133	123	116	112	110	108	105	103	101
OECD Pacific	75	75	78	80	80	78	77	75	74	73	72
FSU	34	40	47	57	69	78	88	97	104	110	114
Eastern Europe	15	17	18	20	21	21	20	20	20	20	21
China	18	25	36	51	72	92	117	146	179	217	260
Other Asia	21	25	31	38	48	56	67	81	98	119	145
India	7	9	13	17	24	29	36	44	56	71	90
Middle East	10	11	13	16	19	22	25	29	32	35	38
Latin America	36	44	54	65	78	86	97	110	125	142	161
Africa	21	25	30	38	47	58	65	71	78	86	98
Total	882	931	992	1,081	1,181	1,257	1,339	1,429	1,530	1,643	1,772

LDV Total Diesel Fuel Consumption (bil litres gasoline-equiv)

OECD North America	8	9	10	11	13	15	17	19	21	23	26
OECD Europe	45	58	73	91	95	95	93	91	90	88	86
OECD Pacific	9	8	6	5	6	6	7	8	8	9	10
FSU	1	1	2	3	4	5	6	7	9	10	12
Eastern Europe	4	4	5	6	8	10	12	15	16	17	18
China	1	1	2	3	4	6	8	11	15	20	27
Other Asia	1	1	1	2	3	3	5	6	8	11	15
India	2	2	2	2	3	3	4	6	8	10	14
Middle East	0	1	1	1	1	1	2	2	3	3	4
Latin America	2	2	3	4	5	6	8	10	12	15	19
Africa	1	1	1	2	3	3	4	5	6	8	10
Total	74	89	107	130	144	154	166	179	196	216	241

LDV Total Ethanol Consumption, all feedstock types (bil litres gasoline-equiv)

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
OECD North America	2	5	11	12	12	13	13	13	13	14	14
OECD Europe	0	1	6	5	5	5	5	4	4	4	4
OECD Pacific	0	1	1	1	1	1	1	1	1	1	1
FSU	0	0	0	0	0	0	0	0	0	0	0
Eastern Europe	0	0	0	0	0	0	0	0	0	0	0
China	0	0	0	0	0	0	0	0	0	0	0
Other Asia	0	0	0	0	0	0	0	0	0	0	0
India	0	0	1	1	1	2	2	2	3	4	5
Middle East	0	0	0	0	0	0	0	0	0	0	0
Latin America	6	7	9	11	13	14	16	18	20	23	26
Africa	0	0	0	0	0	0	0	0	0	0	0
Total	8	15	27	29	32	34	36	39	42	46	50

LDV Total Biodiesel Consumption, all feedstock types (bil litres gasoline-equiv)

OECD North America	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OECD Europe	0.0	0.6	3.1	3.8	3.9	4.0	3.9	3.8	3.7	3.7	3.6
OECD Pacific	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FSU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eastern Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
China	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Asia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
India	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Middle East	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Latin America	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Africa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.6	3.1	3.8	3.9	4.0	3.9	3.8	3.7	3.7	3.6

LDV Total LPG/CNG Consumption, all feedstock types (bil litres gasoline-equiv)

OECD North America	2.1	2.1	2.0	2.0	2.0	2.1	2.1	2.2	2.2	2.2	2.3
OECD Europe	4.8	4.5	4.2	3.9	3.9	3.8	3.7	3.7	3.6	3.5	3.4
OECD Pacific	7.8	7.5	7.2	6.9	7.0	6.9	6.8	6.8	6.8	6.7	6.7
FSU	0.7	0.7	0.7	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
Eastern Europe	0.7	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.9	0.9
China	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3
Other Asia	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3
India	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Middle East	0.4	0.4	0.4	0.4	0.4	0.5	0.6	0.7	0.8	0.8	0.9
Latin America	1.5	1.3	1.2	1.1	1.0	1.1	1.3	1.5	1.7	2.0	2.2
Africa	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.5
Total	18.3	17.3	16.6	16.0	16.2	16.5	16.9	17.3	17.8	18.4	18.9

3.2 Two and Three Wheelers

The reference case for two and three wheelers is based on very sparse data – detailed data for two-wheeler stocks, travel and efficiency was found only for North America, Europe, and several Asian countries. Only stock data for a few countries was available for three wheelers. This section mainly discusses two wheeler assumptions, with a short discussion of three-wheelers at the end.

Data and projections for North America and Europe are based on previous IEA and WEC projections. Data on motorcycle stocks in Asian countries was provided by the Asian Development Bank. Data on motorcycle size distributions and fuel consumption was provided mainly by Honda. CRA provided an analysis of this data that serves as the basis for the reference case.

For the countries with good data available (OECD Regions and Asia), the reference case was constructed using 2000 or other recent year data for passenger km per year, total stock of vehicles, average load factor, average travel per vehicle per year, and average 2-wheeler efficiency. With this information it is possible to calculate the other variables. For other regions, values were selected based on various information sources and judgment about the likely ownership rates in these regions, and sizes and efficiencies of motorcycles. In general, ownership rates for the other regions are assumed to be between the (fairly modest) European rate and the (quite high) Asian rates, and motorcycles are assumed to be of an intermediate size and efficiency relative to these two regions. These are obviously quite general, weak assumptions that could be improved if more data were obtained for these other regions.

Year 2000 values for key parameters – 2–wheelers

	Passenger km per year (billion)	Total stock of 2-wheelers (millions)	Vehicles per 1000 population	Load factor (average # of riders per trip)	Average travel per vehicle (thou kms per year)	Vehicle km per year (billions)	Average 2-wheeler efficiency (L/100 km)	Energy use (exajoules)
OECD North America	30.0	5.0	12	1.2	5.0	25.0	5.1	0.04
OECD Europe	144.0	16.0	31	1.2	7.5	120.0	4.4	0.18
OECD Pacific	50.0	5.6	28	1.2	7.5	41.7	3.5	0.05
FSU	75.0	5.4	21	1.4	10.0	53.6	2.5	0.05
Eastern Europe	50.0	3.6	36	1.4	10.0	35.7	2.5	0.03
China	615.7	37.3	29	1.7	10.0	373.2	1.4	0.18
Other Asia	940.5	57.0	64	1.7	10.0	570.0	1.4	0.28
India	559.6	33.9	33	1.7	10.0	339.1	1.4	0.17
Middle East	100.0	6.1	36	1.7	10.0	60.6	2.5	0.05
Latin America	200.0	12.1	29	1.7	10.0	121.2	2.5	0.11
Africa	200.0	12.1	15	1.7	10.0	121.2	1.4	0.06
‘ World total	2964.8	194.0				1861.3		1.20

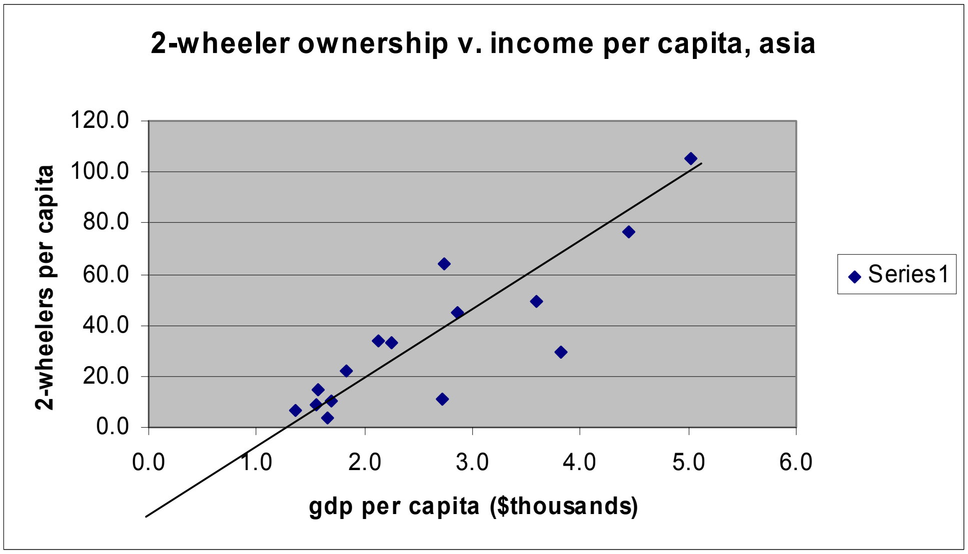
The assumptions currently used result in an estimate of 194 million 2-wheelers world-wide in 2000, and 1.20 exajoules of energy use, about 2% of all road fuel use world-wide.

The Table below shows the projection assumptions for 2-wheeler ownership per 1000 population – the primary driver, along with energy efficiency, of the fuel consumption projection (since travel per vehicle and load factors are assumed to be constant over time in all regions).

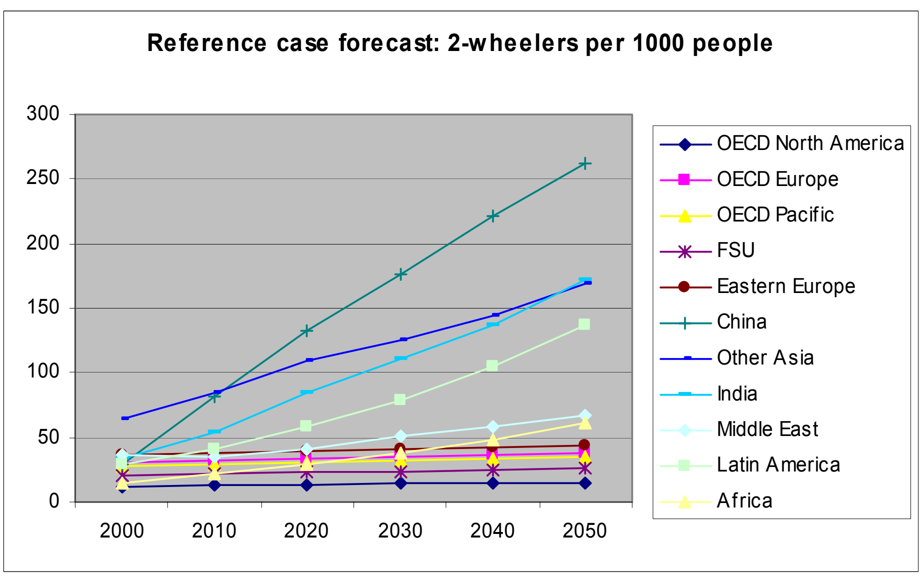
Projections of 2-wheeler ownership per 1000 population

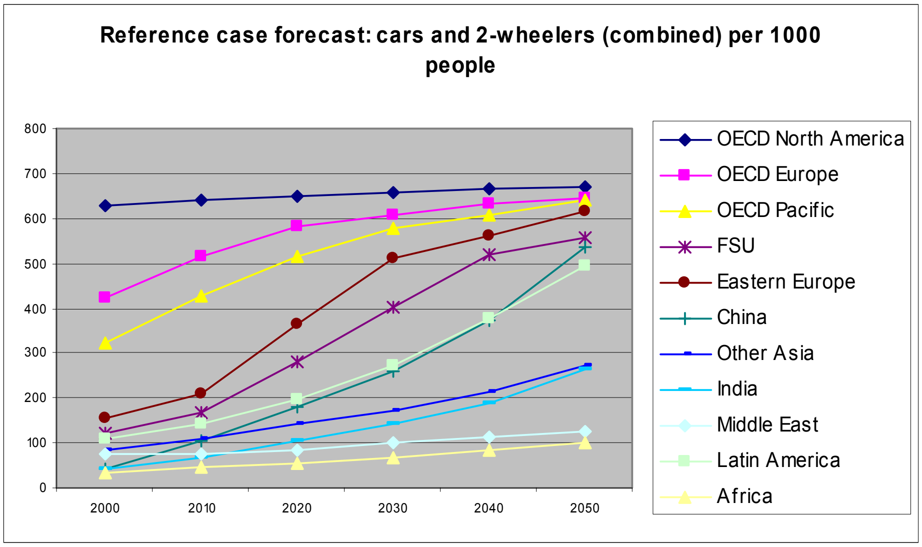
	2000	2010	2020	2030	2040	2050
OECD North America	12	13	13	14	14	15
OECD Europe	31	32	34	35	36	38
OECD Pacific	28	29	30	32	33	34
FSU	21	22	23	24	25	26
Eastern Europe	36	37	39	40	42	44
China	29	82	132	177	221	263
Other Asia	64	84	110	125	144	169
India	33	54	84	111	137	171
Middle East	36	35	41	50	58	67
Latin America	29	41	58	79	105	137
Africa	15	22	30	39	49	61

Ownership rates are assumed to hold constant in OECD regions, Eastern Europe and the Soviet Union (thus stocks rise in proportion with population growth). Ownership rates increase in other developing regions. A logistical growth curve in ownership was applied that follows the approach taken for automobiles (based on Dargay and Gately, 2001), but adjusted for the lower income levels at which countries begin rapid increases in 2-wheeler ownership. As shown in the figure below, based on incomes and ownership levels in five Asian countries in 1990, 1995, and 2000, there is a fairly strong relationship between income and ownership beginning at $2k GDP/capita. What is not clear is how this relationship might continue after countries reach about 100 2-wheelers per capita, since none has yet done so. We have assumed that 2-wheeler ownership will tend to saturate in the developing world at about 1 per family – taking into account than in many countries most women do not drive them. Further, as incomes reach $6k per capita, car ownership rates begin to rise rapidly, which could slow the growth in two-wheelers. Thus, we use a declining growth rate above 100 2-wheelers per household, with saturation at about 300. We also assume that cars plus two wheelers saturates at about 700 per 1000 population, consistent with slow growth in regions that have surpassed 600 (IEA North America and Europe).



The following figure shows our projection for 2-wheeler ownership by region, and cars plus two-wheeler ownership by region. By 2050, China has by far the highest 2-wheeler ownership rate, since it has the fastest income growth, and is approaching 300 per 1000 people. Other regions reach lower levels (and have different sloping growth curves) as per the projection for income growth in those regions. India, “Other Asia” and Latin America reach well above 100 2-wheelers per 1000 people. Other regions are either treated as low-ownership (OECD, FSU and Eastern Europe), or have not had sufficient income growth yet to trigger high ownership levels of 2-wheelers (Africa and Middle East).

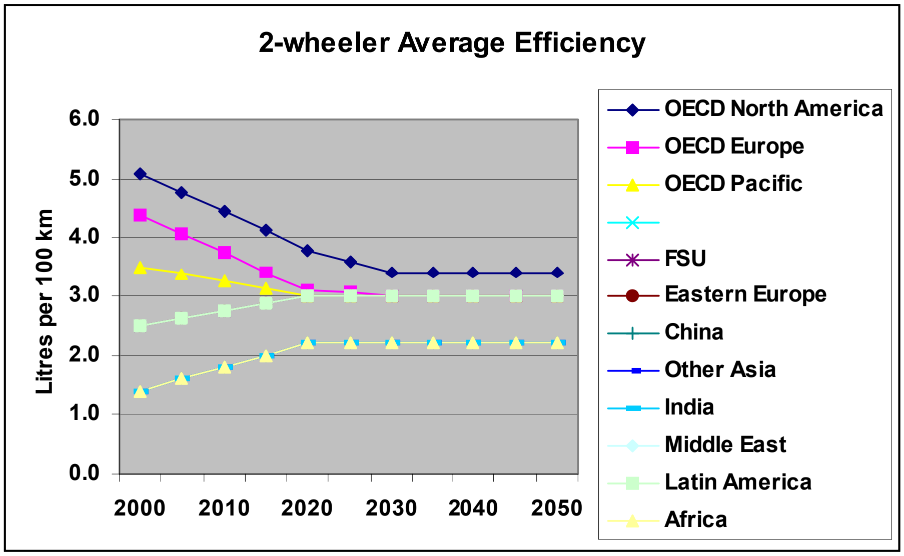




The table below shows the projection for 2-wheeler stock-average efficiency. The main reason that fuel intensity of 2-wheelers is much lower in Asia than in the OECD is that 2-wheelers there are much smaller on average. Over time, it is assumed that this size will increase and approach that of the developed world. On the other hand, motorcycle technology is expected to improve and yield significant efficiency improvements for vehicles of each size-class, so average fuel intensity in the developed world is expected to decline. The wide range in efficiency across regions in 2000 (of 1.4 up to 5.1 L/100 km) is expected to narrow to less than 1 litre (2.2 to 3.0 L/100 km) by 2050. Data for 2-wheeler fuel efficiency in 2000 was obtained from a variety of sources.

Two-wheeler stock-average fuel efficiency (L/100 km)

	2000	2010	2020	2030	2040	2050
OECD North America	5.1	4.5	3.8	3.4	3.4	3.4
OECD Europe	4.4	3.8	3.1	3.0	3.0	3.0
OECD Pacific	3.5	3.3	3.0	3.0	3.0	3.0
FSU	2.5	2.8	3.0	3.0	3.0	3.0
Eastern Europe	2.5	2.8	3.0	3.0	3.0	3.0
China	1.4	1.8	2.2	2.2	2.2	2.2
Other Asia	1.4	1.8	2.2	2.2	2.2	2.2
India	1.4	1.8	2.2	2.2	2.2	2.2
Middle East	2.5	2.8	3.0	3.0	3.0	3.0
Latin America	2.5	2.8	3.0	3.0	3.0	3.0
Africa	1.4	1.8	2.2	2.2	2.2	2.2
World Average	1.9	2.0	2.3	2.3	2.3	2.3



The result of increased 2-wheeler vehicle ownership rates in some regions (and Population growth in most regions), with assumptions of constant vehicle utilization rates over time, combined with the projection changes in efficiency, result in the following fuel use projection. Between 2000 and 2050, two-wheeler fuel consumption is projection to increase by more than 8-fold, and increase from about 2% of road vehicle fuel use to more than 3% by 2050.

Two-wheeler fuel use projection, exajoules

	2000	2010	2020	2030	2040	2050
OECD North America	0.04	0.04	0.04	0.04	0.05	0.05
OECD Europe	0.18	0.17	0.14	0.14	0.14	0.14
OECD Pacific	0.05	0.05	0.05	0.05	0.05	0.05
FSU	0.05	0.05	0.06	0.06	0.06	0.07
Eastern Europe	0.03	0.03	0.04	0.03	0.04	0.04
China	0.18	0.70	1.46	2.01	2.51	2.97
Other Asia	0.28	0.55	1.00	1.27	1.63	2.08
India	0.17	0.40	0.83	1.20	1.56	2.06
Middle East	0.05	0.07	0.12	0.17	0.23	0.30
Latin America	0.11	0.19	0.32	0.48	0.68	0.94
Africa	0.06	0.14	0.28	0.44	0.65	0.93
Total	1.20	2.39	4.35	5.91	7.60	9.63

For three wheelers, data was available only for Asia. This is the only region where there are significant numbers of three-wheelers. These are mainly taxis and delivery vehicles. Data was assembled by CRA and IEA based on various sources. Data on Asian stocks was provided by the Asian Development Bank. Data for travel and efficiency were based on USAID data and IEA data.

The projection is simply to assume constant vehicle stocks and characteristics into the future. There is certainly a strong chance that three wheelers, at least of the type currently used, will eventually be phased out, though as of 2000 their stocks were still growing. However, indications in places like India and Bangladesh are that their growth will be discouraged in the future. Their total energy use, about 0.27 exajoules, is well below 1% of world transport energy use.

Three wheelers – year 2000 attributes

	Vehicle stocks	Travel per vehicle (kms/year)	Fuel use per km	Total fuel use exajoules	Total fuel use Bil litres gasoline-equiv
OECD North America	0			0.00	0.0
OECD Europe	0			0.00	0.0
OECD Pacific	0			0.00	0.0
FSU	0			0.00	0.0
Eastern Europe	0			0.00	0.0
China	2,437	40,000	3.0	0.10	2.9
Other Asia	2,279	40,000	3.0	0.10	2.7
India	1,696	40,000	3.0	0.07	2.0
Middle East				0.00	0.0
Latin America				0.00	0.0
Africa				0.00	0.0
World Total	6,412			0.27	7.69

3.3 Medium and Heavy-duty Trucks

Although data are poor for many regions, trucks have been broken into medium duty freight and heavy duty (long-haul) freight, in order to allow better differentiation of the services they provide and fuels they use. Heavy duty trucks are defined here as long-haul trucks operating almost exclusively on diesel fuel. These trucks carry large loads, on average, with lower energy intensity (energy use per tonne-kilometre of haulage) than medium duty trucks such as delivery trucks. Medium-duty trucks are smaller. These include medium-haul trucks and delivery vehicles.

However, there is very little information available to allow a precise division of data for the two types of trucks, and even many of the estimates available for all trucking are not especially reliable, apart from a few estimates for the US and Europe. We do have some estimates of total tonne-kilometres traveled (from IEA and WEC) and energy use (from IEA) for all trucks by region. The basic approach here has been to start from the most reliable data available - gasoline and diesel road fuel use by region - and employ other available trucking data where possible, while balancing all variables in all regions to preserve the fuel use totals. This is complicated by the fact that IEA fuel use data for non-OECD regions is only available for all road vehicles and, thus,must be shared out among cars, trucks buses and two-wheelers. Data on average energy intensity for medium and heavy trucks has been used as a key divisia variable, as well as data on fuel use by fuel type (gasoline v. diesel), with long-haul trucks assumed to use only diesel fuel and medium duty trucks composed of some combination of gasoline and diesel vehicles.

The following year 2000 estimates reflect these considerations and match IEA fuel use totals within about 1% for each region. The wide range in energy intensity is mainly due to variations in the share of freight movement by large, long-haul trucks (lowest intensity, with highest share in North America) and smaller trucks, including delivery vehicles.

Year 2000 Estimates for All Trucks

	Travel	Energy intensity	Energy Use		
			Total	Gasoline	Diesel fuel
	Tonne-km	(mJ/tonne-km)	(exajoules)	(bil litres)	(bil litres)
OECD North America	2,950	1.8	5.3	16.1	122.4
OECD Europe	2,147	2.0	4.3	8.2	104.0
OECD Pacific	619	3.3	2.0	10.7	43.0
FSU	180	2.7	0.5	3.7	9.2
Eastern Europe	106	2.5	0.3	1.2	5.9
China	223	3.3	0.7	8.8	11.2
Other Asia	662	2.7	1.8	8.0	39.2
India	260	3.0	0.8	1.2	19.3
Middle East	432	3.2	1.4	15.9	21.5
Latin America	651	2.5	1.7	4.7	37.6
Africa	141	3.5	0.5	2.4	10.5
Total, World	8,371	2.3	19.3	80.8	423.9

Thus, among potential sources of error in developing this data is misallocation of gasoline and diesel use between medium and heavy trucks as well as between trucks and light-duty vehicles (cars). Errors in estimates of relative efficiency of heavy v. medium trucks is also an area of concern. However, totals for all trucks should be more reliable, since the breakout between heavy and medium were made in a manner that preserves totals across all trucks, where such data is available.

The following estimates for heavy and medium duty vehicle characteristics have been provided by the indicated sources:

Truck Data for 2000

	Stocks (millions)	Avg VKT/ year	L/100km	MJ/tonne-km	Source
Heavy-duty trucks					
US	4.4	62,000	45		EIA/AEO
EU		80,000	35		Michelin
OECD				1.5-2.0	IEA data
Medium-duty trucks					
US	4.0	27,000	29		EIA/AEO
OECD				2.5-6.0	IEA data

This very "thin" set of data mainly allow us to allocate the overall truck estimates into heavy and medium duty trucks for various regions so that something close to these data points can be hit. For each truck type, we assume fairly similar levels of truck energy intensities in each region (somewhat higher in developing countries due to somewhat smaller trucks, with variations based on WEO and WEC study estimates). The two variables that we adjust in order to hit our target data points are the heavy-duty truck share of total tonne-kilometres (v. medium truck share) and the gasoline / diesel fuel share of medium trucks (the gasoline share for heavy-duty trucks in all regions is set near zero). The resulting year 2000 values for these variables, allow us to hit the targets. These targets are listed in the table below. Also shown is the percent of the total truck tonne-kilometres estimate provided by WEO and WEC that is needed to ensure a final calibration to hit the IEA WEO fuel use numbers in each region. In some cases the tonne-kilometre estimates had to be adjusted substantially – they simply were very out of line with the energy use numbers, taking into account energy intensities and gasoline/diesel use ratios. Again, error could be introduced from over or under counting fuel use in other road sectors such as light-duty vehicles, 2-3 wheelers, or buses.

Key Sharing Factors for Trucks

	Heavy-duty truck share of total truck tonne-km	Gasoline share of medium truck tonne-kms	Pct of year 2000 WEO/WEC TKM Estimate used
OECD North America	92%	50%	109%
OECD Europe	90%	22%	151%
OECD Pacific	64%	24%	185%
FSU	84%	67%	48%
Eastern Europe	85%	37%	68%
China	72%	72%	36%
Other Asia	81%	34%	52%
India	80%	10%	64%
Middle East	75%	75%	135%
Latin America	85%	27%	75%
Africa	75%	28%	40%

These assumptions yield the following sets of estimates for heavy-duty and medium trucks in 2000, that allow us to hit the fuel consumption targets for gasoline and diesel and also the characteristics for medium and heavy trucks shown in the tables above.

Year 2000 Estimates for Heavy-duty Trucks

	Total Medium truck haulage	Diesel Vehicles				Gasoline Vehicles			
		Share of Tonne-kms	Energy Intensity	Fuel Use		Share of Tonne-kms	Energy Intensity	Fuel Use	
	Tonne-km	Pct	mJ/ tonne-km	eJ	bil litres	Pct	mJ/tonne-km	eJ	bil litres
OECD North America	2,714	100%	1.6	4.3	110.4	0%	1.9	0.0	0.1
OECD Europe	1,933	100%	1.7	3.2	82.5	0%	2.0	0.0	0.1
OECD Pacific	396	100%	1.7	0.7	17.7	0%	2.1	0.0	0.0
FSU	151	100%	2.0	0.3	7.8	0%	2.4	0.0	0.0
Eastern Europe	90	100%	1.9	0.2	4.4	0%	2.3	0.0	0.0
China	160	100%	2.1	0.3	8.7	0%	2.5	0.0	0.0
Other Asia	536	100%	2.0	1.1	27.5	0%	2.4	0.0	0.0
India	208	100%	2.1	0.4	11.5	0%	2.6	0.0	0.0
Middle East	150	100%	2.1	0.3	8.1	0%	2.5	0.0	0.0
Latin America	554	100%	2.0	1.1	28.4	0%	2.4	0.0	0.0
Africa	106	100%	2.1	0.2	5.9	0%	2.6	0.0	0.0
World	6,998	100%	1.7	12.1	313.0	0%	2.1	0.0	0.4

Year 2000 Estimates for Medium-duty Trucks

	Total Medium truck haulage	Diesel Vehicles				Gasoline Vehicles			
		Share of Tonne-kms	Energy Intensity	Fuel Use		Share of Tonne-kms	Energy Intensity	Fuel Use	
	Tonne-km	Pct	mJ/ tonne-km	eJ	bil litres	Pct	mJ/tonne-km	eJ	bil litres
OECD North America	236	50%	3.9	0.5	12.0	50%	4.7	0.6	15.9
OECD Europe	215	78%	5.0	0.8	21.5	22%	6.0	0.3	8.1
OECD Pacific	223	76%	5.8	1.0	25.3	24%	6.9	0.4	10.6
FSU	29	33%	5.5	0.1	1.3	67%	6.6	0.1	3.6
Eastern Europe	16	63%	5.7	0.1	1.5	37%	6.8	0.0	1.2
China	62	28%	5.7	0.1	2.6	72%	6.8	0.3	8.8
Other Asia	126	66%	5.4	0.4	11.6	34%	6.5	0.3	8.0
India	52	90%	6.4	0.3	7.8	10%	7.7	0.0	1.2
Middle East	176	25%	5.7	0.3	6.5	75%	6.8	0.9	26.0
Latin America	98	73%	5.4	0.4	10.0	27%	6.5	0.2	4.9
Africa	45	77%	7.1	0.2	6.5	23%	8.6	0.1	2.6
World	1,278	60%	5.3	4.1	106.5	40%	6.3	3.2	90.8

Once estimates were in place for truck tonne-kilometres, energy intensity per tonne-km and energy use, we "backed out" estimates of truck stocks and vehicle kilometers using simple assumptions regarding average tonnes per shipment and average vehicle travel per year based on available data for OECD. These were checked so that the resulting estimates of truck stocks are aligned with the US data for truck stocks. The estimates used are provided below. Note that the average load for heavy-duty trucks seems low – fully loaded trucks are typically much heavier (up to 30+ tonnes). Average travel per vehicle per year also appears somewhat low. But it was necessary to use these lower estimates in order to obtain estimates for vehicles stocks in line with available data. It may be the case that across all trucks operating over the course of a year, the overall average load may be much smaller than some data suggests as "typical" for a truck. For example, perhaps some data on truck loads ignores substantial travel under partial or no load. Either that or our estimates of tonne-kilometres are two low, which would then imply that our estimates of energy intensity (mJ/tonne-km) are too high. Without better data for at least one of these items, it is difficult to know.

Estimates of Truck Stocks, Average Load and Travel per Year, 2000

	Heavy-duty Trucks			Medium-duty Trucks		
	Stocks (1000's)	Avg. vehicle travel per year (kms/veh/year)	Average load (tonnes)	Stocks (1000's)	Avg. vehicle travel per year (kms/veh/year)	Average load (tonnes)
OECD North America	4,523	60,000	10.0	3,575	30,000	2.2
OECD Europe	4,026	60,000	8.0	4,211	30,000	1.7
OECD Pacific	825	60,000	8.0	4,949	30,000	1.5
FSU	420	60,000	6.0	847	20,000	1.7
Eastern Europe	251	60,000	6.0	469	20,000	1.7
China	445	60,000	6.0	1,834	20,000	1.7
Other Asia	1,489	60,000	6.0	3,699	20,000	1.7
India	578	60,000	6.0	1,530	20,000	1.7
Middle East	417	60,000	6.0	5,184	20,000	1.7
Latin America	1,538	60,000	6.0	2,873	20,000	1.7
Africa	294	60,000	6.0	1,336	20,000	1.7

Truck Projections

Once all estimates were in place for 2000, forecasts for medium and heavy duty trucks were made. For truck tonne-km, the growth forecast was made relative to GDP growth, using recent historical trends as the basis. IEA data for OECD countries shows that truck tonne-km of travel is still growing at about the same rate at GDP, though this ratio is changing – in most regions truck travel growth is slowing relative to GDP growth (see table below, note that the ratio of truck tonne-km growth rate relative to GDP growth rate, e.g. 1.08 = truck growth 1.08 times that of GDP, or 8% faster). Based on analysis by Workstream 5-6, it appears that in developing countries the growth rate is considerably higher, about 1.25 times the growth in GDP. But this can also be expected to change in the future, with truck growth slowing as economies mature. This may vary considerably by medium and heavy duty freight, but we do not have any data to allow us to separate these forecasts, so the same growth rates are used for both.

Travel Growth v. GDP growth, by Time Period and OECD Region

	1984-89	1989-94	1994-99
US	0.99	1.14	0.99
EU-8	1.08	1.02	1.00
Japan	1.03	0.96	1.03
Aus (85-95)	1.10	1.02	

Thus, we assume the following relative growth rates for the future tonne-kilometres of trucking relative to GDP (same for both medium and heavy-duty freight)

Reference case projected growth rate relative to GDP growth (ratio)

	2000-2010	2010-2020	After 2020
OECD North America	1.00	0.95	0.90
OECD Europe	1.00	0.95	0.90
OECD Pacific	1.00	0.95	0.90
FSU	1.25	1.10	0.95
Eastern Europe	1.25	1.10	0.95
China	1.25	1.10	0.95
Other Asia	1.25	1.10	0.95
India	1.25	1.10	0.95
Middle East	1.25	1.10	0.95
Latin America	1.25	1.10	0.95
Africa	1.25	1.10	0.95

For energy intensity, past improvements in intensities vary considerably across OECD region and time period, as shown in the table below, and it is difficult to discern any general patterns. Intensity for particular vehicle types is most likely improving, but such trends are confounded by the impacts of changes in the relative proportions of travel by different classes of trucks. Thus, we make simple assumptions about intensity for both medium and heavy trucks across OECD and non-OECD regions. For OECD, we assume intensity drops by an average of 0.8% per year until 2020, when it slows to 0.5% per year (the idea being that many intensity improvements are exhausted by then). For non-OECD we assume it drops more quickly, as for most countries it starts out at a higher level, and (presumably) catches up over time, as technologies transfer and some trucks are sold over to the developing world as they age. The intensity assumptions are shown in the table further below.

IEA Trends data, energy intensity of all trucks, annual percentage change in mJ/tonne-km

	1989-99	1989-94	1994-99
US	-0.9%	-0.7%	0.2%
EU-8	1.2%	-1.4%	
OECD EU-4	0.7%	-0.5%	-1.4%
OECD Nor-4	1.7%	-2.2%	
Japan	-0.5%	1.1%	-1.7%
Aus (85-95)	-2.4%	-2.2%	

Note: negative numbers are reductions, positive numbers are increases in intensity.

Projected truck energy intensity (mJ/tonne-km), annual pct change (negative means reduction)

	2000-2020	2020-2050
OECD North America	-0.75%	-0.50%
OECD Europe	-0.75%	-0.50%
OECD Pacific	-0.75%	-0.50%
FSU	-1.00%	-0.75%
Eastern Europe	-1.00%	-0.75%
China	-1.00%	-0.75%
Other Asia	-1.00%	-0.75%
India	-1.00%	-0.75%
Middle East	-1.00%	-0.75%
Latin America	-1.00%	-0.75%
Africa	-1.00%	-0.75%

Two other assumptions that are not particularly important for the reference case but could be important in policy cases are relative efficiency of alternative freight truck engines / fuel types and the share of these alternative types in moving freight. The shares of all non-diesel or gasoline vehicles are assumed to be near zero in the reference case. The assumed relative energy intensities per tonne-km travelled (same size vehicle) are shown below.

Assumed relative vehicle energy intensities (mJ/tonne-km) compared to diesel medium and heavy trucks

	Medium duty	Heavy duty	Notes
Diesel	-	-	Base vehicle
Gasoline	20% higher energy use	20% higher energy use	Less efficient than compression ignition
Diesel hybrid	10% lower	0% (no change)	Hybrids assumed to provide virtually no benefit on highway duty cycles
Fuel cell (hydrogen)	40% lower	40% lower	But unclear how viable in heavy-duty truck applications – reliability / durability will be key

Finally, the resulting projections for heavy-duty and medium-duty trucks are shown below.

Heavy-duty Trucks, Full Reference Case Projections

Region	Year 2000	2010	2020	2030	2040	2050
Total Stock of Heavy Trucks (thousands)						
OECD North America	4,523	5,812	7,029	8,256	9,606	11,145
OECD Europe	4,026	5,075	6,157	7,080	7,727	8,407
OECD Pacific	825	1,017	1,242	1,466	1,699	1,969
FSU	420	602	872	1,124	1,464	1,907
Eastern Europe	251	381	542	717	1,031	1,483
China	445	874	1,441	2,083	2,928	4,116
Other Asia	1,489	2,428	3,664	5,058	6,940	9,438
India	578	1,050	1,725	2,534	3,608	5,124
Middle East	900	1,231	1,655	2,106	2,555	3,044
Latin America	1,538	2,200	3,068	4,032	5,175	6,618
Africa	294	462	688	945	1,262	1,651
World Total	15,289	21,133	28,084	35,400	43,995	54,901
Average annual growth		3.5%	2.8%	2.3%	2.2%	2.3%
Average travel per vehicle per year (km)						
OECD North America	60,000	60,000	60,000	60,000	60,000	60,000
OECD Europe	60,000	60,000	60,000	60,000	60,000	60,000
OECD Pacific	60,000	60,000	60,000	60,000	60,000	60,000
FSU	60,000	60,000	60,000	60,000	60,000	60,000
Eastern Europe	60,000	60,000	60,000	60,000	60,000	60,000
China	60,000	60,000	60,000	60,000	60,000	60,000
Other Asia	60,000	60,000	60,000	60,000	60,000	60,000
India	60,000	60,000	60,000	60,000	60,000	60,000
Middle East	60,000	60,000	60,000	60,000	60,000	60,000
Latin America	60,000	60,000	60,000	60,000	60,000	60,000
Africa	60,000	60,000	60,000	60,000	60,000	60,000
Total Vehicle-km of travel (bil)						
OECD North America	271.4	348.7	421.8	495.3	576.4	668.7
OECD Europe	241.6	304.5	369.4	424.8	463.6	504.4
OECD Pacific	49.5	61.0	74.5	87.9	102.0	118.1
FSU	25.2	36.1	52.3	67.4	87.8	114.4
Eastern Europe	15.0	22.9	32.5	43.0	61.9	89.0
China	26.7	52.5	86.5	125.0	175.7	246.9
Other Asia	89.3	145.7	219.8	303.5	416.4	566.3
India	34.7	63.0	103.5	152.0	216.5	307.4
Middle East	54.0	73.9	99.3	126.3	153.3	182.7
Latin America	92.3	132.0	184.1	241.9	310.5	397.1
Africa	17.7	27.7	41.3	56.7	75.7	99.0
World Total	917.3	1268.0	1685.0	2124.0	2639.7	3294.0
Average annual growth		3.5%	2.8%	2.3%	2.2%	2.3%

Average load (tonnes)

OECD North America	10.0	10.0	10.0	10.0	10.0	10.0
OECD Europe	8.0	8.0	8.0	8.0	8.0	8.0
OECD Pacific	8.0	8.0	8.0	8.0	8.0	8.0
FSU	6.0	6.0	6.0	6.0	6.0	6.0
Eastern Europe	6.0	6.0	6.0	6.0	6.0	6.0
China	6.0	6.0	6.0	6.0	6.0	6.0
Other Asia	6.0	6.0	6.0	6.0	6.0	6.0
India	6.0	6.0	6.0	6.0	6.0	6.0
Middle East	6.0	6.0	6.0	6.0	6.0	6.0
Latin America	6.0	6.0	6.0	6.0	6.0	6.0
Africa	6.0	6.0	6.0	6.0	6.0	6.0

Total Tonne-km of travel (bil)

OECD North America	2713.6	3487.1	4217.6	4953.4	5763.6	6686.8
OECD Europe	1932.6	2436.2	2955.4	3398.3	3708.8	4035.4
OECD Pacific	395.9	488.1	596.3	703.6	815.7	945.0
FSU	151.2	216.9	313.8	404.5	527.0	686.5
Eastern Europe	90.3	137.2	195.1	258.1	371.3	533.7
China	160.3	314.8	518.9	750.0	1054.1	1481.6
Other Asia	536.1	874.0	1319.1	1821.0	2498.4	3397.8
India	208.1	377.9	620.9	912.2	1299.0	1844.6
Middle East	324.0	443.2	595.9	758.1	919.8	1096.0
Latin America	553.6	791.8	1104.6	1451.5	1862.9	2382.4
Africa	105.9	166.4	247.6	340.2	454.3	594.2
World Total	7171.6	9733.7	12685.0	15750.8	19274.9	23684.0
Average annual growth		3.3%	2.6%	2.1%	2.0%	2.1%

Share of tonne-kms by diesel trucks

OECD North America	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%
OECD Europe	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%
OECD Pacific	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%
FSU	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%
Eastern Europe	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%
China	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%
Other Asia	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%
India	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%
Middle East	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%
Latin America	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%
Africa	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%

Heavy-duty diesel truck average energy intensity (mJ/tonne-km)

OECD North America	1.57	1.46	1.35	1.27	1.21	1.15
OECD Europe	1.65	1.53	1.42	1.34	1.27	1.21
OECD Pacific	1.73	1.61	1.49	1.40	1.33	1.27
FSU	2.01	1.82	1.64	1.50	1.40	1.29
Eastern Europe	1.90	1.72	1.56	1.42	1.32	1.23
China	2.09	1.89	1.71	1.57	1.45	1.35
Other Asia	1.99	1.80	1.63	1.49	1.38	1.28
India	2.14	1.94	1.75	1.60	1.49	1.38
Middle East	2.09	1.89	1.71	1.57	1.45	1.35
Latin America	1.99	1.80	1.63	1.49	1.38	1.28
Africa	2.14	1.94	1.75	1.60	1.49	1.38

FUEL USE

Heavy Freight Truck Total Diesel Fuel Consumption (bil litres gasoline equiv)

OECD North America	122.5	146.0	163.8	180.6	199.9	220.6
OECD Europe	91.6	106.1	119.4	128.9	133.8	138.5
OECD Pacific	19.7	22.5	25.5	28.2	31.1	34.3
FSU	8.7	11.3	14.8	17.5	21.1	25.5
Eastern Europe	4.9	6.8	8.7	10.5	14.1	18.8
China	9.6	17.1	25.5	33.7	43.9	57.3
Other Asia	30.6	45.0	61.5	77.7	98.9	124.8
India	12.8	21.0	31.2	41.9	55.4	72.9
Middle East	19.4	24.0	29.2	34.1	38.3	42.4
Latin America	30.6	39.6	49.9	60.1	71.5	84.9
Africa	6.5	9.2	12.4	15.6	19.4	23.5
Total	356.8	448.6	541.8	629.0	727.5	843.3

Energy use, Exajoules

OECD North America	4.27	5.09	5.71	6.30	6.97	7.69
OECD Europe	3.20	3.74	4.21	4.54	4.72	4.88
OECD Pacific	0.69	0.78	0.89	0.99	1.09	1.20
FSU	0.30	0.39	0.52	0.61	0.74	0.89
Eastern Europe	0.17	0.24	0.30	0.37	0.49	0.65
China	0.34	0.60	0.89	1.18	1.53	2.00
Other Asia	1.07	1.57	2.14	2.71	3.45	4.35
India	0.45	0.73	1.09	1.46	1.93	2.54
Middle East	0.68	0.84	1.02	1.19	1.34	1.48
Latin America	1.10	1.42	1.80	2.16	2.57	3.05
Africa	0.23	0.32	0.43	0.55	0.68	0.82
Total	12.48	15.73	19.00	22.05	25.50	29.56

Medium-duty Truck, Reference Case Projections

	2000	2010	2020	2030	2040	2050
Total Stock of Medium Trucks (thousands)						
OECD North America	3,575	4,594	5,557	6,526	7,594	8,810
OECD Europe	4,211	5,308	6,439	7,404	8,080	8,792
OECD Pacific	4,949	6,102	7,453	8,794	10,196	11,813
FSU	847	1,215	1,758	2,266	2,952	3,846
Eastern Europe	469	712	1,013	1,340	1,927	2,770
China	1,834	3,601	5,935	8,578	12,057	16,947
Other Asia	3,699	6,030	9,100	12,563	17,237	23,442
India	1,530	2,779	4,565	6,707	9,552	13,564
Middle East	3,176	4,345	5,842	7,432	9,017	10,745
Latin America	2,873	4,110	5,733	7,534	9,669	12,365
Africa	1,039	1,631	2,427	3,335	4,454	5,825
World Total	28,201	40,427	55,822	72,480	92,735	118,918
Average annual growth		3.9%	3.2%	2.6%	2.5%	2.5%
Average travel per vehicle per year (km)						
OECD North America	30,000	30,000	30,000	30,000	30,000	30,000
OECD Europe	30,000	30,000	30,000	30,000	30,000	30,000
OECD Pacific	30,000	30,000	30,000	30,000	30,000	30,000
FSU	20,000	20,000	20,000	20,000	20,000	20,000
Eastern Europe	20,000	20,000	20,000	20,000	20,000	20,000
China	20,000	20,000	20,000	20,000	20,000	20,000
Other Asia	20,000	20,000	20,000	20,000	20,000	20,000
India	20,000	20,000	20,000	20,000	20,000	20,000
Middle East	20,000	20,000	20,000	20,000	20,000	20,000
Latin America	20,000	20,000	20,000	20,000	20,000	20,000
Africa	20,000	20,000	20,000	20,000	20,000	20,000
Total Vehicle-km of travel (bil)						
OECD North America	107.3	137.8	166.7	195.8	227.8	264.3
OECD Europe	126.3	159.2	193.2	222.1	242.4	263.8
OECD Pacific	148.5	183.0	223.6	263.8	305.9	354.4
FSU	16.9	24.3	35.2	45.3	59.0	76.9
Eastern Europe	9.4	14.2	20.3	26.8	38.5	55.4
China	36.7	72.0	118.7	171.6	241.1	338.9
Other Asia	74.0	120.6	182.0	251.3	344.7	468.8
India	30.6	55.6	91.3	134.1	191.0	271.3
Middle East	63.5	86.9	116.8	148.6	180.3	214.9
Latin America	57.5	82.2	114.7	150.7	193.4	247.3
Africa	20.8	32.6	48.5	66.7	89.1	116.5
World Total	691.4	968.6	1310.9	1676.8	2113.4	2672.5
Average annual growth		3.6%	3.0%	2.4%	2.3%	2.4%

Average load (tonnes)

OECD North America	2.2	2.2	2.2	2.2	2.2	2.2
OECD Europe	1.7	1.7	1.7	1.7	1.7	1.7
OECD Pacific	1.5	1.5	1.5	1.5	1.5	1.5
FSU	1.7	1.7	1.7	1.7	1.7	1.7
Eastern Europe	1.7	1.7	1.7	1.7	1.7	1.7
China	1.7	1.7	1.7	1.7	1.7	1.7
Other Asia	1.7	1.7	1.7	1.7	1.7	1.7
India	1.7	1.7	1.7	1.7	1.7	1.7
Middle East	1.7	1.7	1.7	1.7	1.7	1.7
Latin America	1.7	1.7	1.7	1.7	1.7	1.7
Africa	1.7	1.7	1.7	1.7	1.7	1.7

Total Tonne-km of travel (bil)

OECD North America	236.0	303.2	366.7	430.7	501.2	581.5
OECD Europe	214.7	270.7	328.4	377.6	412.1	448.4
OECD Pacific	222.7	274.6	335.4	395.7	458.8	531.6
FSU	28.8	41.3	59.8	77.0	100.4	130.8
Eastern Europe	15.9	24.2	34.4	45.6	65.5	94.2
China	62.3	122.4	201.8	291.7	409.9	576.2
Other Asia	125.7	205.0	309.4	427.2	586.0	797.0
India	52.0	94.5	155.2	228.0	324.8	461.2
Middle East	108.0	147.7	198.6	252.7	306.6	365.3
Latin America	97.7	139.7	194.9	256.1	328.7	420.4
Africa	35.3	55.5	82.5	113.4	151.4	198.1
World Total	1199.2	1678.9	2267.2	2895.8	3645.5	4604.5
Average annual growth		3.6%	3.0%	2.4%	2.3%	2.4%

Gasoline vehicle share of total medium truck tonne-kms

OECD North America	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
OECD Europe	78.0%	78.0%	78.0%	78.0%	78.0%	78.0%
OECD Pacific	76.0%	76.0%	76.0%	76.0%	76.0%	76.0%
FSU	33.0%	33.0%	33.0%	33.0%	33.0%	33.0%
Eastern Europe	63.0%	63.0%	63.0%	63.0%	63.0%	63.0%
China	28.0%	28.0%	28.0%	28.0%	28.0%	28.0%
Other Asia	66.0%	66.0%	66.0%	66.0%	66.0%	66.0%
India	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%
Middle East	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%
Latin America	73.0%	73.0%	73.0%	73.0%	73.0%	73.0%
Africa	72.0%	72.0%	72.0%	72.0%	72.0%	72.0%

Average energy intensity of medium-duty trucks (mJ/tonne-km)

OECD North America	3.94	3.65	3.39	3.18	3.02	2.88
OECD Europe	4.96	4.60	4.27	4.01	3.81	3.63
OECD Pacific	5.78	5.36	4.97	4.67	4.44	4.22
FSU	5.48	4.96	4.48	4.10	3.81	3.53
Eastern Europe	5.71	5.16	4.67	4.27	3.96	3.68
China	5.71	5.16	4.67	4.27	3.96	3.68
Other Asia	5.42	4.90	4.43	4.06	3.77	3.49
India	6.42	5.81	5.25	4.81	4.46	4.14
Middle East	5.71	5.16	4.67	4.27	3.96	3.68
Latin America	5.42	4.90	4.43	4.06	3.77	3.49
Africa	7.13	6.45	5.83	5.34	4.96	4.60

FUEL USE

Diesel Fuel Consumption (bil litres gasoline equiv)

OECD North America	13.3	15.9	17.8	19.7	21.8	24.0
OECD Europe	23.8	27.6	31.1	33.6	34.8	36.0
OECD Pacific	28.1	32.1	36.4	40.3	44.4	49.0
FSU	1.5	1.9	2.5	3.0	3.6	4.4
Eastern Europe	1.6	2.3	2.9	3.5	4.7	6.3
China	2.9	5.1	7.6	10.0	13.1	17.0
Other Asia	12.9	19.0	26.0	32.9	41.8	52.7
India	8.6	14.2	21.1	28.3	37.4	49.3
Middle East	4.4	5.5	6.7	7.7	8.7	9.6
Latin America	11.1	14.4	18.1	21.8	25.9	30.8
Africa	5.2	7.4	9.9	12.5	15.5	18.8
Total	113.5	145.3	180.0	213.3	251.8	297.9

Gasoline Fuel Consumption (bil litres)

OECD North America	15.9	18.7	20.7	22.9	25.3	27.9
OECD Europe	8.1	9.3	10.3	11.1	11.6	12.0
OECD Pacific	10.6	12.2	13.8	15.3	16.8	18.6
FSU	3.6	4.7	6.2	7.3	8.8	10.7
Eastern Europe	1.2	1.6	2.0	2.5	3.3	4.4
China	8.8	15.7	23.4	30.9	40.3	52.5
Other Asia	8.0	11.8	16.1	20.3	25.8	32.6
India	1.2	1.9	2.8	3.8	5.0	6.6
Middle East	15.9	19.7	23.9	27.9	31.4	34.7
Latin America	4.7	6.1	7.6	9.2	10.9	13.0
Africa	2.4	3.5	4.6	5.8	7.2	8.8
Total	80.4	105.0	131.5	157.0	186.5	221.7

Energy use, Exajoules

OECD North America	1.02	1.22	1.37	1.51	1.67	1.84
OECD Europe	1.11	1.30	1.46	1.58	1.64	1.70
OECD Pacific	1.35	1.54	1.75	1.94	2.13	2.35
FSU	0.18	0.23	0.30	0.36	0.43	0.52
Eastern Europe	0.10	0.13	0.17	0.21	0.28	0.37
China	0.41	0.72	1.08	1.43	1.86	2.42
Other Asia	0.73	1.07	1.47	1.85	2.36	2.97
India	0.34	0.56	0.83	1.12	1.48	1.95
Middle East	0.71	0.88	1.07	1.24	1.40	1.54
Latin America	0.56	0.72	0.91	1.10	1.30	1.55
Africa	0.27	0.38	0.51	0.64	0.79	0.96
Total	6.77	8.76	10.91	12.97	15.34	18.18

3.4 Buses

Buses have been divided into two size classes, essentially full size buses and "minibuses", with the latter roughly encompassing the range of small buses and large passenger vans, prevalent around the developing world, and typically used for informal "paratransit" services. The available data is not good enough to be able to make a stricter definition, for example on the basis of numbers of seats, though most paratransit vehicles have fewer than 24 seats. In reality there is nearly a continuum in bus sizes from 8 seater up to 80 seater (or even larger, for articulated bus types). The point of creating two classes is simply to allow separate modelling of larger buses that are typically operated in transit systems and the smaller and generally less efficient (per seat-kilometre) paratransit vehicles that often operate independently or in private fleets.

As for trucks, little data could be found on bus numbers and average characteristics by region, so many "weak" assumptions were made, with a goal to ensure that the numbers multiply through in 2000 to match fuel consumption data (along with trucks, LDVs and 2-wheelers) in each region. Basic data for 2000 are shown below. The strongest data is for bus stocks, taken mainly from International Road Federation data, with some adjustments using other data sources. Average travel per vehicle per year is based on data from several cities (including the IEA "Bus Systems for the Future" data set), though the assumptions are quite generalized, as can be seen. Average fuel use is similarly a generalized number, with somewhat lower fuel use for developing countries to reflect smaller average bus sizes. Stock share of full-size buses and diesel share of large buses is set mainly on the basis of ensuring that resulting fuel consumption estimates are aligned with available data. Allocation of data to large and small buses reflects IEA bus data collected for the book *Bus Systems for the Future* (2002) including data for several cities in the developing world (this is the basis for fuel consumption and ridership estimates. Load factor (average passengers per vehicle trip) for minibuses is assumed to be half that of large buses in all regions. Again, these are all (except total stock data) generally very weak assumptions and are intended mainly to make it possible to produce reference case projections and allow "what if" analysis in alternative cases.

Year 2000 Estimates for All Buses (small and large combined)

	Stocks (000)	Stock share of full-size buses	Average travel per vehicle per year	Average fuel use (L/100km)
OECD North America	950	0.8	55	33
OECD Europe	1160	0.8	55	33
OECD Pacific	910	0.7	55	33
FSU	692	0.5	40	28
Eastern Europe	270	0.5	40	28
China	1880	0.3	40	28
Other Asia	2635	0.4	40	28
India	1600	0.4	40	28
Middle East	800	0.4	40	28
Latin America	1200	0.4	40	28
Africa	1450	0.3	40	28
Total	13547			

Year 2000 Estimates for Large Buses

	Stocks	Total Bus Travel	Travel per vehicle	Total passenger travel	Average passengers per vehicle	Average fuel consumption	Total fuel use	Gasoline share
	thousands	billion km	thousand km/yr	billion km		L/100 km	billion litres ge	
OECD North America	760	46	60	556	12	33	15	25.0%
OECD Europe	928	56	60	905	16	33	18	15.0%
OECD Pacific	637	38	60	685	18	33	13	15.0%
FSU	346	14	40	277	20	28	4	60.0%
Eastern Europe	135	5	40	108	20	28	2	20.0%
China	564	23	40	564	25	28	6	30.0%
Other Asia	1054	42	40	1054	25	28	12	20.0%
India	640	26	40	640	25	28	7	5.0%
Middle East	320	13	40	256	20	28	4	30.0%
Latin America	480	19	40	384	20	28	5	20.0%
Africa	435	17	40	435	25	28	5	20.0%
Total	6299	298		5864			91	

Year 2000 Estimates for Small Buses

	Stocks	Total Bus Travel	Travel per vehicle	Total passenger travel	Average passengers per vehicle	Average fuel consumption	Total fuel use	Gasoline share
	thousands	billion km	thousand km/yr	billion km		L/100 km	billion litres ge	
OECD North America	190	7	35	41	6	18	1	50.0%
OECD Europe	232	8	35	66	8	18	1	20.0%
OECD Pacific	273	10	35	86	9	18	2	20.0%
FSU	346	14	40	138	10	16	2	80.0%
Eastern Europe	135	5	40	54	10	16	1	60.0%
China	1316	53	40	658	13	16	8	80.0%
Other Asia	1581	63	40	791	13	16	10	70.0%
India	960	38	40	480	13	16	6	40.0%
Middle East	480	19	40	192	10	16	3	80.0%
Latin America	720	29	40	288	10	16	5	80.0%
Africa	1015	41	40	508	13	16	6	80.0%
Total	7248	286		3301			46	

The key assumptions for generating the reference case projection for large and small buses, for OECD and non-OECD regions is shown below (same assumptions used for all time periods, for all OECD regions and for all non-OECD regions). These are based on educated guesses of the current and likely future trends. Essentially ridership per bus is assumed to decline over time, faster in non-OECD regions since buses are much fuller in these regions – this is assumed to eventually converge with OECD region ridership levels. Vehicle stocks are assumed to rise slowly, with minibus stocks rising much faster. Average travel per vehicle and average fuel consumption is assumed to remain unchanged over the next 50 years. In general, more efficient buses are being produced, but this is offset (or more than offset) by increases in average bus size, weight and power. OECD buses have much more powerful engines than non-OECD buses, and non-OECD buses are likely to catch up over this period.

Percentage change projected over each 5 year period

Bus size	Region	Avg. passengers per vehicle	Vehicle stocks	Average travel per vehicle	Change in vehicle fuel consumption per km
Large	OECD	-1%	1%	0%	0%
Large	Non-OECD	-2.5%	2%	0%	0%
Small	OECD	-1%	1%	0%	0%
Small	Non-OECD	-2.5%	3%	0%	0%

The resulting detailed projections are shown in the following tables.

Reference Case Projection for Large Buses

	2000	**2010**	**2020**	**2030**	**2040**	**2050**
Annual passenger-km of travel (bil)						
OECD North America	556.1	556.0	555.8	555.7	555.6	555.5
OECD Europe	905.3	905.1	905.0	904.8	904.6	904.4
OECD Pacific	684.6	684.5	684.4	684.2	684.1	684.0
FSU	276.7	273.7	270.7	267.7	264.8	261.9
Eastern Europe	108.0	106.8	105.6	104.5	103.3	102.2
China	564.0	557.9	551.7	545.7	539.7	533.8
Other Asia	1054.2	1042.6	1031.2	1019.9	1008.7	997.6
India	640.0	633.0	626.0	619.2	612.4	605.7
Middle East	256.0	253.2	250.4	247.7	245.0	242.3
Latin America	384.0	379.8	375.6	371.5	367.4	363.4
Africa	435.0	430.2	425.5	420.8	416.2	411.7
Total	5863.9	5822.7	5782.0	5741.6	5701.8	5662.3

LDV Load factor (average passengers per vehicle)

OECD North America	12.2	12.0	11.7	11.5	11.3	11.0
OECD Europe	16.3	15.9	15.6	15.3	15.0	14.7
OECD Pacific	17.9	17.6	17.2	16.9	16.5	16.2
FSU	20	19.0	18.1	17.2	16.3	15.5
Eastern Europe	20	19.0	18.1	17.2	16.3	15.5
China	25	23.8	22.6	21.5	20.4	19.4
Other Asia	25	23.8	22.6	21.5	20.4	19.4
India	25	23.8	22.6	21.5	20.4	19.4
Middle East	20	19.0	18.1	17.2	16.3	15.5
Latin America	20	19.0	18.1	17.2	16.3	15.5
Africa	25	23.8	22.6	21.5	20.4	19.4

Vehicle stock (thousands)

OECD North America	760.0	775.3	790.9	806.8	823.0	839.5
OECD Europe	928.0	946.7	965.7	985.1	1004.9	1025.1
OECD Pacific	637.0	649.8	662.9	676.2	689.8	703.6
FSU	345.9	359.8	374.4	389.5	405.2	421.6
Eastern Europe	135.0	140.5	146.1	152.0	158.2	164.6
China	564.0	586.8	610.5	635.2	660.9	687.6
Other Asia	1054.2	1096.8	1141.1	1187.2	1235.1	1285.0
India	640.0	665.9	692.8	720.7	749.9	780.2
Middle East	320.0	332.9	346.4	360.4	374.9	390.1
Latin America	480.0	499.4	519.6	540.6	562.4	585.1
Africa	435.0	452.6	470.9	489.9	509.7	530.3
World Total	6299.1	6506.4	6721.1	6943.5	7173.9	7412.6

Average annual travel per vehicle (1000 kms)

OECD North America	60	60	60	60	60	60
OECD Europe	60	60	60	60	60	60
OECD Pacific	60	60	60	60	60	60
FSU	40	40	40	40	40	40
Eastern Europe	40	40	40	40	40	40
China	40	40	40	40	40	40
Other Asia	40	40	40	40	40	40
India	40	40	40	40	40	40
Middle East	40	40	40	40	40	40
Latin America	40	40	40	40	40	40
Africa	40	40	40	40	40	40

Total vehicle-kms travelled (bil km / yr)

OECD North America	45.6	46.5	47.5	48.4	49.4	50.4
OECD Europe	55.7	56.8	57.9	59.1	60.3	61.5
OECD Pacific	38.2	39.0	39.8	40.6	41.4	42.2
FSU	13.8	14.4	15.0	15.6	16.2	16.9
Eastern Europe	5.4	5.6	5.8	6.1	6.3	6.6
China	22.6	23.5	24.4	25.4	26.4	27.5
Other Asia	42.2	43.9	45.6	47.5	49.4	51.4
India	25.6	26.6	27.7	28.8	30.0	31.2
Middle East	12.8	13.3	13.9	14.4	15.0	15.6
Latin America	19.2	20.0	20.8	21.6	22.5	23.4
Africa	17.4	18.1	18.8	19.6	20.4	21.2
World Total	298.5	307.7	317.2	327.1	337.3	347.9

Vehicle efficiency - Litres per 100 km

OECD North America	33	33	33	33	33	33
OECD Europe	33	33	33	33	33	33
OECD Pacific	33	33	33	33	33	33
FSU	28	28	28	28	28	28
Eastern Europe	28	28	28	28	28	28
China	28	28	28	28	28	28
Other Asia	28	28	28	28	28	28
India	28	28	28	28	28	28
Middle East	28	28	28	28	28	28
Latin America	28	28	28	28	28	28
Africa	28	28	28	28	28	28
World Total						

Vehicle efficiency - mJ per vehicle-km

OECD North America	11.5	11.5	11.5	11.5	11.5	11.5
OECD Europe	11.5	11.5	11.5	11.5	11.5	11.5
OECD Pacific	11.5	11.5	11.5	11.5	11.5	11.5
FSU	9.8	9.8	9.8	9.8	9.8	9.8
Eastern Europe	9.8	9.8	9.8	9.8	9.8	9.8
China	9.8	9.8	9.8	9.8	9.8	9.8
Other Asia	9.8	9.8	9.8	9.8	9.8	9.8
India	9.8	9.8	9.8	9.8	9.8	9.8
Middle East	9.8	9.8	9.8	9.8	9.8	9.8
Latin America	9.8	9.8	9.8	9.8	9.8	9.8
Africa	9.8	9.8	9.8	9.8	9.8	9.8

Passenger fuel efficiency - mJ per pass-km

OECD North America	0.94	0.96	0.98	1.00	1.02	1.04
OECD Europe	0.71	0.72	0.74	0.75	0.77	0.78
OECD Pacific	0.64	0.65	0.67	0.68	0.70	0.71
FSU	0.49	0.51	0.54	0.57	0.60	0.63
Eastern Europe	0.49	0.51	0.54	0.57	0.60	0.63
China	0.39	0.41	0.43	0.45	0.48	0.50
Other Asia	0.39	0.41	0.43	0.45	0.48	0.50
India	0.39	0.41	0.43	0.45	0.48	0.50
Middle East	0.49	0.51	0.54	0.57	0.60	0.63
Latin America	0.49	0.51	0.54	0.57	0.60	0.63
Africa	0.39	0.41	0.43	0.45	0.48	0.50
Total						

Energy use, Exajoules

OECD North America	0.52	0.53	0.55	0.56	0.57	0.58
OECD Europe	0.64	0.65	0.67	0.68	0.69	0.71
OECD Pacific	0.44	0.45	0.46	0.47	0.48	0.49
FSU	0.13	0.14	0.15	0.15	0.16	0.16
Eastern Europe	0.05	0.05	0.06	0.06	0.06	0.06
China	0.22	0.23	0.24	0.25	0.26	0.27
Other Asia	0.41	0.43	0.45	0.46	0.48	0.50
India	0.25	0.26	0.27	0.28	0.29	0.30
Middle East	0.12	0.13	0.14	0.14	0.15	0.15
Latin America	0.19	0.19	0.20	0.21	0.22	0.23
Africa	0.17	0.18	0.18	0.19	0.20	0.21
Total	3.15	3.25	3.35	3.45	3.55	3.66

Energy use, mtoe

OECD North America	12.5	12.8	13.0	13.3	13.6	13.8
OECD Europe	15.3	15.6	15.9	16.2	16.6	16.9
OECD Pacific	10.5	10.7	10.9	11.1	11.4	11.6
FSU	3.2	3.4	3.5	3.6	3.8	3.9
Eastern Europe	1.3	1.3	1.4	1.4	1.5	1.5
China	5.3	5.5	5.7	5.9	6.2	6.4
Other Asia	9.8	10.2	10.6	11.1	11.5	12.0
India	6.0	6.2	6.5	6.7	7.0	7.3
Middle East	3.0	3.1	3.2	3.4	3.5	3.6
Latin America	4.5	4.7	4.8	5.0	5.2	5.5
Africa	4.1	4.2	4.4	4.6	4.8	4.9
Total	75.35	77.62	79.96	82.38	84.88	87.47

Energy use, bil litres ge

OECD North America	15.0	15.4	15.7	16.0	16.3	16.6
OECD Europe	18.4	18.7	19.1	19.5	19.9	20.3
OECD Pacific	12.6	12.9	13.1	13.4	13.7	13.9
FSU	3.9	4.0	4.2	4.4	4.5	4.7
Eastern Europe	1.5	1.6	1.6	1.7	1.8	1.8
China	6.3	6.6	6.8	7.1	7.4	7.7
Other Asia	11.8	12.3	12.8	13.3	13.8	14.4
India	7.2	7.5	7.8	8.1	8.4	8.7
Middle East	3.6	3.7	3.9	4.0	4.2	4.4
Latin America	5.4	5.6	5.8	6.1	6.3	6.6
Africa	4.9	5.1	5.3	5.5	5.7	5.9
Total	90.54	93.27	96.08	98.99	102.00	105.11

Gasoline Share of total (includes biofuel blends in gasoline)

OECD North America	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%
OECD Europe	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%
OECD Pacific	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%
FSU	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%
Eastern Europe	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%
China	30.0%	30.0%	30.0%	30.0%	30.0%	30.0%
Other Asia	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%
India	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Middle East	30.0%	30.0%	30.0%	30.0%	30.0%	30.0%
Latin America	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%
Africa	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%

Diesel share of total (includes biofuel blends in diesel)

OECD North America	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
OECD Europe	85.0%	85.0%	85.0%	85.0%	85.0%	85.0%
OECD Pacific	85.0%	85.0%	85.0%	85.0%	85.0%	85.0%
FSU	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Eastern Europe	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%
China	70.0%	70.0%	70.0%	70.0%	70.0%	70.0%
Other Asia	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%
India	95.0%	95.0%	95.0%	95.0%	95.0%	95.0%
Middle East	70.0%	70.0%	70.0%	70.0%	70.0%	70.0%
Latin America	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%
Africa	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%

Bus Total Diesel Consumption (bil litres gasoline equiv)

OECD North America	11.3	11.5	11.7	12.0	12.2	12.5
OECD Europe	15.6	15.3	15.6	15.9	16.2	16.6
OECD Pacific	10.7	10.9	11.2	11.4	11.6	11.8
FSU	1.5	1.6	1.7	1.7	1.8	1.9
Eastern Europe	1.2	1.3	1.3	1.4	1.4	1.5
China	4.4	4.6	4.8	5.0	5.2	5.4
Other Asia	9.4	9.8	10.2	10.6	11.1	11.5
India	6.8	7.1	7.4	7.7	8.0	8.3
Middle East	2.5	2.6	2.7	2.8	2.9	3.1
Latin America	4.3	4.5	4.7	4.8	5.0	5.2
Africa	3.9	4.1	4.2	4.4	4.6	4.8
Total	71.8	73.3	75.5	77.7	80.1	82.5

Bus Total Gasoline Consumption (bil litres gasoline equiv)

OECD North America	3.7	3.8	3.8	3.9	4.0	4.1
OECD Europe	2.8	2.7	2.8	2.8	2.9	2.9
OECD Pacific	1.9	1.9	1.9	2.0	2.0	2.1
FSU	2.3	2.4	2.5	2.6	2.7	2.8
Eastern Europe	0.3	0.3	0.3	0.3	0.4	0.4
China	1.9	2.0	2.0	2.1	2.2	2.3
Other Asia	2.4	2.5	2.6	2.7	2.8	2.9
India	0.4	0.4	0.4	0.4	0.4	0.4
Middle East	1.1	1.1	1.2	1.2	1.3	1.3
Latin America	0.9	1.0	1.0	1.0	1.1	1.1
Africa	1.0	1.0	1.1	1.1	1.1	1.2
Total	18.6	19.0	19.6	20.2	20.8	21.5

Reference Case Projection for Small Buses (paratransit and minibuses)

	2000	**2010**	**2020**	**2030**	**2040**	**2050**
Annual passenger-km of travel (bil)						
OECD North America	40.5	40.5	40.5	40.5	40.5	40.5
OECD Europe	66.0	66.0	66.0	66.0	66.0	65.9
OECD Pacific	85.6	85.6	85.5	85.5	85.5	85.5
FSU	138.3	139.5	140.7	141.9	143.1	144.3
Eastern Europe	54.0	54.5	54.9	55.4	55.9	56.3
China	658.0	663.7	669.3	675.0	680.8	686.6
Other Asia	790.6	797.4	804.2	811.0	817.9	824.9
India	480.0	484.1	488.2	492.4	496.6	500.8
Middle East	192.0	193.6	195.3	196.9	198.6	200.3
Latin America	288.0	290.5	292.9	295.4	297.9	300.5
Africa	507.5	511.8	516.2	520.6	525.0	529.5
Total	3300.7	3327.1	3353.8	3380.7	3407.8	3435.1

LDV Load factor (average passengers per vehicle)

OECD North America	6.1	6.0	5.9	5.7	5.6	5.5
OECD Europe	8.1	8.0	7.8	7.7	7.5	7.4
OECD Pacific	9.0	8.8	8.6	8.4	8.3	8.1
FSU	10.0	9.5	9.0	8.6	8.2	7.8
Eastern Europe	10.0	9.5	9.0	8.6	8.2	7.8
China	12.5	11.9	11.3	10.7	10.2	9.7
Other Asia	12.5	11.9	11.3	10.7	10.2	9.7
India	12.5	11.9	11.3	10.7	10.2	9.7
Middle East	10.0	9.5	9.0	8.6	8.2	7.8
Latin America	10.0	9.5	9.0	8.6	8.2	7.8
Africa	12.5	11.9	11.3	10.7	10.2	9.7

Vehicle stock (thousands)

OECD North America	190.0	193.8	197.7	201.7	205.7	209.9
OECD Europe	232.0	236.7	241.4	246.3	251.2	256.3
OECD Pacific	273.0	278.5	284.1	289.8	295.6	301.6
FSU	345.9	366.9	389.3	413.0	438.1	464.8
Eastern Europe	135.0	143.2	151.9	161.2	171.0	181.4
China	1316.1	1396.2	1481.3	1571.5	1667.2	1768.7
Other Asia	1581.2	1677.5	1779.7	1888.1	2003.1	2125.1
India	960.0	1018.5	1080.5	1146.3	1216.1	1290.2
Middle East	480.0	509.2	540.2	573.1	608.0	645.1
Latin America	720.0	763.8	810.4	859.7	912.1	967.6
Africa	1015.0	1076.8	1142.4	1212.0	1285.8	1364.1
World Total	7248.2	7661.3	8098.9	8562.6	9054.0	9574.7

Average annual travel per vehicle (1000 kms)

OECD North America	35	35	35	35	35	35
OECD Europe	35	35	35	35	35	35
OECD Pacific	35	35	35	35	35	35
FSU	40	40	40	40	40	40
Eastern Europe	40	40	40	40	40	40
China	40	40	40	40	40	40
Other Asia	40	40	40	40	40	40
India	40	40	40	40	40	40
Middle East	40	40	40	40	40	40
Latin America	40	40	40	40	40	40
Africa	40	40	40	40	40	40

Total vehicle-kms travelled (bil km / yr)

OECD North America	6.7	6.8	6.9	7.1	7.2	7.3
OECD Europe	8.1	8.3	8.4	8.6	8.8	9.0
OECD Pacific	9.6	9.7	9.9	10.1	10.3	10.6
FSU	13.8	14.7	15.6	16.5	17.5	18.6
Eastern Europe	5.4	5.7	6.1	6.4	6.8	7.3
China	52.6	55.8	59.3	62.9	66.7	70.7
Other Asia	63.2	67.1	71.2	75.5	80.1	85.0
India	38.4	40.7	43.2	45.9	48.6	51.6
Middle East	19.2	20.4	21.6	22.9	24.3	25.8
Latin America	28.8	30.6	32.4	34.4	36.5	38.7
Africa	40.6	43.1	45.7	48.5	51.4	54.6
World Total	286.5	302.9	320.3	338.8	358.4	379.1

Vehicle efficiency - Litres per 100 km

OECD North America	18	18	18	18	18	18
OECD Europe	18	18	18	18	18	18
OECD Pacific	18	18	18	18	18	18
FSU	16	16	16	16	16	16
Eastern Europe	16	16	16	16	16	16
China	16	16	16	16	16	16
Other Asia	16	16	16	16	16	16
India	16	16	16	16	16	16
Middle East	16	16	16	16	16	16
Latin America	16	16	16	16	16	16
Africa	16	16	16	16	16	16
World Total						

Vehicle efficiency - mJ per vehi-km

OECD North America	6.3	6.3	6.3	6.3	6.3	6.3
OECD Europe	6.3	6.3	6.3	6.3	6.3	6.3
OECD Pacific	6.3	6.3	6.3	6.3	6.3	6.3
FSU	5.6	5.6	5.6	5.6	5.6	5.6
Eastern Europe	5.6	5.6	5.6	5.6	5.6	5.6
China	5.6	5.6	5.6	5.6	5.6	5.6
Other Asia	5.6	5.6	5.6	5.6	5.6	5.6
India	5.6	5.6	5.6	5.6	5.6	5.6
Middle East	5.6	5.6	5.6	5.6	5.6	5.6
Latin America	5.6	5.6	5.6	5.6	5.6	5.6
Africa	5.6	5.6	5.6	5.6	5.6	5.6

Passenger fuel efficiency – mJ per pass-km

OECD North America	1.03	1.05	1.07	1.09	1.11	1.14
OECD Europe	0.77	0.79	0.80	0.82	0.84	0.85
OECD Pacific	0.70	0.71	0.73	0.74	0.76	0.77
FSU	0.56	0.59	0.62	0.65	0.68	0.72
Eastern Europe	0.56	0.59	0.62	0.65	0.68	0.72
China	0.45	0.47	0.49	0.52	0.55	0.57
Other Asia	0.45	0.47	0.49	0.52	0.55	0.57
India	0.45	0.47	0.49	0.52	0.55	0.57
Middle East	0.56	0.59	0.62	0.65	0.68	0.72
Latin America	0.56	0.59	0.62	0.65	0.68	0.72
Africa	0.45	0.47	0.49	0.52	0.55	0.57
Total						

Energy use, Exajoules

OECD North America	0.04	0.04	0.04	0.04	0.05	0.05
OECD Europe	0.05	0.05	0.05	0.05	0.06	0.06
OECD Pacific	0.06	0.06	0.06	0.06	0.06	0.07
FSU	0.08	0.08	0.09	0.09	0.10	0.10
Eastern Europe	0.03	0.03	0.03	0.04	0.04	0.04
China	0.29	0.31	0.33	0.35	0.37	0.39
Other Asia	0.35	0.37	0.40	0.42	0.45	0.47
India	0.21	0.23	0.24	0.26	0.27	0.29
Middle East	0.11	0.11	0.12	0.13	0.14	0.14
Latin America	0.16	0.17	0.18	0.19	0.20	0.22
Africa	0.23	0.24	0.25	0.27	0.29	0.30
Total	1.61	1.71	1.80	1.91	2.02	2.13

Energy use, mtoe

OECD North America	1.0	1.0	1.0	1.1	1.1	1.1
OECD Europe	1.2	1.2	1.3	1.3	1.3	1.3
OECD Pacific	1.4	1.5	1.5	1.5	1.5	1.6
FSU	1.8	2.0	2.1	2.2	2.3	2.5
Eastern Europe	0.7	0.8	0.8	0.9	0.9	1.0
China	7.0	7.4	7.9	8.4	8.9	9.4
Other Asia	8.4	8.9	9.5	10.1	10.7	11.3
India	5.1	5.4	5.8	6.1	6.5	6.9
Middle East	2.6	2.7	2.9	3.1	3.2	3.4
Latin America	3.8	4.1	4.3	4.6	4.9	5.2
Africa	5.4	5.7	6.1	6.5	6.8	7.3
Total	38.55	40.74	43.07	45.54	48.16	50.93

Energy use, bil litres ge

OECD North America	1.2	1.2	1.2	1.3	1.3	1.3
OECD Europe	1.5	1.5	1.5	1.6	1.6	1.6
OECD Pacific	1.7	1.8	1.8	1.8	1.9	1.9
FSU	2.2	2.3	2.5	2.6	2.8	3.0
Eastern Europe	0.9	0.9	1.0	1.0	1.1	1.2
China	8.4	8.9	9.5	10.1	10.7	11.3
Other Asia	10.1	10.7	11.4	12.1	12.8	13.6
India	6.1	6.5	6.9	7.3	7.8	8.3
Middle East	3.1	3.3	3.5	3.7	3.9	4.1
Latin America	4.6	4.9	5.2	5.5	5.8	6.2
Africa	6.5	6.9	7.3	7.8	8.2	8.7
Total	46.32	48.96	51.76	54.73	57.87	61.20

Gasoline Share of total (includes biofuel blends in gasoline)

OECD North America	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
OECD Europe	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%
OECD Pacific	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%
FSU	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%
Eastern Europe	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%
China	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%
Other Asia	70.0%	70.0%	70.0%	70.0%	70.0%	70.0%
India	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
Middle East	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%
Latin America	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%
Africa	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%

Diesel share of total (includes biofuel blends in diesel)

OECD North America	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
OECD Europe	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%
OECD Pacific	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%
FSU	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%
Eastern Europe	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
China	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%
Other Asia	30.0%	30.0%	30.0%	30.0%	30.0%	30.0%
India	60.0%	60.0%	60.0%	60.0%	60.0%	60.0%
Middle East	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%
Latin America	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%
Africa	20.0%	20.0%	20.0%	20.0%	20.0%	20.0%

Bus Total Diesel Consumption (bil litres gasoline equiv)

OECD North America	0.6	0.6	0.6	0.6	0.6	0.7
OECD Europe	1.2	1.1	1.2	1.2	1.2	1.2
OECD Pacific	1.4	1.4	1.4	1.5	1.5	1.5
FSU	0.4	0.5	0.5	0.5	0.6	0.6
Eastern Europe	0.3	0.4	0.4	0.4	0.4	0.5
China	1.7	1.8	1.9	2.0	2.1	2.3
Other Asia	3.0	3.2	3.4	3.6	3.8	4.1
India	3.7	3.9	4.1	4.4	4.7	5.0
Middle East	0.6	0.7	0.7	0.7	0.8	0.8
Latin America	0.9	1.0	1.0	1.1	1.2	1.2
Africa	1.3	1.4	1.5	1.6	1.6	1.7
Total	15.2	15.9	16.8	17.7	18.6	19.6

Bus Total Gasoline Consumption (bil litres gasoline equiv)

OECD North America	0.6	0.6	0.6	0.6	0.6	0.6
OECD Europe	0.3	0.3	0.3	0.3	0.3	0.3
OECD Pacific	0.3	0.3	0.4	0.4	0.4	0.4
FSU	1.8	1.9	2.0	2.1	2.2	2.4
Eastern Europe	0.5	0.5	0.6	0.6	0.7	0.7
China	6.7	7.1	7.6	8.0	8.5	9.0
Other Asia	7.1	7.5	8.0	8.4	9.0	9.5
India	2.5	2.5	2.6	2.8	3.0	3.1
Middle East	2.5	2.6	2.8	2.9	3.1	3.3
Latin America	3.2	3.4	3.6	3.8	4.0	4.3
Africa	5.2	5.5	5.8	6.2	6.6	7.0
Total	30.6	32.3	34.2	36.2	38.4	40.6

3.5 Air Travel

Air travel is treated in a fairly simplified manner in the model: passenger kilometres (actually revenue passenger kilometres, RPK) are multiplied by energy use per RPK (energy intensity) in order to derive energy use. CO_2 emissions are estimated based on fuel use. All air travel in each region (domestic and international) are treated together, due to weaknesses in the data available for separating the two types of air travel.

The air travel projections are based primarily on published forecasts by Boeing, with the Boeing projections converted to SMP model regions by Charles River Associates. Another adjustment was needed since the Boeing projections were based on higher GDP projections than the OECD projections used in this reference case. As shown in the table below, the Boeing RPK growth rate was compared to their assumed GDP growth rates, providing a ratio for each region, ranging from 1.2 to 1.8 – i.e. passenger kilometres growing from 20% to 80% faster than GDP. Using these same relative growth rates, but applying them to the lower OECD projections, passenger kilometre projections were generated for use here. The Boeing projections only extend to 2025. These were extended to 2050 using the same ratio of air travel increase to GDP increase, in part because air travel rates per capita will still be relatively low in 2025 in most regions of the world. However, since GDP growth rates decline over time, the growth rate in air travel also declines in this period (last column in table).

Data and Assumptions Used to Generate Air Passenger Kilometre Projections

	From Boeing Forecast				Adjusted to OECD GDP projections		
	RPK, 2000	Average annual GDP growth, 2003-2022	Average growth in RPK, 20003-2022	Ratio, RPK / GDP	Average annual GDP growth, 2000-25	Resulting RPK projection, 2000-25	IEA RPK APG, 2025-50
OECD North America	1,277	3.2%	4.4%	1.4	2.2%	3.0%	2.3%
OECD Europe	871	2.5%	4.0%	1.6	2.1%	3.3%	1.7%
OECD Pacific	333	3.2%	4.0%	1.3	2.1%	2.6%	2.1%
FSU	63	3.8%	5.2%	1.4	3.1%	4.2%	3.7%
Eastern Europe	49	3.5%	5.2%	1.5	3.3%	4.8%	5.3%
China	141	6.2%	7.2%	1.2	5.0%	5.7%	4.2%
Other Asia	197	5.0%	6.0%	1.2	3.9%	4.6%	4.0%
India	50	5.0%	6.0%	1.2	4.7%	5.6%	4.5%
Middle East	102	4.0%	5.6%	1.4	2.7%	3.7%	2.8%
Latin America	216	4.0%	7.0%	1.8	3.0%	5.1%	4.5%
Africa	77	4.0%	5.5%	1.4	3.7%	4.9%	4.1%
World	3,376	3.2% [a]	5.1%	1.6	3.0%	3.6%	2.9%

[a] Note that the average annual GDP growth rate, world-wide, reported by Boeing doesn't appear to align with the regional growth rates (mostly much higher) and could be an error.

The energy intensity of air travel proved to be very difficult to align with estimates of both revenue passenger kilometres and estimates of energy use (the three forming an identity). When RPK is divided by energy use data (jet fuel) for each region, wide variations in average energy intensity result, that are not plausible. This suggests errors in either RPK or energy use, or both. However, global average energy intensity (of 2.7 megajoules per passenger kilometre) when dividing global RPK by global jet fuel consumption appears reasonable. It, thus, appears likely that accounting systems for energy use in each region are not aligned with those for allocating passenger kilometres among regions (even taking into account different regional organizations of the two data sets). IEA and the SMP decided that the data did not support anything more complex than using the global average energy intensity in each region, even though there are very likely significant differences (for example European flights are generally shorter than Asian flights, and thus are probably more energy intensive).

The projection of future energy intensity is based on IEA indicators data over the 1990-2000 period, when intensity improved at about 0.7% per year. This is assumed to continue in the future. This assumption results, for example, in about a 20% reduction in fleet energy intensity between 2000 and 2030. Given the recent announcement by Boeing of plans to build a new model (the "7E7") that will be 20% less energy intensive than current planes, projecting a general evolution of the entire airline fleet to be 20% less energy intensive in 30 years (about the time needed for the entire airline fleet to turn over), seems reasonable. The resulting projection of average air travel energy intensity is shown in the table below.

Air travel energy intensity, reference case projection (megajoules per RPK)

	2000	2010	2020	2030	2040	2050
OECD North America	2.7	2.5	2.3	2.1	2.0	1.9
OECD Europe	2.7	2.5	2.3	2.1	2.0	1.9
OECD Pacific	2.7	2.5	2.3	2.1	2.0	1.9
FSU	2.7	2.5	2.3	2.1	2.0	1.9
Eastern Europe	2.7	2.5	2.3	2.1	2.0	1.9
China	2.7	2.5	2.3	2.1	2.0	1.9
Other Asia	2.7	2.5	2.3	2.1	2.0	1.9
India	2.7	2.5	2.3	2.1	2.0	1.9
Middle East	2.7	2.5	2.3	2.1	2.0	1.9
Latin America	2.7	2.5	2.3	2.1	2.0	1.9
Africa	2.7	2.5	2.3	2.1	2.0	1.9

3.6 Rail Travel

Rail travel is handled similarly to air travel, with only three variables tracked: travel activity, energy intensity per unit travel activity, and energy use. For rail, passenger and freight are tracked separately.

To develop the rail travel projections, the SMP commissioned Lou Thompson (consultant, formerly of the World Bank) to synthesize his and other previous work on this topic. The result was a detailed set of passenger and freight travel growth projections, tailored to each SMP model region, with travel a varying function of GDP growth in that region. This is shown in the table below.

Rail Transport Estimates from Thompson, 2003

	Total rail passenger kilometres of travel, 2000	Total rail tonne-kilometres of travel, 2000	Ratio of rail travel growth to GDP growth 2000-2050	
			passenger	freight
OECD North America	48	2,427	0.42	0.77
OECD Europe	301	248	0.75	0.74
OECD Pacific	241	156	0.69	0.60
FSU	251	1,576	0.56	0.68
Eastern Europe	66	130	0.51	0.64
China	441	1,334	0.67	0.69
Other Asia	87	31	0.64	0.51
India	431	305	0.61	0.70
Middle East	80	30	0.94	0.78
Latin America	14	118	0.29	0.49
Africa	18	115	0.66	0.70
World total	1,977	6,470		

To estimate rail energy intensity, the IEA relied on our estimates of rail energy use, broken into passenger and rail travel and then divided into Thompson's estimates of rail travel. However, given difficulties in making this allocation (data is only available for most regions for all rail), and for simplicity, the much smaller energy use in rail passenger travel was allocated using the same average figure for intensity in all regions – 0.3 megajoules per passenger kilometre. Then, when the remaining energy use was allocated to freight, it resulted in energy intensity estimates that, though varying fairly widely across regions in 2000, seem reasonable compared to available estimates of average energy intensity of rail systems (for example, as presented in IEA, 2001). In general, regions with longer average distances for freight rail (such as the US and Former Soviet Union, and where more raw materials are transported (such as coal), show a lower energy intensity than other regions. This is shown in the table below.

For future improvements in rail energy intensity, IEA indicator data over the past 10 years was used to estimate recent trends. Future trends in passenger and freight were set close to the recent trend levels, but adjusted to ensure that the energy use projections are close to the WEO 2002 projection. Reductions in energy intensity of about 1% per year for passenger travel and 2-3% for freight rail transport result. The lower rate of improvement for passenger reflects, in part, expectations of declining ridership levels and load factors in many passenger rail systems in the future.

	Average rail energy intensity, 2000		Average annual rate of improvement, 2000-2050	
	Passenger (mj per passenger-km)	**Freight (mj per tonne-km)**	**passenger**	**freight**
OECD North America	0.30	0.20	1%	2%
OECD Europe	0.30	0.40	1%	3%
OECD Pacific	0.30	0.40	1%	2%
FSU	0.30	0.20	1%	2%
Eastern Europe	0.30	0.25	1%	3%
China	0.30	0.35	1%	3%
Other Asia	0.30	0.25	1%	3%
India	0.30	0.20	1%	3%
Middle East	0.30	0.25	1%	3%
Latin America	0.30	0.25	1%	3%
Africa	0.30	0.25	1%	3%

One other important aspect for rail is the type of energy used. There are two basic types: diesel fuel and electricity. The share of these fuels varies dramatically by passenger v. freight and from region to region, though the breakout between passenger and freight is relatively uncertain. It appears that except for a few regions, freight use is dominated by diesel engines rather than electric power. Given a lack of available information on trends in relative fuel use, we have retained the 2000 shares throughout the projections for each region.

Electricity share of rail energy use, 2000 and all projected years (remainder is predominantly diesel fuel).

	Passenger	Freight
OECD North America	80%	2%
OECD Europe	90%	50%
OECD Pacific	90%	43%
FSU	80%	26%
Eastern Europe	80%	34%
China	34%	0%
Other Asia	15%	0%
India	23%	0%
Middle East	20%	0%
Latin America	75%	15%
Africa	75%	10%

3.7 Water-borne Shipping

For water-borne shipping, there was only adequate data to support the projection of energy use; there are various data available on shipping quantities, but these could not be resolved against existing IEA energy use data (in terms of ship types, regions, etc.) in a manner that made sense. And since the study decided not to investigate potential policies for reducing energy use from shipping, it was decided that to just track energy use, for purposes of overall accounting of transport energy use, would be sufficient.

Energy use in 2000 from national shipping (including all coastal and inland water ship and boat travel) and international shipping are shown below. As can be seen, in most regions, and overall, international shipping accounted for far more energy use than national shipping. This is taken directly from IEA's energy data, as reported by countries around the world. While nearly all international shipping uses residual (bunker) fuel, much of national shipping uses diesel fuel.

Energy use, 2000 (Petajoules)

	National Shipping		International Shipping
Fuel Type:	Diesel	Residual	Residual
OECD North America	170	25	1,183
OECD Europe	253	54	1,722
OECD Pacific	134	275	536
FSU	31	12	10
Eastern Europe	5	7	74
China	187	71	300
Other Asia	88	37	969
India	13	14	4
Middle East	0	0	423
Latin America	48	37	295
Africa	15	0	329
Total	943		5,844

Projections for future changes in waterborne energy use are based on a simple ratio to the growth in regional GDP. The relationships are based on recent trends around the world, while ensuring rough alignment with the WEO 2002 (also based on energy / GDP relationships). As can be seen in the table below, the expected growth in shipping energy use is much lower than that for GDP, about one-third as much in OECD countries and for international shipping regardless of region.

Ratio of Growth in Energy Use to Growth in GDP, 2000-2050

Fuel Type:	National Shipping Diesel	National Shipping Residual	International Shipping Residual
OECD North America	0.33	0.33	0.33
OECD Europe	0.33	0.33	0.33
OECD Pacific	0.33	0.33	0.33
FSU	0.50	0.50	0.33
Eastern Europe	0.50	0.50	0.33
China	0.50	0.50	0.33
Other Asia	0.50	0.50	0.33
India	0.50	0.50	0.33
Middle East	0.50	0.50	0.33
Latin America	0.50	0.50	0.33
Africa	0.50	0.50	0.33

3.8 Greenhouse Gas Emissions

The model tracks greenhouse gas emissions from all vehicle types, both from vehicles themselves and "upstream" emissions (during fuel production and transport to refuelling sites). The approach is straightforward: for emissions from vehicles, a coefficient for CO_2 per unit fuel consumption is used to estimate CO_2 emissions. For upstream emissions, factors for CO_2-equivalent emissions of CO_2, N2O and CH4 are used. For vehicles, IEA's CO_2 emissions factors are used, except where unavailable (see table). For upstream ("well-to-tank") emissions, factors are taken from the study by GM/LBST (source). The same coefficients are used for all regions and years. These are shown in the second table below.

Vehicle (tank-to-wheel) CO_2 emissions by fuel type

	kg CO_2 / mJ	**kg CO_2 /litre ge**	**Source**
Motor Gasoline	69.3	2.42	IEA
Distillate Fuel (No. 1, No. 2, No. 4 Fuel Oil and Diesel)	74.1	2.58	IEA
Jet Fuel	71.5	2.49	IEA
CNG (methane)		1.73	US EIA
Liquified Petroleum Gases (LPG)	63.1	2.20	IEA
Residual Fuel (No. 5 and No. 6 Fuel Oil)	77.4	2.70	IEA
Ethanol	71.3	2.48	GM/LBST
RME (biodiesel)	76.7	2.67	GM/LBST

Upstream (well-to-tank) CO_2-equivalent GHG emissions

Fuel/feedstock/process	GHG, kg CO_2-equiv/MJ	GHG, kg CO_2-equiv / litre gasoline-equiv.
Gasoline <10ppm S	13.2	0.46
Diesel <10ppm S	10.4	0.36
CNG - EU NG mix	14	0.49
CNG - long pipeline (Russia to EU)	29	1.01
CNG - LNG, remote location	16	0.56
FT-D EU NG mix in central plant	30	1.05
FT-D EU NG remote location	28	0.98
CGH2 - from CNG long pipeline (Russia to EU) central plant	109	3.80
CGH2 - EU NG central plant, 70 Mpa vehicle tanks	90	3.14
CGH2 - EU NG onsite production, 70 Mpa vehicle tanks	103	3.59
Electricity - EU mix	129	4.50
Electricity – wind	0	0.00
Electricity - EU mix CCGT	117	4.08
CGH2 - EU mix regional electrolysis plant	208	7.25
CGH2 - regional electrolysis from wind regional plant	0	0.00
CGH2 - EU mix CCGT regional electrolysis	190	6.62
CGH2 - EU mix on-site electrolysis	208	7.25
CGH2 - onsite electrolysis from wind power	0	0.00
CGH2 - EU mix CCGT onsite electrolysis	188	6.56
CGH2 gasification of residual woody biomass	7	0.24
CGH2 gasification of dedicated crop (poplar)	21.7	0.76
E100 enzymatic hydrolysis of lignocelluslose (crop residue: wheat straw)	-55.7	-1.94
E100 enzymatic hydrolysis of lignocelluslose (sugar beet)	-70.3	-2.45
E100 enzymatic hydrolysis of lignocelluslose (dedicated crop: poplar)	-29.5	-1.03
E100 B43conventional fermentation of sugar beet	-15.1	-0.53
Biodiesel from rape seed	-48	-1.67

3.9 Pollutant Emissions

Pollutant emissions tracking was implemented in the model to allow the Sustainable Mobility Project to better understand the vehicle emissions trends that result from the projection of vehicle sales, stocks and travel. At a world regional average level of aggregation, there is no information in the model about where vehicles are travelling (e.g. urban v. rural) or how various emissions translate into atmospheric concentrations. The emissions trends are included to provide a general directional sense of whether total emissions from road vehicles increasing or decreasing over time. Five types of pollutants are tracked: nitrogen oxides (NOx), particulate matter (PM-10), carbon monoxide (CO), hydrocarbons (HC or VOC) and lead (Pb). Note that for lead, a different approach is used which is discussed after the other pollutants. Pollutant emissions tracking has been developed only for road vehicles - no tracking for rail, air or shipping.

The approach used for light-duty vehicles has been to rely primarily on existing tailpipe emissions standards for new vehicles around the world, and the announced plans for phase-in of future, generally tighter, standards. For the developing world, in cases where information on existing or planned future standards was unavailable, simple assumptions were made regarding adoption of standards similar to the EU system (EURO 1 through EURO 5) in the future, at a certain time-lag after these have been implemented in Europe.

For other road vehicles (2/3 wheelers, trucks and buses), since the model does not track new vehicles or stock turnover, but only the existing stock of vehicles, estimates are based on assumed average emissions across the vehicle stock, and evolution of this average.

Several types of data are thus needed to generate estimates: average emissions for new and existing vehicles in the base year (2000), and estimated emissions of new vehicles, or in the case of non-LDVs estimated improvements in the stock average, in the future. While the new LDV emissions estimates are based primarily on current and future emissions standards, other sources were needed for the estimates related to existing vehicles. Few such sources exist that cover non-OECD regions.

The best source found for average in-use emissions in 2000 was a very recent (and as of May 2004, still unpublished) report from an OECD Environment Directorate study, part of their MOVE II project. The IEA has not been involved in that study, but obtained relevant estimates through internal communication. The study is highly relevant since it generates average emissions for all types of road vehicles by region (with a similar but not identical regional classification system as used here), vehicle type, vehicle vintage, and emissions control category (with seven categories, from uncontrolled up through the equivalent of EURO IV control levels). However, the authors warn that estimates are not final and could change. The IEA also relied on input from SMP Workstreams 2 and 3, including both data and review of the estimates and projections contained herein.

An important difference between the projections here and the OECD projections is the assumption here that all world regions will eventually adopt the same emissions standards being implemented in OECD regions. The OECD report restricts improvements to those emissions standards already announced or nearly finalized. This leads to a large difference in the projection – if developing regions do not continue to follow the OECD country lead (with some regions such as Africa and the Middle East assumed not to adopt any standards at all), then total emissions for each of the four pollutants in the developing world rises over time, rather than dropping in the projections used here, with the assumption of a 10-15 year lag time in adopting OECD emissions standards in the developing world (described in more detail below).

Estimates of Average Pollutant Emissions for Existing Vehicles in 2000 (g/km)

	Gasoline Vehicles				Diesel Vehicles			
	PM	**NOx**	**VOC**	**CO**	**PM**	**NOx**	**VOC**	**CO**
Light-duty Vehicles								
OECD North America	0.08	1.2	4.0	30.0	0.20	1.0	0.5	1.1
OECD Europe	0.08	1.2	4.0	30.0	0.20	1.0	0.5	1.1
OECD Pacific	0.08	1.2	4.0	30.0	0.20	1.0	0.5	1.1
FSU	0.18	2.0	10.0	60.0	0.40	1.5	1.3	2.2
Eastern Europe	0.18	2.0	10.0	60.0	0.40	1.5	1.3	2.2
China	0.18	2.0	10.0	60.0	0.40	1.5	1.3	2.2
Other Asia	0.18	2.0	10.0	60.0	0.40	1.5	1.3	2.2
India	0.18	2.0	10.0	60.0	0.40	1.5	1.3	2.2
Middle East	0.18	2.0	10.0	60.0	0.40	1.5	1.3	2.2
Latin America	0.18	2.0	10.0	60.0	0.40	1.5	1.3	2.2
Africa	0.18	2.0	10.0	60.0	0.40	1.5	1.3	2.2
Heavy Trucks and Large Buses								
OECD North America	0.3	4.0	4.0	30.0	0.6	10.0	0.6	5.0
OECD Europe	0.3	4.0	4.0	30.0	0.6	10.0	0.6	5.0
OECD Pacific	0.3	4.0	3.8	30.0	0.5	10.0	0.6	5.0
FSU	0.6	8.0	10.0	80.0	1.2	15.0	2.0	8.0
Eastern Europe	0.6	8.0	10.0	80.0	1.2	15.0	2.0	8.0
China	0.6	8.0	10.0	80.0	1.2	15.0	2.0	8.0
Other Asia	0.6	8.0	10.0	80.0	1.2	15.0	2.0	8.0
India	0.6	8.0	10.0	80.0	1.2	15.0	2.0	8.0
Middle East	0.6	8.0	10.0	80.0	1.2	15.0	2.0	8.0
Latin America	0.6	8.0	10.0	80.0	1.2	15.0	2.0	8.0
Africa	0.6	8.0	10.0	80.0	1.2	15.0	2.0	8.0
Medium Trucks and Small Buses								
OECD North America	0.2	4.5	2.6	25.0	0.3	5.5	0.3	1.1
OECD Europe	0.2	4.5	2.6	25.0	0.3	5.5	0.3	1.1
OECD Pacific	0.1	4.0	2.5	25.0	0.3	5.0	0.3	1.1
FSU	0.5	6.0	8.0	60.0	1.0	10.0	1.3	2.0
Eastern Europe	0.5	6.0	8.0	60.0	1.0	10.0	1.3	2.0
China	0.5	6.0	8.0	60.0	1.0	10.0	1.3	2.0
Other Asia	0.5	6.0	8.0	60.0	1.0	10.0	1.3	2.0
India	0.5	6.0	8.0	60.0	1.0	10.0	1.3	2.0
Middle East	0.5	6.0	8.0	60.0	1.0	10.0	1.3	2.0
Latin America	0.5	6.0	8.0	60.0	1.0	10.0	1.3	2.0
Africa	0.5	6.0	8.0	60.0	1.0	10.0	1.3	2.0

2/3 Wheelers (gasoline only)

OECD North America	0.1	0.3	4.0	20.0
OECD Europe	0.1	0.3	4.0	20.0
OECD Pacific	0.1	0.3	4.0	20.0
FSU	0.2	0.3	6.0	25.0
Eastern Europe	0.2	0.3	6.0	25.0
China	0.2	0.3	6.0	25.0
Other Asia	0.2	0.3	6.0	25.0
India	0.2	0.3	6.0	25.0
Middle East	0.2	0.3	6.0	25.0
Latin America	0.2	0.3	6.0	25.0
Africa	0.2	0.3	6.0	25.0

For light-duty vehicles, the projection of emissions factors into the future is based primarily on existing and planned emissions standards in OECD countries, with assumptions regarding the future adoption of similar standards in non-OECD countries, as is beginning to occur around the world. The key assumptions include:

- That the developing world adopts similar standards as OECD countries, but with approximately a 10 year lag time in most regions. Slightly longer lag times are assumed for Africa and the Middle East than for other regions.

- No additional tightening of standards is assumed once current plans are fully realised (e.g. EURO-5, Tier II-Bin 8, etc.), except that each region is assumed to eventually adopt the most stringent currently planned anywhere (e.g. EURO V PM standard becomes global standard by 2025).

- Vehicle in-use emissions are assumed to increase over time as a vehicle ages. The rate of increase is 25% every 5 years, compounded, in OECD and 50% in non-OECD. For example, in OECD regions vehicles emit about $1.25^3 = 1.95$, or 95% more after 15 years of vehicle life than when new. in non-OECD regions they emit about 230% more after 15 years of vehicle life.

- Gasoline and diesel hybrids and gaseous-fuelled (CNG/LPG) vehicles are assumed to have half the emissions per kilometre as similarly-fuelled conventional (non-hybridised) vehicles; hydrogen fuel cells are assumed to have no pollutant emissions. This holds across all pollutants and years.

Projections for the phase-in of standards, and resulting estimates of emissions per kilometre for new LDVs is shown in the tables below.

Assumed adoption of pollutant emissions standards around the world – Particulate Matter (PM-10)

	PM Standard (or assumed)					
LD Gasoline Vehicle - standard	2000	2005	2010	2015	2020	2025
OECD North America	Tier-1	Tier-2	Tier-2 Bin 8	Euro-5	Euro-5	Euro-5
OECD Europe	Euro-3	Euro-4	Euro-5	Euro-5	Euro-5	Euro-5
OECD Pacific	Japan 1998	Japan 2002	Euro-4	Euro-5	Euro-5	Euro-5
FSU	Euro-1	Euro-2	Euro-3	Euro-4	Tier-2 Bin 8	Euro-5
Eastern Europe	Euro-1	Euro-2	Euro-3	Euro-4	Tier-2 Bin 8	Euro-5
China	Euro-1	Euro-2	Euro-4	Euro-4	Tier-2 Bin 8	Euro-5
Other Asia	Euro-1	Euro-2	Euro-4	Euro-4	Tier-2 Bin 8	Euro-5
India	Euro-1	Euro-2	Euro-3	Euro-4	Tier-2 Bin 8	Euro-5
Middle East	Euro-1	Euro-1	Euro-2	Euro-3	Euro-4	Tier-2 Bin 8
Latin America	Euro-1	Euro-2	Euro-3	Euro-4	Tier-2 Bin 8	Euro-5
Africa	Euro-1	Euro-1	Euro-2	Euro-3	Euro-4	Tier-2 Bin 8
LD Gasoline Vehicle - value	PM value-g/km					
OECD North America	0.062	0.050	0.006	0.003	0.003	0.003
OECD Europe	0.050	0.025	0.003	0.003	0.003	0.003
OECD Pacific	0.080	0.052	0.025	0.003	0.003	0.003
FSU	0.140	0.080	0.050	0.025	0.006	0.003
Eastern Europe	0.140	0.080	0.050	0.025	0.006	0.003
China	0.140	0.080	0.025	0.025	0.006	0.003
Other Asia	0.140	0.080	0.025	0.025	0.006	0.003
India	0.140	0.080	0.050	0.025	0.006	0.003
Middle East	0.140	0.140	0.080	0.050	0.025	0.006
Latin America	0.140	0.080	0.050	0.025	0.006	0.003
Africa	0.140	0.140	0.080	0.050	0.025	0.006
LD Diesel Vehicle - Value	PM value-g/km					
OECD North America	0.062	0.050	0.006	0.003	0.003	0.003
OECD Europe	0.050	0.025	0.003	0.003	0.003	0.003
OECD Pacific	0.080	0.052	0.025	0.003	0.003	0.003
FSU	0.140	0.080	0.050	0.025	0.006	0.003
Eastern Europe	0.140	0.080	0.050	0.025	0.006	0.003
China	0.140	0.080	0.025	0.025	0.006	0.003
Other Asia	0.140	0.080	0.025	0.025	0.006	0.003
India	0.140	0.080	0.050	0.025	0.006	0.003
Middle East	0.140	0.140	0.080	0.050	0.025	0.006
Latin America	0.140	0.080	0.050	0.025	0.006	0.003
Africa	0.140	0.140	0.080	0.050	0.025	0.006

Assumed adoption of pollutant emissions standards around the world – NOx

LD Gasoline Vehicle - standard	NOx standard (or assumed) 2000	2005	2010	2015	2020	2025
OECD North America	Tier-1	Tier-2	Tier-2 Bin 8	Tier-2 Bin 8	Tier-2 Bin 8	Tier-2 Bin 8
OECD Europe	Euro-3	Euro-4	Euro-5	Tier-2 Bin 8	Tier-2 Bin 8	Tier-2 Bin 8
OECD Pacific	Japan 1998	Japan 2002	Tier-2 Bin 8	Tier-2 Bin 8	Tier-2 Bin 8	Tier-2 Bin 8
FSU	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Tier-2 Bin 8
Eastern Europe	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Tier-2 Bin 8
China	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Tier-2 Bin 8
Other Asia	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Tier-2 Bin 8
India	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Tier-2 Bin 8
Middle East	Euro-1	Euro-1	Euro-2	Euro-3	Euro-4	Tier-2 Bin 8
Latin America	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Tier-2 Bin 8
Africa	Euro-1	Euro-1	Euro-2	Euro-3	Euro-4	Tier-2 Bin 8

LD Gasoline Vehicle - value	NOx value-g/km					
OECD North America	0.372	0.186	0.043	0.043	0.043	0.043
OECD Europe	0.150	0.080	0.080	0.043	0.043	0.043
OECD Pacific	0.080	0.050	0.043	0.043	0.043	0.043
FSU	0.484	0.214	0.150	0.080	0.080	0.043
Eastern Europe	0.484	0.214	0.150	0.080	0.080	0.043
China	0.484	0.214	0.150	0.080	0.080	0.043
Other Asia	0.484	0.214	0.150	0.080	0.080	0.043
India	0.484	0.214	0.150	0.080	0.080	0.043
Middle East	0.484	0.484	0.214	0.150	0.080	0.043
Latin America	0.484	0.214	0.150	0.080	0.080	0.043
Africa	0.484	0.484	0.214	0.150	0.080	0.043

LD Diesel Vehicle - Value	NOx value-g/km					
OECD North America	1.000	0.186	0.043	0.043	0.043	0.043
OECD Europe	0.500	0.250	0.080	0.043	0.043	0.043
OECD Pacific	2.000	0.140	0.043	0.043	0.043	0.043
FSU	1.000	0.500	0.150	0.080	0.080	0.043
Eastern Europe	1.000	0.500	0.150	0.080	0.080	0.043
China	1.000	0.500	0.150	0.080	0.080	0.043
Other Asia	1.000	0.500	0.150	0.080	0.080	0.043
India	1.000	0.500	0.150	0.080	0.080	0.043
Middle East	1.000	1.000	0.500	0.150	0.080	0.043
Latin America	1.000	0.500	0.150	0.080	0.080	0.043
Africa	1.000	1.000	0.500	0.150	0.080	0.043

Assumed adoption of pollutant emissions standards around the world – VOCs

LD Gasoline Vehicle - standard	VOC standard (or assumed) 2000	2005	2010	2015	2020	2025
OECD North America	Tier-1	Tier-2	Tier-2 Bin 8	Tier-2 Bin 8	Tier-2 Bin 8	Tier-2 Bin 8
OECD Europe	Euro-3	Euro-4	Euro-5	Tier-2 Bin 8	Tier-2 Bin 8	Tier-2 Bin 8
OECD Pacific	Japan 1998	Japan 2002	Japan 2002	Tier-2 Bin 8	Tier-2 Bin 8	Tier-2 Bin 8
FSU	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Tier-2 Bin 8
Eastern Europe	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Tier-2 Bin 8
China	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Tier-2 Bin 8
Other Asia	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Tier-2 Bin 8
India	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Tier-2 Bin 8
Middle East	Euro-1	Euro-1	Euro-2	Euro-3	Euro-4	Tier-2 Bin 8
Latin America	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Tier-2 Bin 8
Africa	Euro-1	Euro-1	Euro-2	Euro-3	Euro-4	Tier-2 Bin 8
LD Gasoline Vehicle - value	VOC value-g/km					
OECD North America	0.155	0.097	0.047	0.047	0.047	0.047
OECD Europe	0.200	0.100	0.100	0.047	0.047	0.047
OECD Pacific	0.400	0.120	0.120	0.047	0.047	0.047
FSU	0.646	0.286	0.200	0.100	0.100	0.047
Eastern Europe	0.646	0.286	0.200	0.100	0.100	0.047
China	0.646	0.286	0.200	0.100	0.100	0.047
Other Asia	0.646	0.286	0.200	0.100	0.100	0.047
India	0.646	0.286	0.200	0.100	0.100	0.047
Middle East	0.646	0.646	0.286	0.200	0.100	0.047
Latin America	0.646	0.286	0.200	0.100	0.100	0.047
Africa	0.646	0.646	0.286	0.200	0.100	0.047
LD Diesel Vehicle - Value	VOC value-g/km					
OECD North America	0.155	0.097	0.047	0.047	0.047	0.047
OECD Europe	0.200	0.100	0.100	0.047	0.047	0.047
OECD Pacific	0.400	0.120	0.120	0.047	0.047	0.047
FSU	0.646	0.286	0.200	0.100	0.100	0.047
Eastern Europe	0.646	0.286	0.200	0.100	0.100	0.047
China	0.646	0.286	0.200	0.100	0.100	0.047
Other Asia	0.646	0.286	0.200	0.100	0.100	0.047
India	0.646	0.286	0.200	0.100	0.100	0.047
Middle East	0.646	0.646	0.286	0.200	0.100	0.047
Latin America	0.646	0.286	0.200	0.100	0.100	0.047
Africa	0.646	0.646	0.286	0.200	0.100	0.047

Assumed adoption of pollutant emissions standards around the world – CO

LD Gasoline Vehicle - standard	CO standard (or assumed) 2000	2005	2010	2015	2020	2025
OECD North America	Tier-1	Tier-2	Tier-2 Bin 8	Euro-5	Japan 2002	Japan 2002
OECD Europe	Euro-3	Euro-4	Euro-5	Euro-5	Japan 2002	Japan 2002
OECD Pacific	Japan 1998	Japan 2002	Japan 2002	Japan 2002	Japan 2002	Japan 2002
FSU	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Japan 2002
Eastern Europe	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Japan 2002
China	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Japan 2002
Other Asia	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Japan 2002
India	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Japan 2002
Middle East	Euro-1	Euro-1	Euro-2	Euro-3	Euro-4	Japan 2002
Latin America	Euro-1	Euro-2	Euro-3	Euro-4	Euro-5	Japan 2002
Africa	Euro-1	Euro-1	Euro-2	Euro-3	Euro-4	Japan 2002
LD Gasoline Vehicle - value	CO value-g/km					
OECD North America	2.604	2.604	2.108	1.000	0.630	0.630
OECD Europe	2.300	1.000	1.000	1.000	0.630	0.630
OECD Pacific	2.100	0.630	0.630	0.630	0.630	0.630
FSU	3.160	2.604	2.300	1.000	1.000	0.630
Eastern Europe	3.160	2.604	2.300	1.000	1.000	0.630
China	3.160	2.604	2.300	1.000	1.000	0.630
Other Asia	3.160	2.604	2.300	1.000	1.000	0.630
India	3.160	2.604	2.300	1.000	1.000	0.630
Middle East	3.160	3.160	2.604	2.300	1.000	0.630
Latin America	3.160	2.604	2.300	1.000	1.000	0.630
Africa	3.160	3.160	2.604	2.300	1.000	0.630
LD Diesel Vehicle - Value	CO value-g/km					
OECD North America	2.604	2.604	2.108	0.630	0.630	0.630
OECD Europe	0.640	0.500	0.500	0.500	0.500	0.500
OECD Pacific	2.100	0.630	0.630	0.630	0.630	0.630
FSU	3.160	2.604	2.300	1.000	1.000	0.630
Eastern Europe	3.160	2.604	2.300	1.000	1.000	0.630
China	3.160	2.604	2.300	1.000	1.000	0.630
Other Asia	3.160	2.604	2.300	1.000	1.000	0.630
India	3.160	2.604	2.300	1.000	1.000	0.630
Middle East	3.160	3.160	2.604	2.300	1.000	0.630
Latin America	3.160	2.604	2.300	1.000	1.000	0.630
Africa	3.160	3.160	2.604	2.300	1.000	0.630

For trucks and buses, estimates were obtained for current average emissions of each pollutant, and how this average is likely to evolve over the next 10-20 years. We generally assume that the average stops improving after 2030 in OECD countries, in line with a fairly complete evolution of currently planned emissions standards penetrating the entire fleet (or vast majority, especially on a vehicle tonne-km basis). As for cars, heavy-duty vehicle emissions are measured and tracked in units of grams per kilometre. Large buses are assumed to have the same average emissions as trucks using the same fuel type (gasoline or diesel); small buses assumed to have the same as medium duty trucks.

Estimates for current average emissions are based primarily on the recent OECD/Environment Directorate study mentioned above, but also on recent estimates developed by the US EPA using the Mobile 5 model. Projections to 2010 are based primarily on the EPA work for the US, with an assumption of a 10-15 year lag in improvements of in-use average emissions of heavy-duty vehicles in developing countries. As for light-duty vehicles, these are dependent on the assumption that all developing countries eventually move ahead with tighter standards and enforcement, following the lead of OECD countries. If this does not occur, or takes longer than the assumed 10-15 year lag time, then obviously emissions levels will be higher. Some such scenarios were run for the SMP and are contained in the “Mobility 2030” report.

The following table shows the average emissions by pollutant and region – approximately the same estimates were used for all OECD regions, and for all non-OECD regions, so individual regions are not shown. Emissions factors for medium trucks/small buses also is not shown here; these are generally similar, though somewhat lower, than for these larger vehicles.

Heavy Trucks and Large Buses – average emissions (g/km) across vehicle stock, by fuel type and pollutant

	2000	2010	2020	2030	2040	2050
PM-10 Emissions						
Gasoline Vehicles						
OECD Regions	0.30	0.06	0.02	0.02	0.02	0.02
Non-OECD Regions	0.60	0.40	0.18	0.04	0.02	0.02
Diesel Vehicles						
OECD North America	0.60	0.10	0.02	0.02	0.02	0.02
Non-OECD Regions	1.20	0.80	0.35	0.06	0.02	0.02
NOx Emissions						
Gasoline Vehicles						
OECD Regions	4.00	2.50	0.60	0.20	0.20	0.20
Non-OECD Regions	8.00	5.33	3.25	1.55	0.40	0.20
Diesel Vehicles						
OECD North America	10.00	5.00	1.00	0.40	0.40	0.40
Non-OECD Regions	15.00	11.67	7.50	3.00	0.70	0.40
VOC Emissions						
Gasoline Vehicles						
OECD Regions	4.00	1.20	0.50	0.40	0.40	0.40
Non-OECD Regions	10.00	6.00	2.60	0.85	0.45	0.40
Diesel Vehicles						
OECD North America	0.60	0.30	0.20	0.15	0.15	0.15
Non-OECD Regions	2.00	1.07	0.45	0.25	0.18	0.15
CO Emissions						
Gasoline Vehicles						
OECD Regions	30.00	10.00	7.50	7.00	7.00	7.00
Non-OECD Regions	80.00	46.67	20.00	8.75	7.25	7.00
Diesel Vehicles						
OECD North America	5.00	1.30	0.30	0.20	0.20	0.20
Non-OECD Regions	8.00	6.00	3.15	0.80	0.25	0.20

Emissions estimates for two/three wheelers are, as for trucks and buses, based on stock-average in-use emissions by region. Estimates for 2000 are based primarily on the OECD/Environment analysis. Rates of improvement in the future are based on expected improvement rates for new vehicles, which is based in part on emissions standards for new two wheelers in OECD countries, but also based on an assumption that improvement rates will be similar to those for light-duty vehicles with about a ten year lag to hit similar emissions levels, on average. Three wheelers (only assumed to be sold in Asian regions) are assumed to show similar average emissions levels as two-wheelers. This could in fact change, given the trend toward fuel switching of three wheelers to gaseous fuels – but this is not reflected in our reference case.

The resulting reference case projections by pollutant and region are shown in the table below.

Two/Three Wheelers – average emissions (g/km) across vehicle stock, by pollutant

	2000	2010	2020	2030	2040	2050
PM-10 Emissions						
OECD North America	0.100	0.074	0.066	0.030	0.004	0.003
OECD Europe	0.100	0.070	0.058	0.010	0.003	0.003
OECD Pacific	0.100	0.080	0.090	0.024	0.003	0.003
FSU	0.200	0.164	0.174	0.122	0.032	0.006
Eastern Europe	0.200	0.167	0.179	0.142	0.042	0.006
China	0.200	0.158	0.156	0.085	0.020	0.005
Other Asia	0.200	0.163	0.166	0.101	0.022	0.005
India	0.200	0.155	0.166	0.105	0.027	0.005
Middle East	0.200	0.166	0.199	0.168	0.062	0.016
Latin America	0.200	0.161	0.174	0.124	0.032	0.005
Africa	0.200	0.166	0.193	0.183	0.088	0.022
NOx Emissions						
OECD North America	0.30	0.600	0.446	0.155	0.059	0.059
OECD Europe	0.30	0.600	0.327	0.084	0.055	0.055
OECD Pacific	0.30	0.600	0.196	0.055	0.055	0.055
FSU	0.30	0.600	0.667	0.383	0.145	0.090
Eastern Europe	0.30	0.600	0.796	0.442	0.175	0.094
China	0.30	0.600	0.496	0.303	0.124	0.079
Other Asia	0.30	0.600	0.623	0.354	0.135	0.080
India	0.30	0.600	0.452	0.330	0.130	0.079
Middle East	0.30	0.600	0.813	0.545	0.194	0.087
Latin America	0.30	0.600	0.594	0.389	0.146	0.085
Africa	0.30	0.600	0.882	0.597	0.264	0.108
VOC Emissions						
OECD North America	4.00	3.000	0.750	0.096	0.063	0.063
OECD Europe	4.00	3.000	0.750	0.101	0.059	0.059
OECD Pacific	4.00	3.000	0.750	0.105	0.059	0.059
FSU	6.00	4.000	1.500	0.507	0.180	0.101
Eastern Europe	6.00	4.000	1.500	0.587	0.220	0.106
China	6.00	4.000	1.500	0.400	0.153	0.087
Other Asia	6.00	4.000	1.500	0.469	0.168	0.089
India	6.00	4.000	1.500	0.436	0.161	0.087
Middle East	6.00	4.000	1.500	0.725	0.250	0.097
Latin America	6.00	4.000	1.500	0.515	0.182	0.094
Africa	6.00	4.000	1.500	0.795	0.345	0.123
CO Emissions						
OECD North America	20.00	15.000	6.467	2.476	0.997	0.864
OECD Europe	20.00	15.000	6.575	1.216	0.897	0.801
OECD Pacific	20.00	15.000	4.628	0.795	0.801	0.800
FSU	25.00	20.000	7.500	3.832	1.656	1.180
Eastern Europe	25.00	20.000	7.500	4.229	1.860	1.209
China	25.00	20.000	7.500	3.352	1.500	1.085
Other Asia	25.00	20.000	7.500	3.670	1.576	1.095
India	25.00	20.000	7.500	3.518	1.544	1.077
Middle East	25.00	20.000	7.500	4.664	2.334	1.153
Latin America	25.00	20.000	7.500	3.890	1.649	1.131
Africa	25.00	20.000	7.500	4.949	2.886	1.308

Lead (Pb) Emissions

Since lead (Pb) emissions are regulated per kilometre, and are directly related to fuel use (and lead concentration in fuel), lead has been modelled differently than the other pollutant emissions. It is treated as a simple function of leaded gasoline fuel use and average lead content per litre.

Lead has been almost completely phased out in most regions of the world, and has begun to be phased out in the remaining ones (Africa, Middle East, Former Soviet Union). Based on several recent sources, but especially a recent review by the International Fuel Quality Centre (IFQC, 2004), the following estimates of leaded fuel share and lead content per litre were developed. These are regional approximations based on reported activities in various countries in each region.

Average lead content per litre has dropped steadily in most countries that use lead in fuel, with most countries today using no more than 0.5 grams per litre of lead, and an average of around 0.3 is assumed for all non-OECD regions. This reduction trend is assumed to continue in the future. More importantly, the steady drive toward phase out of leaded fuel is assumed to continue until no leaded fuel is used anywhere. All regions are expected to have fully (or almost fully) phased out leaded fuel by 2015.

Lead (Pb) Average emissions factors for all leaded gasoline fuel for all vehicle types (g/litre of leaded fuel used)

	2000	2005	2010	2015	2020
OECD North America	0.20	0.20	0.20	0.20	0.20
OECD Europe	0.20	0.20	0.20	0.20	0.20
OECD Pacific	0.20	0.20	0.20	0.20	0.20
FSU	0.30	0.25	0.20	0.20	0.20
Eastern Europe	0.30	0.25	0.20	0.20	0.20
China	0.30	0.25	0.20	0.20	0.20
Other Asia	0.30	0.25	0.20	0.20	0.20
India	0.30	0.25	0.20	0.20	0.20
Middle East	0.30	0.25	0.20	0.20	0.20
Latin America	0.30	0.25	0.20	0.20	0.20
Africa	0.30	0.25	0.20	0.20	0.20

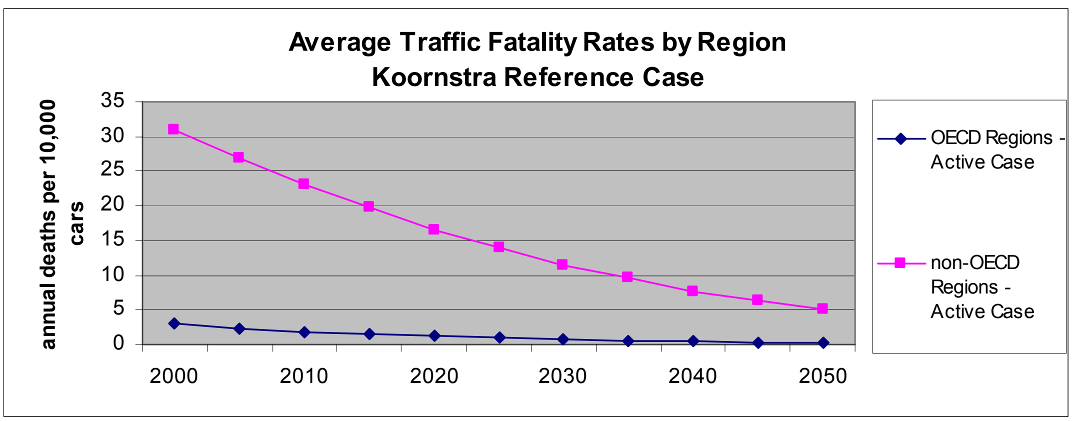
Leaded Fuel - Share of Total Gasoline Fuel Use

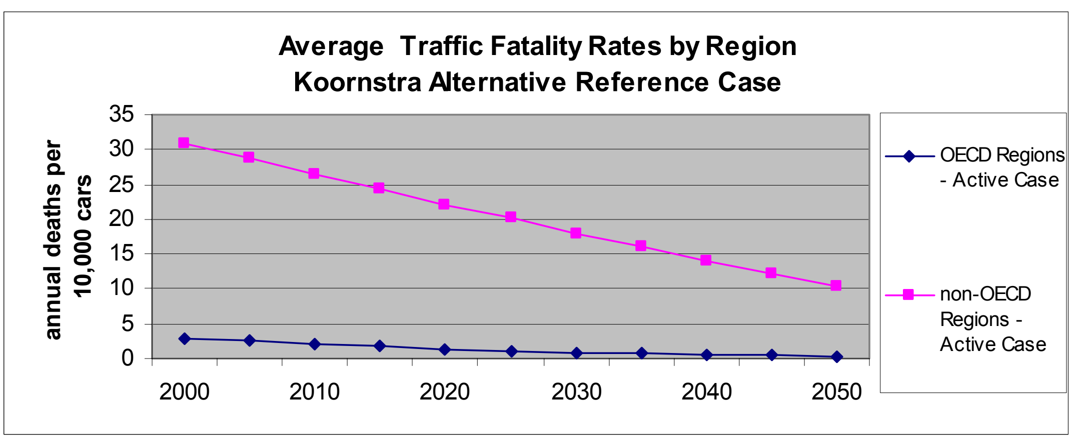
	2000	2005	2010	2015	2020
OECD North America	2.0%	0.0%	0.0%	0.0%	0.0%
OECD Europe	2.0%	1.0%	0.0%	0.0%	0.0%
OECD Pacific	2.0%	1.0%	0.0%	0.0%	0.0%
FSU	75.0%	50.0%	25.0%	1.0%	0.0%
Eastern Europe	25.0%	5.0%	1.0%	0.0%	0.0%
China	10.0%	2.0%	0.0%	0.0%	0.0%
Other Asia	25.0%	5.0%	1.0%	0.0%	0.0%
India	10.0%	2.0%	0.0%	0.0%	0.0%
Middle East	75.0%	50.0%	5.0%	1.0%	0.0%
Latin America	50.0%	25.0%	2.0%	1.0%	0.0%
Africa	75.0%	50.0%	10.0%	1.0%	0.0%

3.10 Safety

As mentioned in the key results section, the SMP commissioned three separate papers on safety, of which one, by M. Koornstra, included the development of global/regional projections. The details of Koornstra's analysis are available separately and are not discussed in detail here. His projections of fatality and injury rates (per 10,000 vehicles) are shown in the tables below. These were adjusted by Koornstra to match the regional definitions used in the SMP model (that in turn match the IEA ETP model). However, since Koornstra's paper was completed, some minor changes in the SMP projection of total vehicles has resulted in slightly different overall deaths and injury projections than shown in Koornstra's paper, when multiplied by Koornstra's death and injury rates.

The Figures below show death rates both per 10,000 motor vehicles. The difference in death rates in Koornstra's "Reference Case" v. his "Alternative Reference Case" is difficult to discern in the figures, but drop much more quickly in the reference case. This difference is more evident in the tables, which also show death rates per billion vehicle kilometres traveled, as well as injury rates. Details for Koornstra's reference case are shown in the first table, then his Alternative Reference Case are shown next. Other Koornstra cases are not shown, but are available in his paper for the SMP.





SAFETY - Koornstra Reference Model

Traffic Fatality rates (per 10,000 cars)

	2000	2010	2020	2030	2040	2050
OECD Regions - Active Case	2.9	1.9	1.1	0.7	0.4	0.3
non-OECD Regions - Active Case	30.9	23.1	16.5	11.5	7.6	4.9
	2000	**2010**	**2020**	**2030**	**2040**	**2050**
OECD Regions - Reference Case	2.9	1.9	1.1	0.7	0.4	0.3
non-OECD Regions - Reference Case	30.9	23.1	16.5	11.5	7.6	4.9

Traffic Fatality rates (per billion km)

	2000	2010	2020	2030	2040	2050
OECD Regions - Active Case	19.6	12.3	7.5	4.6	2.8	1.7
non-OECD Regions - Active Case	251.4	193.6	141.2	99.6	66.6	44.0
	2000	**2010**	**2020**	**2030**	**2040**	**2050**
OECD Regions - Reference Case	19.6	12.3	7.5	4.6	2.8	1.7
non-OECD Regions - Reference Case	251.4	193.6	141.2	99.6	66.6	44.0

Total Traffic Fatalities (thousands)

	2000	2010	2020	2030	2040	2050
OECD Regions - Active Case	178.2	126.8	88.9	58.4	37.6	24.1
non-OECD Regions - Active Case	1027.1	1128.2	1204.1	1151.2	1039.4	935.4
	2000	**2010**	**2020**	**2030**	**2040**	**2050**
OECD Regions - Reference Case	178.2	126.8	88.9	58.4	37.6	24.1
non-OECD Regions - Reference Case	1027.1	1128.2	1204.1	1151.2	1039.4	935.4

Traffic Injury rates (per 10,000 cars)

	2000	2010	2020	2030	2040	2050
OECD Regions - Active Case	41.1	30.7	19.8	12.8	8.2	5.3
non-OECD Regions - Active Case	188.1	245.4	179.5	128.6	88.0	59.4
	2000	**2010**	**2020**	**2030**	**2040**	**2050**
OECD Regions - Reference Case	41.1	30.7	19.8	12.8	8.2	5.3
non-OECD Regions - Reference Case	188.1	245.4	179.5	128.6	88.0	59.4

Traffic Injury rates (per billion km)

	2000	2010	2020	2030	2040	2050
OECD Regions - Active Case	274.2	203.4	130.5	83.2	52.7	33.4
non-OECD Regions - Active Case	1529.4	2059.8	1539.5	1116.8	772.1	528.4
	2000	**2010**	**2020**	**2030**	**2040**	**2050**
OECD Regions - Reference Case	274.2	203.4	130.5	83.2	52.7	33.4
non-OECD Regions - Reference Case	1529.4	2059.8	1539.5	1116.8	772.1	528.4

Total Traffic Injuries (thousands)

	2000	2010	2020	2030	2040	2050
OECD Regions - Active Case	2493.0	2099.2	1537.2	1050.3	704.5	471.8
non-OECD Regions - Active Case	6248.8	12000.3	13132.6	12908.1	12058.1	11237.8
	2000	**2010**	**2020**	**2030**	**2040**	**2050**
OECD Regions - Reference Case	2493.0	2099.2	1537.2	1050.3	704.5	471.8
non-OECD Regions - Reference Case	6248.8	12000.3	13132.6	12908.1	12058.1	11237.8

SAFETY - Koornstra Alternative Reference Model

Traffic Fatality rates (per 10,000 cars)

	2000	2010	2020	2030	2040	2050
OECD Regions - Active Case	2.9	2.0	1.3	0.9	0.6	0.4
non-OECD Regions - Active Case	30.9	26.6	22.1	18.0	13.9	10.4
	2000	**2010**	**2020**	**2030**	**2040**	**2050**
OECD Regions - Reference Case	2.9	2.0	1.3	0.9	0.6	0.4
non-OECD Regions - Reference Case	30.9	26.6	22.1	18.0	13.9	10.4

Traffic Fatality rates (per billion km)

	2000	2010	2020	2030	2040	2050
OECD Regions - Active Case	19.6	13.5	8.8	5.7	3.6	2.3
non-OECD Regions - Active Case	251.4	223.0	189.6	156.2	122.0	92.4
	2000	**2010**	**2020**	**2030**	**2040**	**2050**
OECD Regions - Reference Case	19.6	13.5	8.8	5.7	3.6	2.3
non-OECD Regions - Reference Case	251.4	223.0	189.6	156.2	122.0	92.4

Total Traffic Fatalities (thousands)

	2000	2010	2020	2030	2040	2050
OECD Regions - Active Case	178.2	139.2	103.3	72.5	48.8	32.5
non-OECD Regions - Active Case	1027.1	1299.2	1617.0	1805.8	1905.2	1965.7
	2000	**2010**	**2020**	**2030**	**2040**	**2050**
OECD Regions - Reference Case	178.2	139.2	103.3	72.5	48.8	32.5
non-OECD Regions - Reference Case	1027.1	1299.2	1617.0	1805.8	1905.2	1965.7

Traffic Injury rates (per 10,000 cars)

	2000	2010	2020	2030	2040	2050
OECD Regions - Active Case	41.1	33.7	23.0	15.8	10.6	7.0
non-OECD Regions - Active Case	188.1	284.0	242.8	203.4	162.2	124.5
	2000	**2010**	**2020**	**2030**	**2040**	**2050**
OECD Regions - Reference Case	41.1	33.7	23.0	15.8	10.6	7.0
non-OECD Regions - Reference Case	188.1	284.0	242.8	203.4	162.2	124.5

Traffic Injury rates (per billion km)

	2000	2010	2020	2030	2040	2050
OECD Regions - Active Case	274.2	223.5	151.4	102.6	68.1	44.5
non-OECD Regions - Active Case	1529.4	2383.2	2082.5	1766.4	1422.7	1106.7
	2000	**2010**	**2020**	**2030**	**2040**	**2050**
OECD Regions - Reference Case	274.2	223.5	151.4	102.6	68.1	44.5
non-OECD Regions - Reference Case	1529.4	2383.2	2082.5	1766.4	1422.7	1106.7

Total Traffic Injuries (thousands)

	2000	2010	2020	2030	2040	2050
OECD Regions - Active Case	2493.0	2307.2	1783.2	1295.4	910.4	628.9
non-OECD Regions - Active Case	6248.8	13884.8	17764.6	20416.3	22219.2	23534.5
	2000	**2010**	**2020**	**2030**	**2040**	**2050**
OECD Regions - Reference Case	2493.0	2307.2	1783.2	1295.4	910.4	628.9
non-OECD Regions - Reference Case	6248.8	13884.8	17764.6	20416.3	22219.2	23534.5