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International comparison of light-duty vehicle fuel economy and related characteristics

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Prepared by François Cuenot and Lew Fulton

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Executive summary

The International Energy Agency, in partnership with the Global Fuel Economy Initiative (GFEI), and with a grant from FIA Foundation (a GFEI partner), has undertaken a research program on fuel economy of light-duty vehicles (LDVs) around the world. This brief is a product of that effort, and reports on IEA's analysis of vehicle characteristics, including fuel economy, in 21 countries around the world and the EU. In particular, it reports what may be the first ever global average estimate for LDV fuel economy world-wide.

This effort involved collecting data on vehicle registrations and technical characteristics at the make/model/configuration level of detail for each country, and aggregating this data to derive average estimates of key variables. The major part of the effort was in developing the database, particularly for fuel economy. Further research, such as multivariate analysis, should be possible with this database.

The primary goal of the analysis has been to estimate the global average fuel consumption of new LDVs and a range of national and regional averages for 2005 and 2008 in order to:

- create a base year estimate for use by the Global Fuel Economy Initiative (GFEI), and help establish global average fuel economy estimates that others may find useful;
- analyse how fuel economy and other vehicle characteristics compare across a range of countries and regions; and,
- obtain an initial sense of how fuel economy and other vehicle characteristics have recently changed in different countries, by comparing the 2008 and 2005 results.

This report provides interesting and useful findings, but some caveats are in order. All estimates are based on unofficial data on vehicle registrations, acquired from Polk and other data sources. The database includes various technical characteristics of new vehicles, at the make/model/configuration level. Not all variables are included for each country, though in most cases our database includes more than two thirds coverage of vehicle registrations, with a similar share for most variables, including fuel economy. Using a very large, stratified random sample (across vehicle market segments), the resulting averages are statistically robust. Since the study focuses on 21 countries, it does not include all vehicle markets in the world, but it does include countries that together represented 85% of total worldwide vehicle registrations in 2005. Thus while the results of this study are not official they should be reasonably representative at a global and national level.

The overall findings of the analysis are as follows:

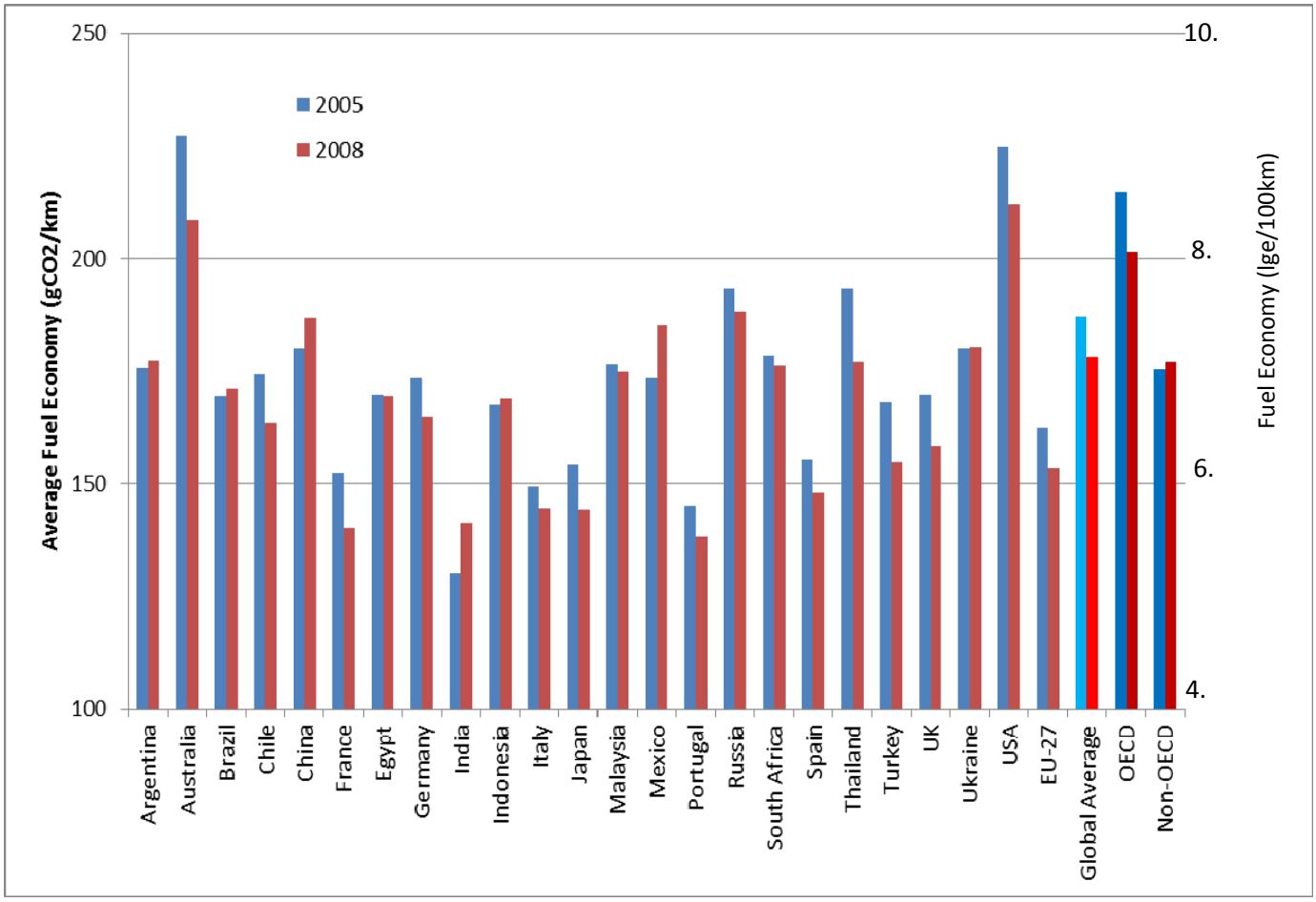
- the rated fuel economy of the average 2005 car sample across 21 countries is estimated to be just over 8 litres gasoline-equivalent per 100 kilometres (Lge/100km), and improves to 7.65 in 2008.
- as shown in Table ES1, this represents a 1.6% annual improvement over the 2005 to 2008 period. This is well below the required average annual improvement rate to reach the 2030 GFEI objective of a 50% reduction (to 4 L/100km), which calls for a 2.7% improvement per year from 2005 to 2030.

Table ES1: Fuel economy status worldwide and long-term GFEI objective comparison

		2005	2008	2030	Average Annual Percentage Change
Fuel Economy (Lge/100km)	Estimated Global Average	8.07	7.67		2005 to 2008 (actual): -1.7%
	GFEI Base and Objective	8.07		4.03	2005 to 2030 (required): -2.7%

National level average fuel economy shows a wide range of value and improvement rates; in some countries – particularly the non-OECD -- the average rate of fuel consumption increased, as shown in Figure ES1.

Figure ES1: Fuel economy estimates by country and year



Sampled non-OECD countries have a significantly lower average fuel consumption than sampled OECD countries, but their average has increased between 2005 and 2008. The global improvement appears to be mainly due to progress made in OECD countries, where average fuel consumption rates decreased by 1.5% per year between 2005 and 2008; the global average also benefited from much larger increases in sales in non-OECD countries, tilting the average towards the lower non-OECD average fuel consumption.

Better technologies, fuel type shares and vehicle size shifts are the main drivers of fuel economy improvement around the world, where each country has its specific policies, economic conditions and habits regarding automobile purchases. A deeper analysis of the contribution of each of these factors to vehicle purchase decisions (and manufacturer production decisions) is needed; we take some initial steps in this report.

Overall our findings suggest that the GFEI objective is ambitious, and faster rates of improvement will be needed over the next 20 years in order to meet the 2030 target.

Introduction

This report presents IEA analysis (and IEA-funded analysis) on LDV fuel economy characteristics for a range of countries around the world. The report provides indicative results using a sampling approach; thus the results here should be seen as indicators of approximate levels and trends. Some additional work will be needed to further verify various estimates, in order to be able to use these estimates in an authoritative manner (e.g. official data for national benchmarking purposes).

The analysis uses a range of sources, but especially draws upon data from Polk Inc. (purchased by the IEA) that includes number of registrations and vehicle characteristics for various vehicle types at the make/model/configuration level of detail (with the specific variables and percentage of registration coverage different across the 21 countries in the study). This data was augmented with other data (such as, fuel economy estimates) to create a final database, which was then used to estimate vehicle sales and various characteristics by vehicle size/market class for each of the countries in the study, and across all the countries[1]. The IEA analysis includes LDVs for the countries detailed in Table 1.

Table 1: New registrations covered by fuel economy information by country, 2005 and 2008

	Analysis performed			
Country	Total new registrations (millions)		Fuel economy (% data covered)	
	2005	2008	2005	2008
Argentina	0.3	0.5	82%	79%
Australia	1.0	1.0	57%	71%
Brazil	1.4	2.2	71%	81%
Chile	0.1	0.1	66%	77%
China	3.7	6.2	74%	79%
Egypt	0.1	0.2	67%	71%
France	2.1	2.1	73%	77%
Germany	3.3	3.1	65%	68%
India	1.2	1.5	71%	89%
Indonesia	0.1	0.1	63%	85%
Italy	2.3	2.2	65%	71%
Japan	4.7	4.2	97%	92%
Malaysia	0.4	0.5	74%	79%
Mexico	0.7	0.6	69%	78%
Russia	1.4	2.9	68%	76%
South Africa	0.4	0.3	67%	84%
Thailand	0.2	0.2	75%	84%
Turkey	0.4	0.3	81%	80%
Ukraine	0.3	0.6	59%	72%
United Kingdom	2.4	2.1	67%	71%
USA	16.6	13.2	65%	76%
Total	**43.0**	**44.1**	**71%**	**78%**
Worldwide production	50	55.5	61%	62%
Registration Coverage	**86%**	**79%**		

[1] A more detailed analysis of five countries (US, China, India, France and Germany) was developed by ICF international, under contract to the IEA, for a subset of countries; this paper will be made available separately.

In both cases, a detailed database of vehicle registrations for the year 2005 and 2008 was obtained from Polk Inc. Additional information was added to this data base, notably fuel economy (litres per 100 km as well as its direct correlate, CO_2 emissions per km) and empty weight (for year 2008 and partially for 2005). Given the very large number of vehicle models and sub-model specifications (such as, engine size, transmission type and other factors) that result in sub-models with varying fuel economy estimates, it was not possible within the resources available for this study to record the needed data for the entire database. The approach used was to focus on larger selling models and sub-model configurations, to reach at least 60% of total sales in each country (and up to 95% in some cases). In addition, the sample for each country was stratified by vehicle size (market) class, with 50% of sales reached in each class, to ensure a representative distribution of vehicle types was included in our analysis.

With this approach, there is some indication that in some cases, the resulting average fuel economy estimates are up to 10% different than reported averages where available, though most are within a few percent of reported averages. Thus the estimates reported here must be viewed as indicative and are not meant to imply official estimates. More work is needed to achieve a dataset that can be considered a strong basis for comparing fuel economy across countries and tracking country progress in the future. However, the findings and the supporting analysis provide a range of insights into how countries are similar and different in regards to the types of vehicles purchased, their characteristics and the potential for fuel economy improvements.

It is important to note that the Polk Data is divided into Passenger Cars and Light Commercial Vehicles (LCVs); in most cases, this corresponds to the split of passenger versus commercial (M1 vs. N1) vehicles. . However, for the United States and Australia, LCV models that appear to have large passenger car market share have also been included. These include large sport-utility vehicles (SUVs) and some pick-up truck models. Though not possible at this time, for future versions of the database, an effort will be made to include all light commercial vehicles for all countries, and report averages with and without LCVs.

Fuel economy figures have been reported in the corresponding national test procedure, where available, meaning some countries are not directly comparable with others. This report highlights the evolution of each country, and global averages should be taken as an indication of the average global fuel economy from new vehicles, as tested in the respective country of registration.

Vehicle characteristics of interest

There are a number of aspects that contribute to vehicle fuel economy, and vehicles in different countries can vary, on average, in terms of fuel economy levels and related characteristics. These differences include average vehicle size, weight and engine power, and a range of specific technologies that affect these characteristics and fuel use directly. Consumer behaviour also plays a key role, as this determines which types of vehicles are purchased from among those available. In making buying choices, some of the most important vehicle attributes include (as described in Meyer, 2006):

- Vehicle price, fuel price and fiscality
- Fuel type (fiscality and emission related)
- Parking space availability
- Design, style
- Safety
- Interior space, design
- Cargo volume
- Power, power to weight ratio
- Reliability
- Brand’s image

Energy use and CO_2 emissions are concerns of growing importance in many countries, as oil price volatility favours caution from the potential car buyer. Fuel economy and/or CO_2 emission labelling is now in use in most OECD

countries (although with a wide range of scales and units and little harmonisation in approaches across countries), and several countries now base their vehicle tax systems taking into account CO_2 emissions or fuel economy.

Technical parameters that affect fuel economy and CO_2 emissions at the vehicle level are also numerous; technical characteristics affecting fuel economy that are analysed in this paper include:

- Powertrain characteristics:
  - Engine displacement
  - Transmission type
  - Fuel type
  - Engine aspiration type
  - Engine Power (e.g. kW)
- Vehicle size
- Vehicle weight

Other factors that have an impact on fuel economy such as aerodynamics, Heating, Ventilation and Air-Conditioning (HVAC) systems, tires or lighting are not included in this analysis.

As described below, our database for 2008 has good coverage for technical details for most vehicles in most countries; this is less true for 2005, in particular, with very little information on engine types and characteristics for that year.

Data and methodology

The principal aim of this report is to estimate the vehicle and fuel economy characteristics for recently (2005 and 2008) registered vehicles in countries with available data. The database constructed reflects this purpose but also includes a range of other variables that may help explain fuel economy differences. It also includes additional years of data for some variables, so in some cases the evolution of characteristics over the past 15 years is presented, though this has not been possible to do for fuel economy. The analysis of fuel economy starts for vehicles registered in 2005. This is considered the base year for the GFEI.

The data includes new vehicle registrations by make (manufacturer), model and sub model configuration (engine type, fuel type, transmission type, etc). It contains other technical information for each vehicle record, and the total number of registrations for each. The IEA has augmented the database with fuel economy test data for 2005 and 2008 as well as with data on "empty weight" for 2008, using the data sources detailed below and in Annex I. Finally, the IEA allocated all vehicles to a size (segment) category based on the classification system described below. The data base does not have all variables covered for all records; for the main vehicles characteristics, the data coverage is listed in Table 2, by region, for 2008.

Table 2: data coverage for main technical characteristics, 2008

	Non-OECD	OECD	Global
Weight	50%	57%	55%
Engine displacement	73%	100%	90%
Power	58%	100%	84%
Vehicle size (segment)	100%	100%	100%
Traction (2/4 wheel drive)	74%	100%	91%
Transmission type	62%	99%	85%

Starting with the raw data, the first task consisted of splitting vehicle sizes into classes, in order to take averages and compare vehicle market segments. Comparing fuel economy by segment helps to reduce the effect of variations in vehicle size and weight and to understand how other factors may influence fuel economy, such as the presence of efficiency technologies.

Table 3 shows the segments available in the data base and some typical vehicles that characterise the respective segments. Segments are then further aggregated for an even simpler view of the market.

Table 3: Segmentation of the available car type and size on the market

Typical vehicle	IEA segment	Simplified segmentation
Smart fortwo Fiat 500	A	Small
Opel Corsa Renault Clio	B	
Toyota Corolla VW Golf	C	Medium
Honda Accord Mercedes C Class	D	Large
BMW 7 series Ford Fusion (US model)	E	
Porsche Carrera Bentley Arnage	F	
Wuling Zhiguang Maruti / Suzuki Wagon R	Micro truck	Small
Renault Kangoo Renault Modus	Compact truck	Medium
Toyota Rav4 Suzuki Gran Vitara	Medium Truck	
Audi Q7 Chevrolet Silverado	Large Truck	Large

In the database, light trucks are further disaggregated into vans (multi-purpose vehicles or MPVs), sport utility vehicles (SUVs) and pick-ups for each micro / compact / medium / large size category.

BOX: Definitions and elements of language

Lge
Litres in gasoline equivalent terms; this energy unit is used for different fuels such as gasoline and diesel on an energy-equivalent basis. Unless otherwise specified, all fuel economy figures are expressed in Lge/100km.

Fuel economy versus Fuel efficiency versus Fuel intensity versus Fuel consumption versus Technical efficiency
Throughout this report, fuel economy is expressed in Lge/100km and in some places as gCO_2/km; improving fuel economy means that Lge/100km and gCO_2/km go down; the fuel efficiency is better; and fuel intensity is lower. "Fuel consumption" can also be used to mean fuel economy in Lge/100km. We use all these terms but try to mainly use "fuel economy." In contrast, "technical efficiency" can use different units, such as energy per unit tonne-km. A larger, heavier vehicle would be more technically efficient than a smaller lighter one if it uses using less fuel per tonne-km of travel. Thus it would be less fuel-efficient but more technically efficient on that basis.

Tested Fuel Economy
Fuel consumption per km on a given tested driving cycle; there are different test cycles according to the country. Only the US and Japan have separate test cycles in the set of countries for which data have been analyzed – all others report fuel economy using the European NEDC test cycle (or 3rd party reporting is in those units). Real-world fuel economy can vary considerably from tested measures. Though it has not been used in this analysis, a test cycle converter is available on the ICCT website (http://www.theicct.org/passenger-vehicles/global-pv-standards-update/ see link to converter, accessed 29 August 2011).

Market Segment, or market class
A market segment is a category of vehicle, which can be based on vehicle size or other attributes. See Table 3 for more on vehicle market segmentation as defined by the IEA.

Developing fuel economy data

Since the Polk database did not include information on fuel economy for most countries, it was necessary to add this variable. To fill fuel economy data, IEA proceeded by obtaining a range of sources containing official tested fuel economy for vehicle models sold in 2005 and 2008 and present in the database. Given literally thousands of different vehicles (on the make/model/configuration level) in the database with different fuel economy ratings, it was not possible to track down and assign fuel economy data for every record in the data base. The strategy was to fill in data for the highest selling models first, filling all engine alternatives, then work down to less popular models. Fuel economy data was obtained from various sources, most of them official from governments, ministries or agencies:

- The "Catalogue de la Revue Automobile" edited by the Swiss magazine "La revue automobile" which gathers information on most of the vehicles sold worldwide. Fuel economy data is often provided, together with the test cycle associated EU, EPA or other.
- www.vcarfueldata.org.uk website gathering all European vehicle data back to 2001, and their official value on the test cycle. Variants are not always easy to distinguish in this website, as power output is not always displayed.
- The guide "Consommations conventionnelles de carburant et emissions de gaz carbonique" edited by ADEME on a yearly basis. It contains the official vehicle information with good detail, especially for French vehicles.
- www.fueleconomy.gov website from the US Department of Energy covering most cars sold in the US since the mid 1990s. Some caveats have been found and vehicle identification is often difficult as power output is not displayed.
- The Chinese Car catalogue, edited by the China Motor Vehicle Documentation Centre, gathers information on nearly all vehicles sold in China, with technical specifications and production volumes. Fuel consumption is often stated, but with no source for the value. Another website from the Ministry of Industry (MIIT) details each vehicle's official fuel economy, and has been used in most cases.
- The Japanese MLIT website dedicated to fuel consumption of new vehicles.
- Other national websites for specific markets, such as Australia and Mexico.

The complete list of sources can be found in Annex I.

In each country, the vehicle market segment sales distribution has been used to stratify the sample; each segment has minimum fuel economy data sampling coverage of 50% to minimise biases in the sample. Then, the full sales-weighted average across all vehicle registration records has been used to calculate the national average for each variable. In order to increase the total registrations covered for fuel economy, the EU-27 countries have been added (after post treating the data available in the European Union in 2009), even though fewer technical characteristics are available. After adding the EU-27 countries, total registrations for year 2005 and 2008 sums up to 44 and 46 million respectively, which is 94% and 88 % of the vehicles produced that year, as published by OICA (2010).

In addition to adding fuel economy data, other steps were taken to clean and improve the data set. These included removing clearly erroneous data points, eliminating a few records that appeared to be duplicates or otherwise in error and checking on the values of a range of variables (vehicle attributes), where alternative sources were available.

Results: Vehicle registrations by size and market segment

Vehicle size is a key factor influencing fuel economy and is closely linked to vehicle weight, and therefore the (required) engine cylinder capacity and power rating. The distribution of vehicle size across new vehicle registrations varies dramatically across different countries and is fairly correlated to income levels and market maturity. Culture also plays an important role in the vehicle size choice.

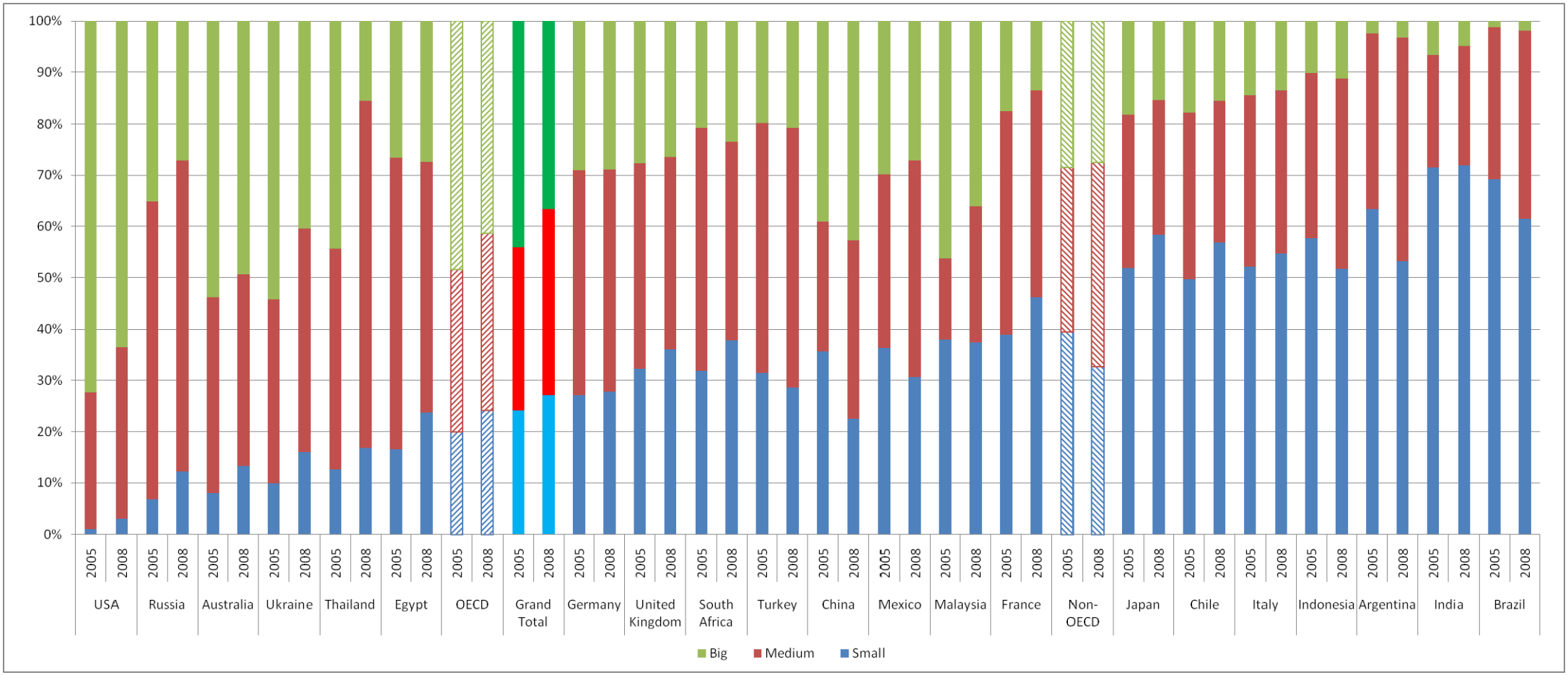
Based on the countries analysed, small vehicles (when combining A, B, micro and compact trucks segments) are very popular in Asian countries, accounting for between 30% and 70% of new registrations in 2008 (Figure 1). The United States is at the opposite extreme, with less than 5% market share of small vehicles. European countries have a more even distribution of all vehicle sizes; this could reflect the increasingly common practice in Europe to have two cars per household, a larger one for long family trips, and a smaller one for short distance trips and commuting. Many developing countries (*e.g.* Egypt, Thailand and Turkey) appear to favour mid-size vehicles, perhaps as the first car of the household, to fit all needs.

Although in many countries vehicles became larger between 2005 and 2008, across all vehicles in the study (weighted average of sales across the 21 countries), the average size of vehicles decreased, or at least the market share of large vehicles decreased while that for small vehicles increased. This is somewhat surprising and deserves more study and on-going tracking in the future. Looking at averages for OECD and non-OECD, one can see them moving in opposite directions; in the OECD small cars gained about 5% market share at the expense of large vehicles; in non-OECD medium sized cars took about 7% market share away from small cars.

However, some non-OECD countries (such as Thailand and Ukraine) showed a significant decline in the market share of large vehicles in this time frame. There could be different reasons at work, including: a) a trend toward more eco-friendly vehicles; b) a reaction to the economic recession that began in some countries in 2008; and c) a strong increase in vehicle purchases by the middle class, resulting in a surge in medium and small car sales, with large car sales to wealthy already well established and growing far less. A multivariate analysis of such factors in different countries could be revealing, but is beyond the scope of this study.

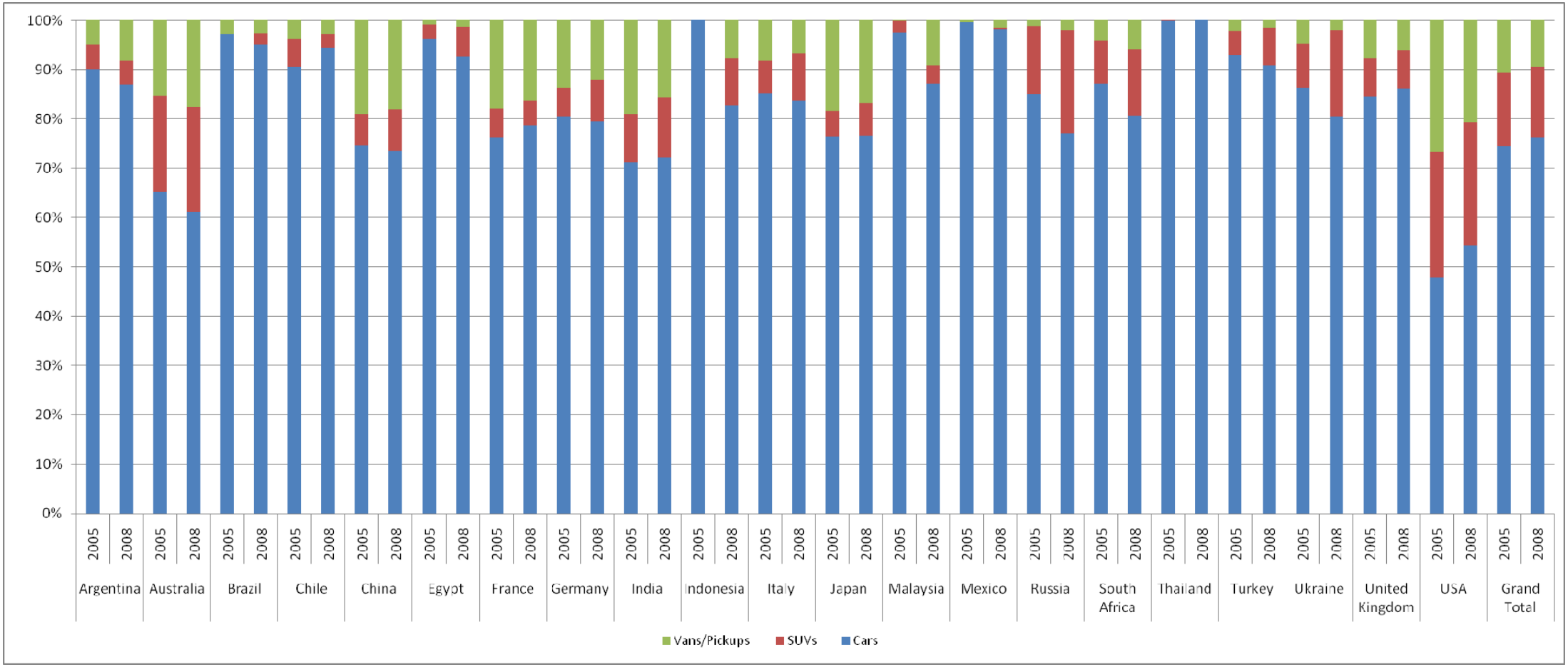
Breaking out the categories somewhat differently, with all cars separated from SUVs and from minivans/pickup trucks (Figure 2), one can see that the US has far more in the latter two categories (collectively termed “light trucks”) than any other country, with approximately 50% of sales in 2005, though dropping to approximately 45% in 2008. Among other countries, the highest share of light trucks was in India and China, though in both cases below 30%. The situation in the US and Australia has to be considered separately as LCVs are included in the analysis, which is not the case of other countries. On the other hand, LCVs comprise a larger share of sales in the US and Japan than in most other markets.

Figure 1 : Market segmentation, 2005 and 2008 new vehicle registrations, simplified segmentation



Note: countries and regions sorted by 2005 small car share, from low to high.

Figure 2: Market share of cars, SUVs and vans/pickups, 2005 and 2008



Vehicle weight

Vehicle weight is highly correlated with vehicle size and market segment. For a given market segment, the average weight of the vehicle is a function of a number of factors. Higher weight can be an indicator of vehicle refinement, comfort, and safety; on the other hand, lower weight can reflect the use of advanced materials to improve fuel economy. As seen in Figure 3, countries have major differences in average weight across the three simplified vehicle size classes.

Since lower weight is correlated with better fuel efficiency, countries with vehicles of low average weight are likely to also have more fuel efficient vehicles. (Other technologies are also important, as discussed below).

Thus while there is not sufficient information to understand why different countries have vehicles of different average weight within a size class, at least certain tendencies emerge. The United States has slightly heavier than average vehicles in each size class; Malaysia and Brazil have somewhat lighter than average vehicles. But for most countries there are mixed results, and it is difficult to draw any clear conclusions about how weight varies by vehicle class from country to country. Though not shown, the differences in weight for medium and large vehicles come, in part, from the composition of these classes – namely the share of vans/SUVs/pick-ups in the respective countries.

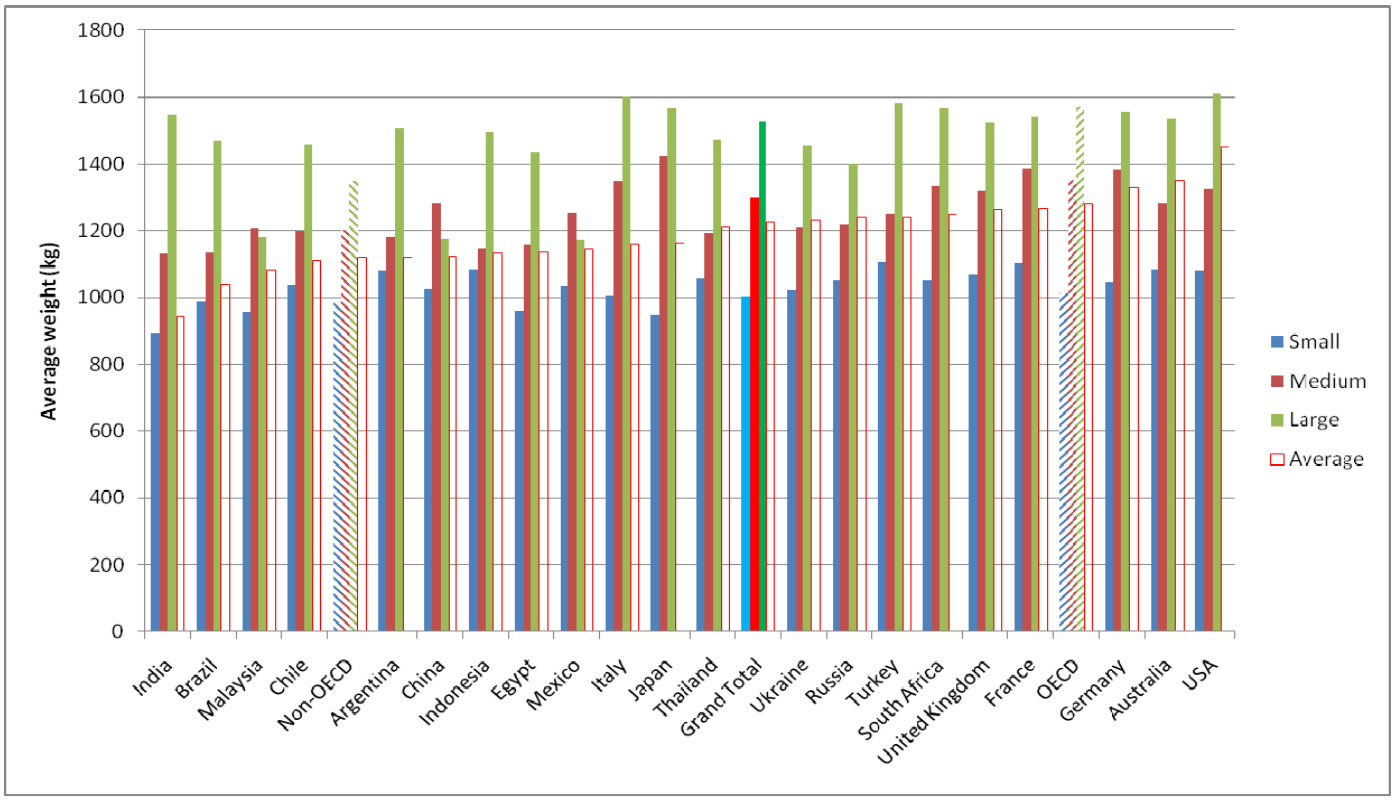


Figure 3: Average weight by simplified segment, 2008 new registered vehicles

Note: countries and regions sorted by average weight.

Powertrain specifications comparison

The powertrain (*i.e.* engine and drive train system) is crucial to determining vehicle fuel economy, and continuous technical improvements over recent decades have served to dramatically increase power output while maintaining or reducing fuel consumption along with strong reductions in harmful exhaust gas emissions in cars around the world.

This section shows the present status of various vehicle attribute specifications in selected countries, and highlights last decade's evolution of these attributes for a range of countries.

Engine displacement

Engine displacement is a key indicator of fuel economy, as displacement is a direct proxy of the air quantity sucked inside the engine, and therefore of the fuel quantity needed in order to keep the air/fuel mix close to optimal operation points (in a gasoline engine). As shown in Figure 4, in 2008 there was a wide range of different market share levels for different engine size categories. For example, in Indonesia nearly 90% of engines are below 1 600 cc (1.6 L). In Japan, due mainly to the popularity of its very small "kei car" category with engines of 660 cc or less, about one-third of new cars had engines below 800 cc. At the other extreme, in the United States over 40% of engines were larger than 3200 cc. In all but the United States and Australia, engines under 2 000 cc accounted for more than 80% of sales.

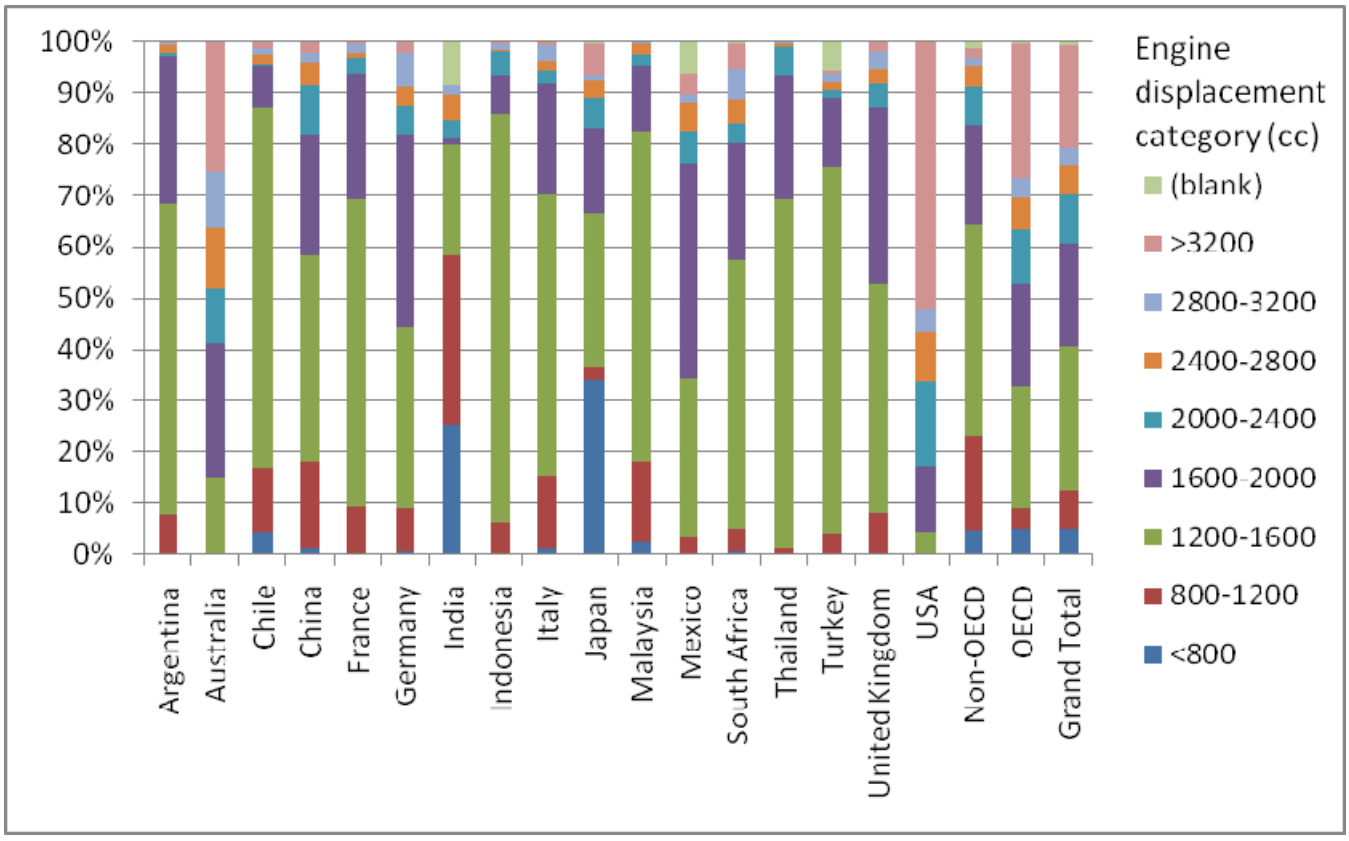


Figure 4: Vehicle sales share by engine displacement category (in cubic centimetres) and by country, 2008

For 2008, nearly all of the countries had a majority of new passenger LDV sales under 1.6 L of displacement. The main exceptions were:

- The US and to a certain extent Australia: in the US, more than 80% of the vehicles registered in 2008 had a displacement above 2 000 cc, and aproximately 50% were above 2 800 cc; in Australia these shares drop to about 40% and 20% respectively.
- Japan: Kei-cars have a great influence on new registrations, as more than one-third of the new vehicles registered in Japan in what year were under 800 cc.

For earlier years, adequate data is not available, and only a few countries have good coverage of engine displacement data, as shown in Figure 5.

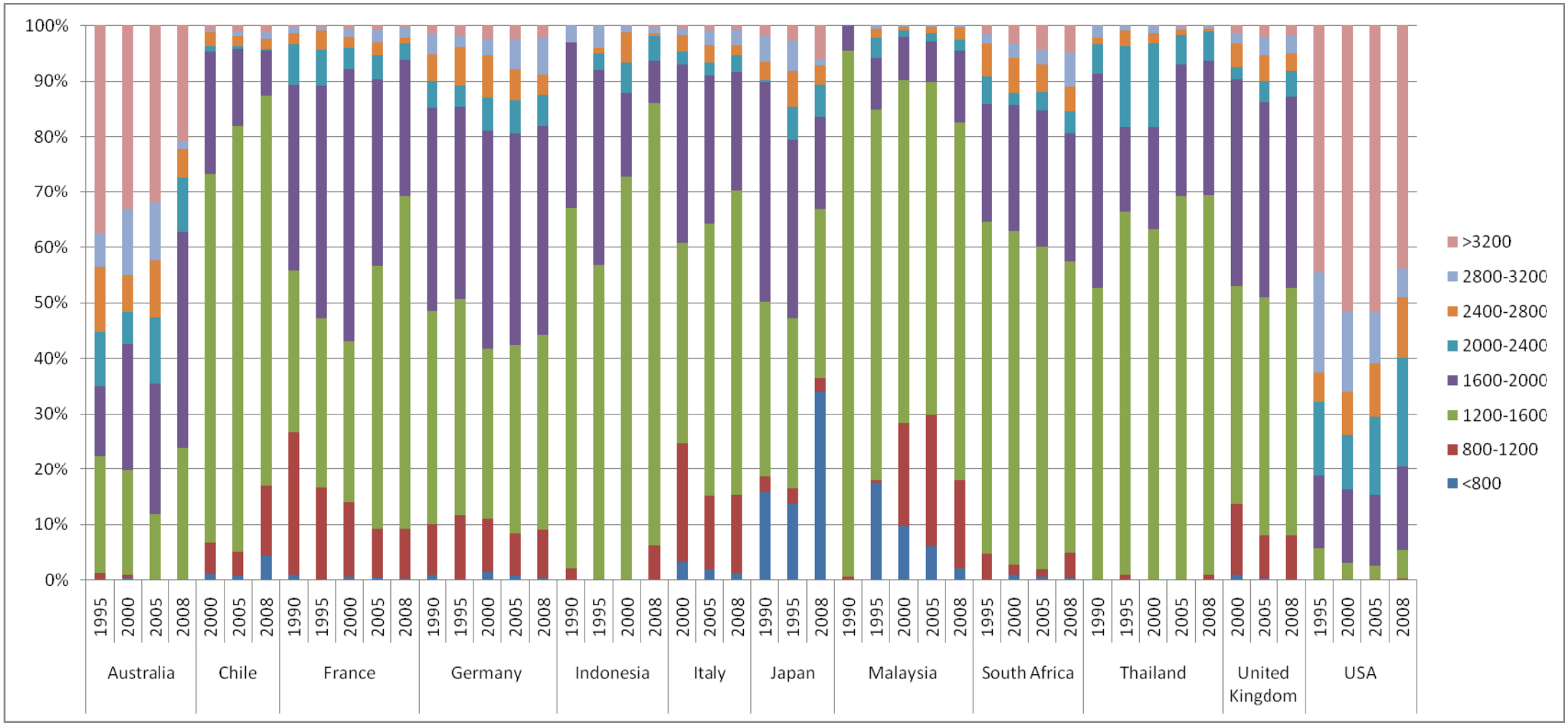


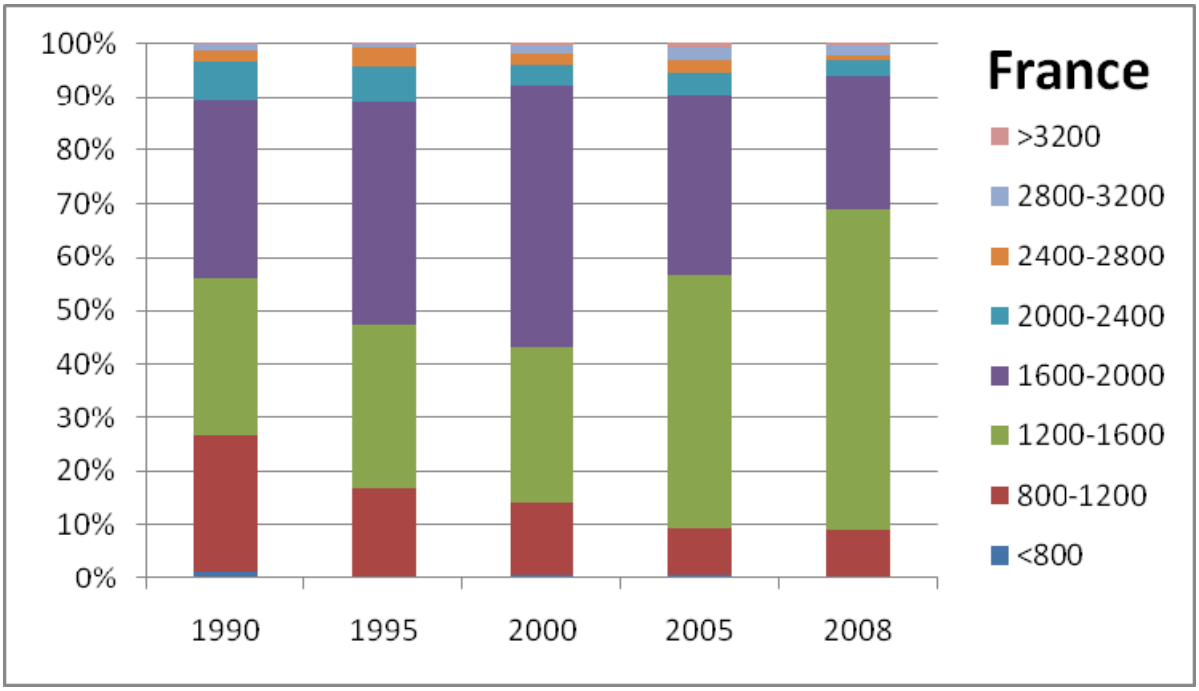
Figure 5: Vehicle sales share by engine displacement category and by country, 1990 to 2008

Figure 5 shows a clear trend towards engine downsizing between 2005 and 2008 in the covered countries. This appears to be a slight trend in EU countries, stronger in developing countries and very strong in Australia and the US, two countries where engines are the largest among the countries analysed. Only in Malaysia has engine size increased between 2005 and 2008, though from a lower starting point.

Longer term evolution of engine size; selected case studies

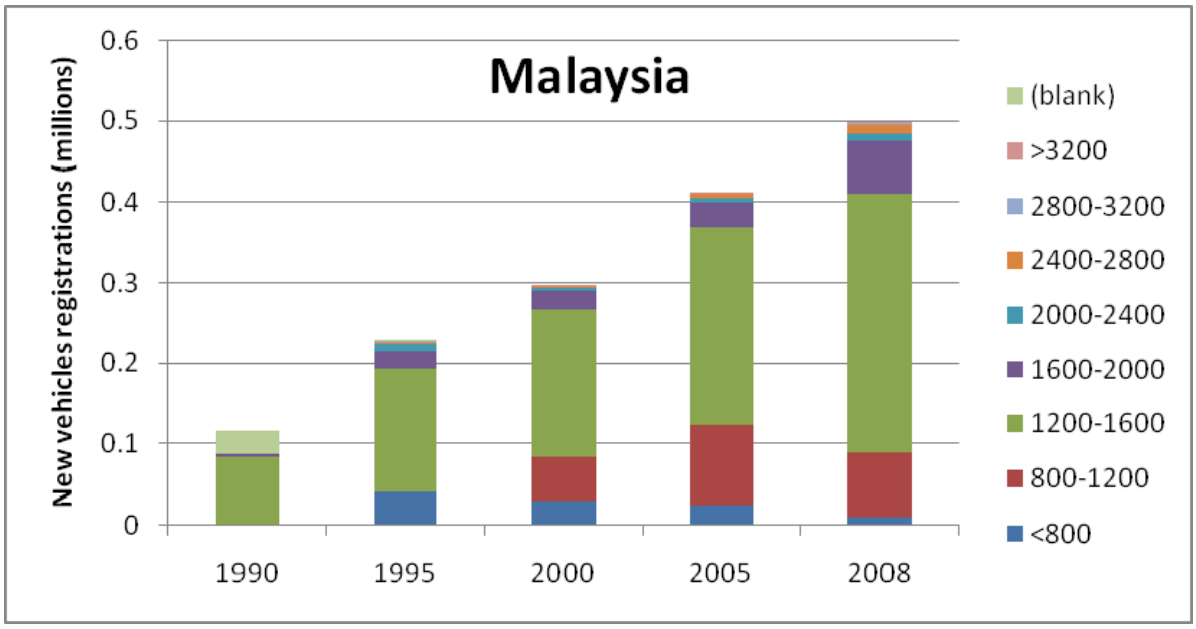
Given the availability of more years of data for engine size in some countries, it was possible to do some longer term tracking of this variable. The evolution of France's engine size distribution during the last two decades is shown in Figure 6. This shows a trend toward larger engines in the 1990s, which reversed direction starting in the early 2000s: the pre-2000 evolution can partly be explained by factors such as trends in fuel type toward dieselisation, which typically requires larger displacement than gasoline engines. Though this diesel trend continued after 2000, the effect on engine sizes stabilised, and a broader engine downsizing effect began to dominate. The introduction of the "Bonus-Malus" vehicle tax system for cars (with taxes based on rated CO_2 emissions) at the beginning of 2008 further increased the buyer's interest in small engines. It is also interesting to note that engines smaller than 1 200cc have continued to see reductions in market share after 2000, reflecting declining sales share of very small cars, and increased engine sizes in this segment.

Figure 6: France's engine displacement distribution (cc), 1990-2008



In Malaysia, where new registrations jumped from 0.1 million vehicles in 1990 to 0.5 million in 2008, there is a slight trend towards larger engines, as shown in Figure 7. It is somewhat difficult to analyse market segment changes when sales levels are changing so fast, but it is clear that most growth has occurred in the 1 200-1 600 cc range of cars, with some growth in the engine sizes just above and below; there is almost no market share for other engine sizes. It is likely that in 1990, a substantial share of registrations were for taxis (usually very uniform in specifications), with a larger range of purchaser types over time helping to explain the emergence of other engine size classes.

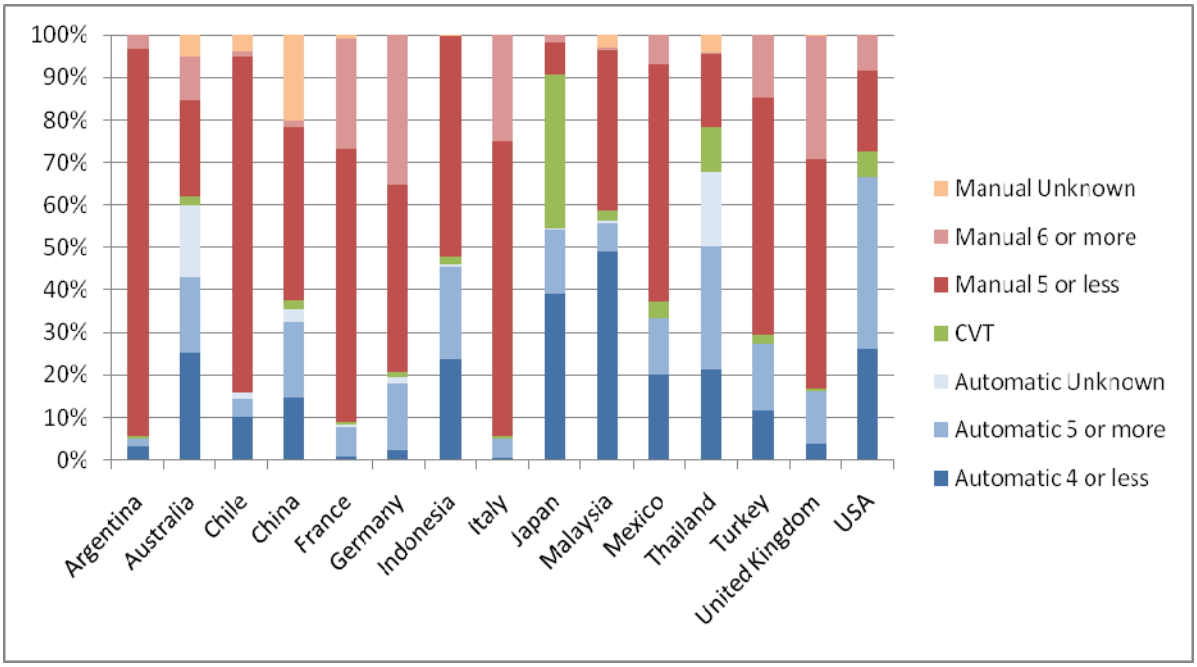
Figure 7: Malaysia's engine displacement new registration split, 1990-2008



Transmission type

The transmission delivers the engine mechanical energy to the wheels, by adapting engine and wheels revolution speeds. Different transmission types have different efficiency characteristics; manual transmissions tend to be more efficient than automatic. Within manual, more gears tend to improve efficiency, if used correctly by the driver. There are great differences in transmission type shares in the countries studied, as highlighted in Figure 8; the data split the transmission type into manual and automatic; two categories for the number of gears is also available, and continuously variable transmission (CVT) are included – a very efficient technology with a continuous (and effectively infinite) number of speed ratios.

Figure 8 : Transmission type market shares, 2008



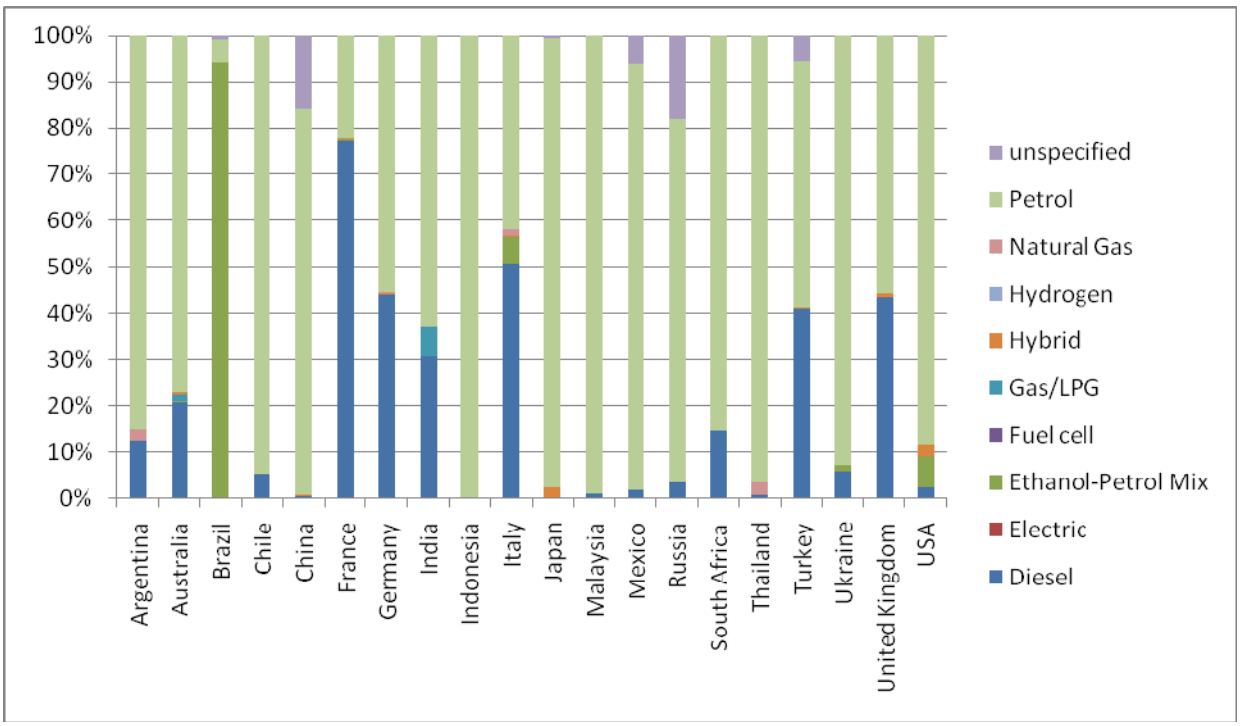
Europe and Latin America tend to have widely adopted manual transmissions, whereas Asia and North America tend to have high shares of automatic transmission. Only Japan has reached significant CVT market share, especially in the small kei cars and for hybridised vehicles. Continuously variable transmission deployment is still restricted by torque limitations, even though technology progress seems to allow for CVT to be coupled with larger engines.

Fuel type

Fuel type can influence (or be correlated with) fuel efficiency. In particular, diesel vehicles are typically 20% to 30% more efficient than similar gasoline vehicles. Different fuels also have different carbon content. Thus tracking fuel shares is relevant to fuel economy and CO_2 reductions.

The two extremes shown in Figure 9, Brazil and France, are showing different ways to reduce fossil fuel consumption from the typical gasoline engine. More than 90% of the vehicles sold in Brazil in 2008 can operate on both gasoline and a mixture of up to 85% ethanol in the fuel mix. The sudden rise of flex-fuel vehicles in Brazil, from about 0% in 2000 to dominance by 2008, shows how fast new technologies can penetrate the market, at least when the benefits are clear for the user, and when the premium cost is so limited that the feature can be standard in all vehicles, along with fiscal incentives making the premium invisible to car buyers (as was the case in Brazil with a reduced VAT for flex-fuel vehicles). In 2008, France was the European leader in diesel sales, with nearly 80% of the new vehicles. This reflects fuel tax discounts in France but also the diesel efficiency advantage and diesel availability for a wide range of French vehicle models. Similar trends can be seen in Italy, Spain and Germany, as seen in Figure 9.

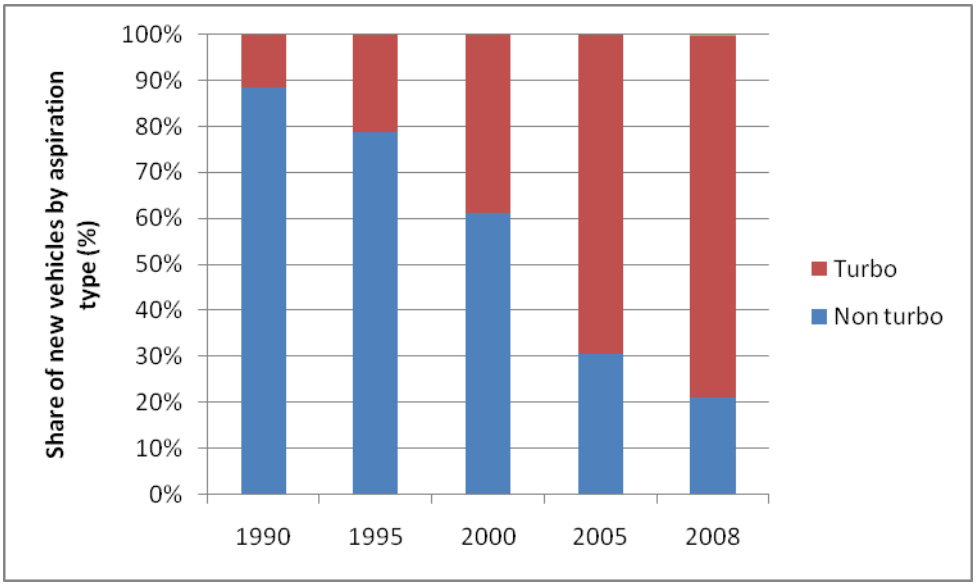
Figure 9: New registrations by fuel type, 2008



Turbocharging

When first adopted in small gasoline engines typically for sports cars, turbochargers provided significant increases in power output of the engines with equal or lower fuel consumption. Turbochargers do this by recovering part of the energy lost in the exhaust gas to compress the inlet charge about to enter the combustion chamber. The power boost it provides also facilitates engine downsizing and improves efficiency. Figure 10 shows the steady diffusion of turbo charged engines in France, which now has the world's highest share in new sales, showing in particular a strong uptake of turbocharged diesel engines, which have become nearly standard among French diesel vehicles since the early 2000s.

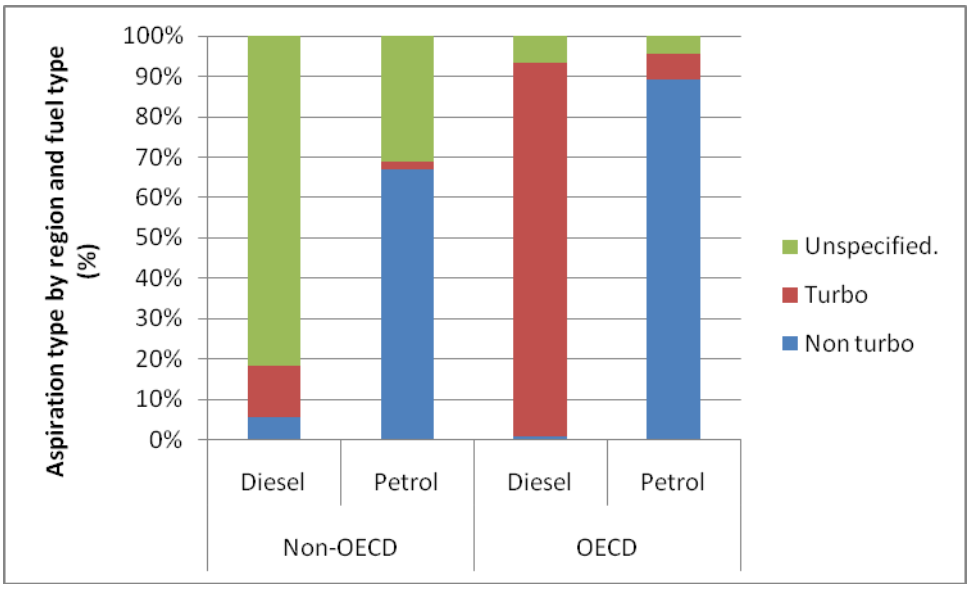
Figure 10: Turbo-chargers penetration in France, 1990-2008



Note: in the data, superchargers and turbochargers and both included in Turbo

Figure 11 shows that diesel engines are now almost always fitted with turbochargers in OECD countries. The benefits of turbocharging and downsizing also apply to gasoline engines, but the price premium that has to be paid for gasoline engines tends to slow down market penetration.

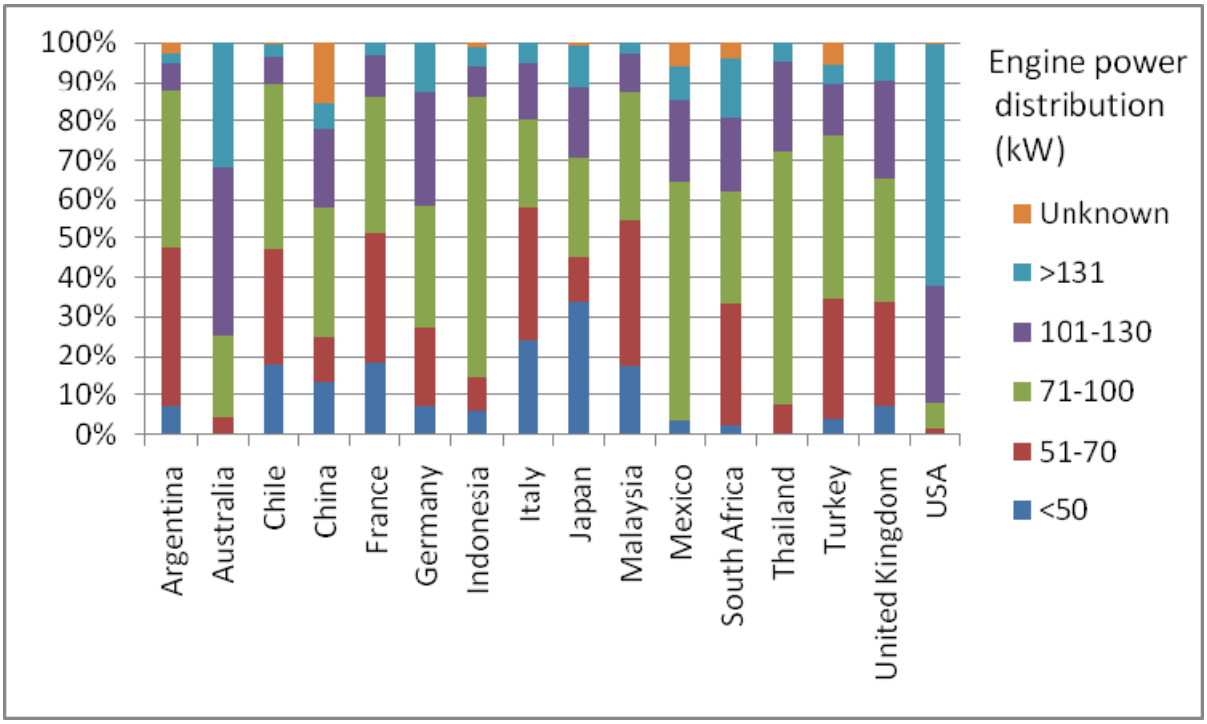
Figure 11 : Turbo-charger penetration by region and engine fuel type, 2008



Engine power

The power of the engine (in kW) directly impacts the capability of a vehicle to accelerate, carry loads and reach top speeds, and so is integral to driving experience. It also influences fuel efficiency. Figure 12 shows that the US has far more powerful vehicles than most other countries in the world, with Australia second. This clearly relates to the average size and weight of vehicles in these countries. Germany and South Africa also had particularly powerful vehicles registered in 2008. Japan, France and Italy, along with Argentina and Malaysia, have relatively less powerful engines.

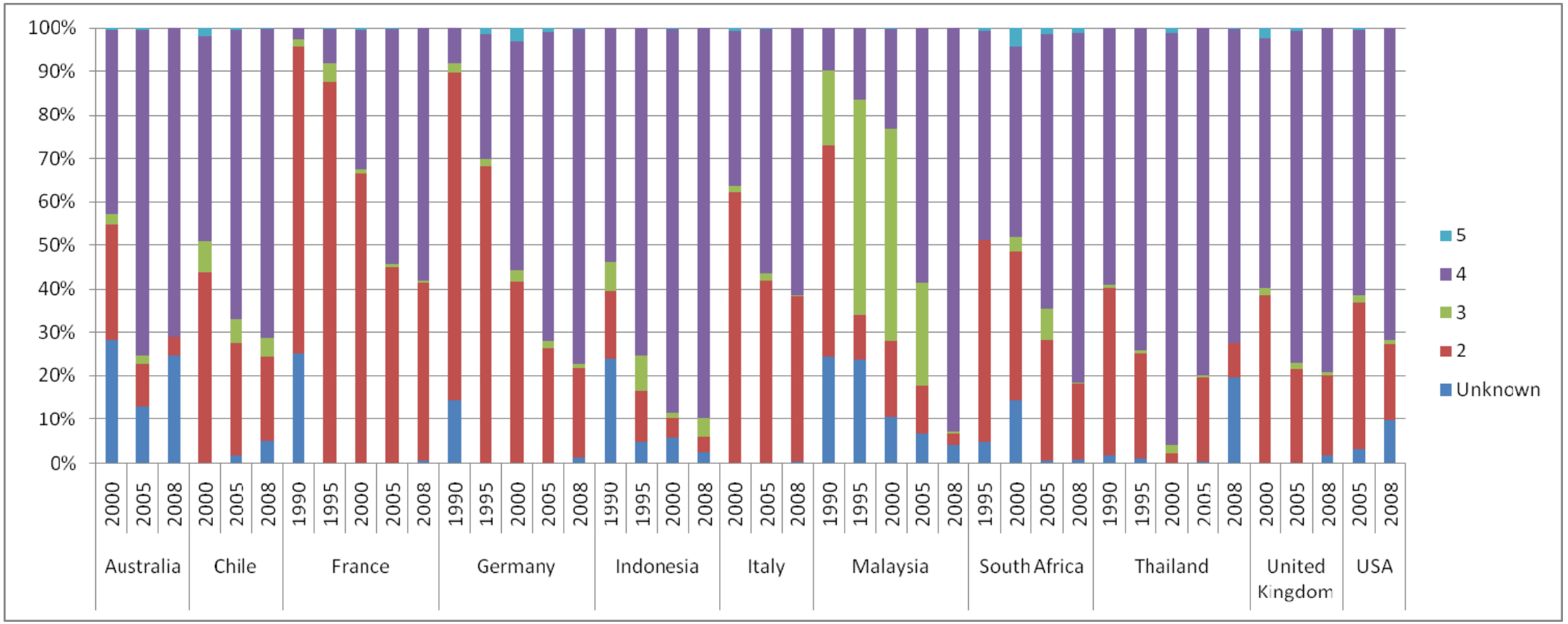
Figure 12: Engine power distribution for selected countries, 2008



Valves per cylinder

In gasoline engines, increasing from two to four valves per cylinder has provided important fuel economy benefits through more uniform fuel/air mixtures in the engine combustion chamber. This is of lesser importance for diesel engines, due to the different combustion process. Nevertheless, modern diesel engines also feature four valves per cylinder, as turbo chargers created the need for more efficient filling of the combustion chamber. Four-valve engines are now widely used in recent model cars across all markets, as seen in Figure 13. Significant increases in market penetration occurred between 2005 and 2008 in a few markets where penetration had been lower.

Figure 13: Valves per cylinder in key markets, 2005 and 2008



Fuel economy

As described in the data and methodology section above, it was necessary to add data on fuel economy into the original database. This was done for a majority of models sold in each country for 2005 and 2008, but remains a sample. As shown above in Table 1, good data coverage has been achieved for the 21 countries analysed. This enabled estimation of country averages and also, weighted by the number of registrations in each country, estimation of an average fuel economy across the 21 countries. Since these countries represented about 80% of global LDV sales in 2008, with a representation of a range of different types of countries and most of the world's major markets, it seems reasonable to assume that the estimates here approximate overall global averages.

Figure 14 shows the average fuel economy and registration numbers for the augmented data base, and encompasses 21 countries and an additional 22 countries included within the EU-27 average. This equates to a total of 43 countries representing approximately 90% of vehicle sales worldwide. In Figure 14, countries are ordered along the x axis according to 2005 fuel consumption, with both 2005 and 2008 fuel consumption shown, along with the number of registrations represented by the size of the circles. The figure shows a wide range of average fuel economy across the different countries, from about 6 L/100km for the least fuel-intensive end of the spectrum (India) to over 9 L/100 km at the most fuel-intensive end (the United States). Converting to CO_2 (taking into account fuel CO_2 content differences between gasoline and diesel), the range is about 130 to 200 g/km.

This range in fuel use and CO_2 per kilometre reflects many factors, such as those discussed above (vehicle size, weight, power and the presence of various efficiency technologies on the vehicle). Thus the reasons for differences in this figure are many, and a country that has vehicles with better average fuel economy does not necessarily mean that the country has more technically efficient vehicles. For example, though in 2005 India had the most fuel efficient vehicles, it also had the smallest average vehicle size of any country except Brazil (as shown above in Figure 1).

Most countries achieved an improvement in new LDV fuel economy between 2005 and 2008, but some saw fuel consumption per km increase. India was one such country, with the result that while it had the lowest fuel intensity in 2005, in 2008 Portugal was the country with the lowest average intensity among countries in this analysis. The results indicate that most countries with fuel economy standards (the United States, European Union and Japan) tended to improve fuel economy, whereas many other countries (mostly in the developing world) saw it worsen. China saw an increase in L/100 km despite having fuel economy standards, mainly because of increases in vehicle size and weight, as shown in Figure 14.

China's situation suggests that the presence of fuel economy standards does not always result in better fuel economy, and highlights the importance of avoiding purchase shifts to larger, more energy intensive vehicles. China's standard is set specifically for each of a range of different weight categories (or "bins"). It does not use a corporate average, but a cap on fuel consumption per kilometre for each individual model; other countries (such as Japan, EU) use similar weight-class approaches but provide a corporate average to be met for each bin; the US now uses a vehicle size-based standard. In countries like the US, with very large average vehicle sizes compared to most other countries, outright reductions in vehicle size (e.g. through consumer purchase shifts) could help achieve long-term targets such as very low CO_2 emissions per vehicle. But much can be achieved via reductions in vehicle weight and adoption of fuel economy technologies in each size class. The use of corporate average standards across all vehicle classes would help prevent a shift towards heavier or larger vehicles, even though there might be exceptions as highlighted in Cuenot (2009).

Figure 14: Average fuel economy and new vehicles registrations, 2005 and 2008

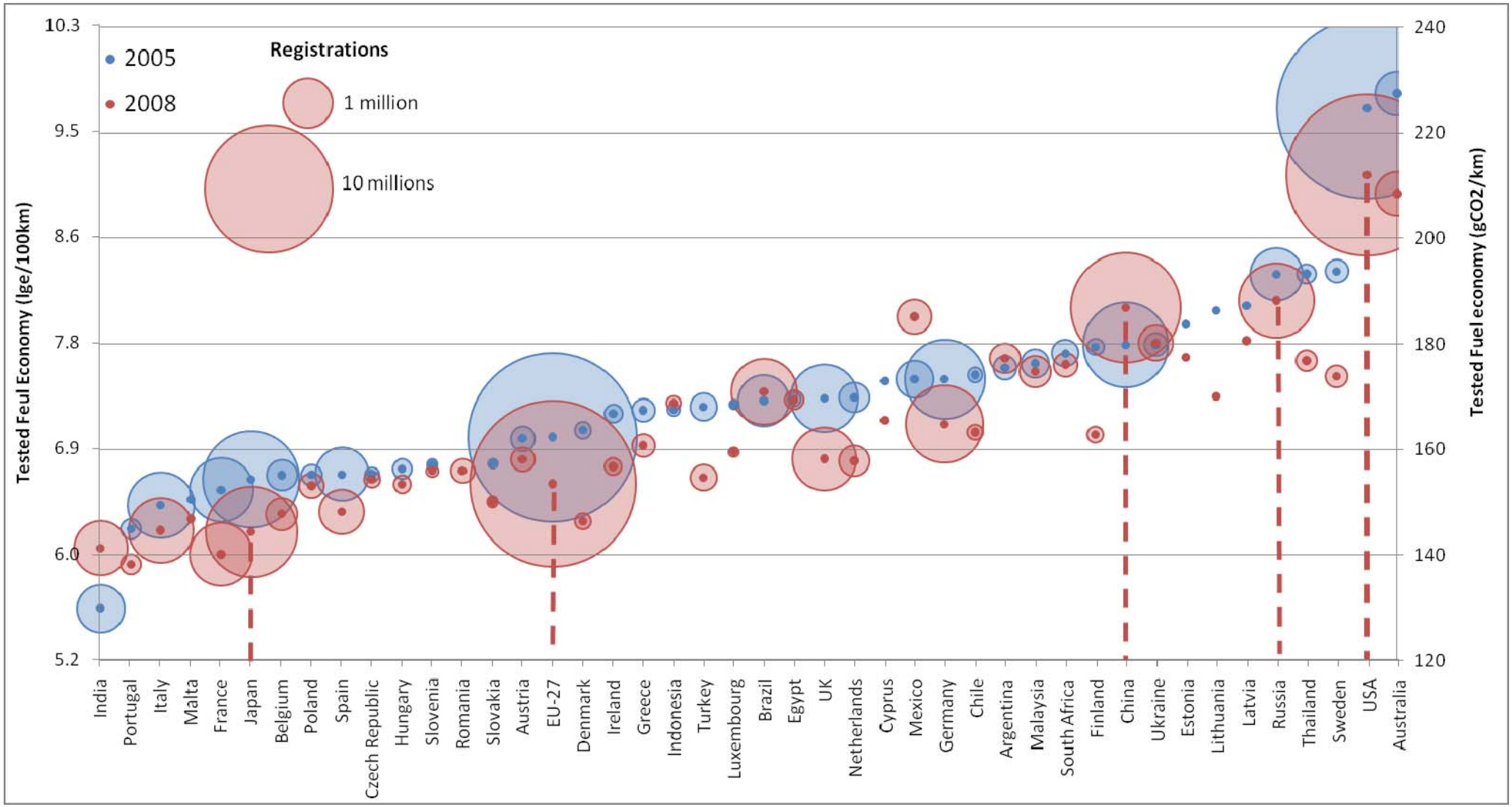
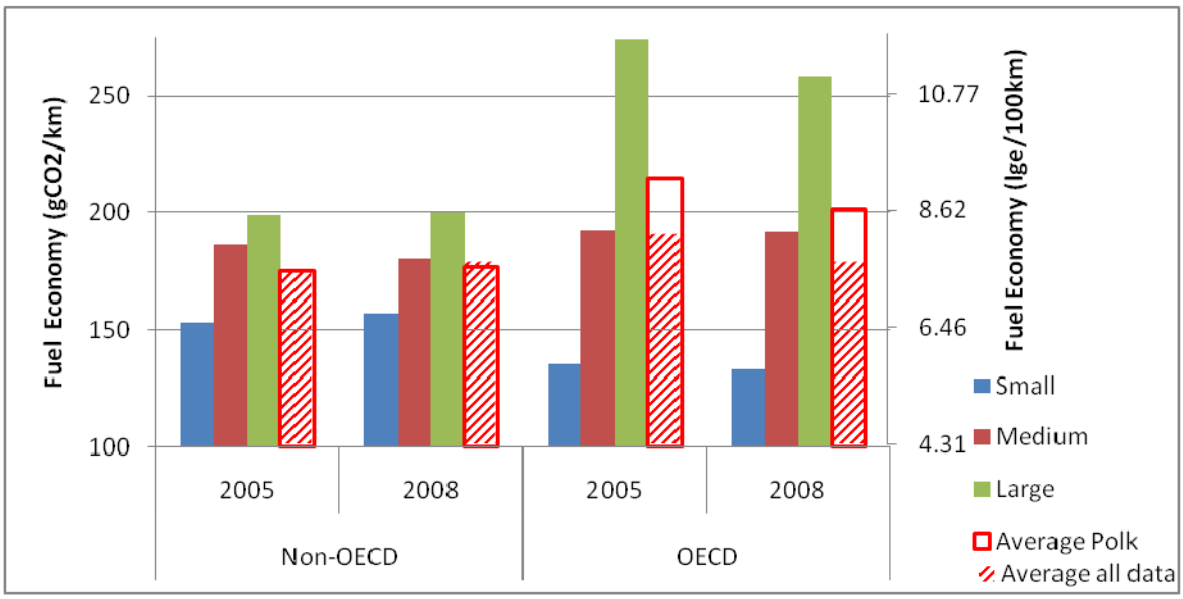


Figure 15 shows OECD and non-OECD average fuel economy broken out by simplified size class. This results in several observations:

- Across the three vehicle size classes (*i.e.* all vehicles), the OECD country average in 2005 was about 13% less fuel-efficient than non-OECD countries. However, OECD narrowed the gap to 8% in 2008, with a 5% improvement over the three-year period, while non-OECD countries experienced a slight deterioration (though statistically basically unchanged).
- The range between small and large vehicles' average fuel economy in OECD countries is much wider than in non-OECD. This deserves more investigation, but may suggest that large cars in OECD are actually larger (and more powerful) than those in non-OECD, since they include more SUVs and luxury segments (F segment vehicles and large trucks represent 40% of large vehicles registrations in OECD countries versus 16% of large vehicles in non-OECD countries in 2008). On the other hand, small cars in OECD might be more efficient because they are more optimised, and possess more fuel efficiency technologies.
- In non-OECD, the slight improvement in fuel economy of medium-sized vehicles was offset by a slight increase in small vehicles' fuel consumption and by a shift towards larger vehicles that led to an overall slight increase in average fuel economy between 2005 and 2008. In OECD countries, it is mainly the drop of fuel consumption in large vehicles that allowed the average to decrease significantly from 2005 to 2008

Figure 15: Fuel economy by simplified segment and country group, 2005 and 2008



Note: the difference between the "Average Polk" and the "Average all data" is due to the fact that for some countries (from EU-27), we had only the global average; the detailed segmentation analysis could only be done for the countries for which Polk data was available; many of the EU27 countries that were not in the Polk data set have low values that push the average down.

Baseline for GFEI

A principle objective of the Global Fuel Economy Initiative (GFEI) is to halve the 2005 fuel consumption of new vehicles worldwide by 2030 compared to 2005 levels. This report helps to define the 2005 baseline value and illuminates trends from 2005 to 2008 to enable some initial tracking of progress towards the GFEI targets. Table 4 summarises 2005 and 2008 fuel economy (in Lge/100 km), and shows the annual evolution over the 2005 to 2008 period, as well as what would be required from 2005 to 2030 to meet the GFEI target.

Table 4 shows that the average annual improvement rate in fuel economy worldwide in the 2005-2008 period was about 1.7%. This is well below the rate needed to hit GFEI targets, which is 2.7% per year. Thus the rate of improvement globally needs to be accelerated to be on track to reach the GFEI 50% objective. It can also be noted that the global average decreased in part due to the fact that non-OECD country vehicle sales rose much faster than OECD sales, while gaining market share. Since, as shown in Figure 15, their average fuel economy is better than that in OECD countries, non-OECD country vehicle sales pushed the global average towards better fuel economy, despite the fact that no individual countries (or vehicles) improved.

Table 4 : Fuel economy status worldwide and long-term GFEI objective comparison

	2005	2008	2030	Annual change 2005-2008	Required annual change 2005-2030
OECD average	8.21	7.66		-2.1%	
Non-OECD average	7.49	7.68		0.3%	
Global average	8.07	7.67		-1.7%	
GFEI objective	8.07		4.03		-2.7%

The GFEI target of a 50% reduction in new car-fuel intensity between 2005 and 2030 is a global target; it is not intended to be applied at a country-by-country level. It is expected that some countries will improve by more than 50% and others less. This reflects different starting points, different market and demographic situations, etc. Nonetheless, it is useful to see how individual countries are doing and track rates of change, as an indicator of whether the global target is achievable. For example, if a large share of countries is on track to meet a 50% improvement, this is a good sign and indicates that the target could be met; if only a few are on track, the prognosis is more pessimistic.

Table 5 shows our estimates for national average LDV fuel economy in 2005 and 2008, along with the global average and the GFEI target. A handful of countries have matched or exceeded the target global fuel economy improvement rate, suggesting such rates of change are indeed possible; countries such as Sweden and Denmark have tended to start from a higher-than-average fuel consumption level. Nonetheless, investigation into recent policies in such countries (*e.g.* standards, vehicle taxation policy, fuel taxes) and their role in fast rates of change could be revealing.

Table 5 – National fuel economy averages in 2005 and 2008

	2005	2008	Annual Change 2005-2008	Test Cycle considered	Vehicles Considered
Argentina	7.56	7.64	0.3%	NEDC	Passenger Cars
Australia	9.80	8.98	-2.9%	NEDC	PCs + LCVs
Austria	6.98	6.81	-0.8%	NEDC	Passenger Cars
Belgium	6.68	6.37	-1.6%	NEDC	Passenger Cars
Brazil	7.29	7.37	0.3%	NEDC	Passenger Cars
Chile	7.50	7.04	-2.1%	NEDC/FTP	Passenger Cars
China	7.75	8.05	1.3%	NEDC	Passenger Cars
Cyprus	7.45	7.13	-1.5%	NEDC	Passenger Cars
Czech Republic	6.69	6.65	-0.2%	NEDC	Passenger Cars
Denmark	7.05	6.31	-3.7%	NEDC	Passenger Cars
Estonia	7.91	7.64	-1.1%	NEDC	Passenger Cars
Finland	7.73	7.02	-3.2%	NEDC	Passenger Cars
France	6.56	6.04	-2.7%	NEDC	Passenger Cars
Egypt	7.30	7.30	0.0%	NEDC	Passenger Cars
Germany	7.47	7.10	-1.7%	NEDC	Passenger Cars
Greece	7.21	6.93	-1.3%	NEDC	Passenger Cars
Hungary	6.73	6.61	-0.6%	NEDC	Passenger Cars
India	5.60	6.09	2.9%	Low NEDC	Passenger Cars
Indonesia	7.22	7.27	0.3%	NEDC	Passenger Cars
Ireland	7.19	6.75	-2.1%	NEDC	Passenger Cars
Italy	6.44	6.23	-1.1%	NEDC	Passenger Cars
Japan	6.65	6.22	-2.2%	10-15	Passenger Cars
Latvia	8.07	7.78	-1.2%	NEDC	Passenger Cars
Lithuania	8.03	7.33	-3.0%	NEDC	Passenger Cars
Luxembourg	7.26	6.87	-1.8%	NEDC	Passenger Cars
Malaysia	7.60	7.53	-0.3%	NEDC	Passenger Cars
Malta	6.49	6.33	-0.8%	NEDC	Passenger Cars
Mexico	7.47	7.98	2.2%	FTP	Passenger Cars
Netherlands	7.32	6.80	-2.4%	NEDC	Passenger Cars
Poland	6.69	6.60	-0.4%	NEDC	Passenger Cars
Portugal	6.24	5.96	-1.6%	NEDC	Passenger Cars
Romania		6.72		NEDC	Passenger Cars
Russia	8.33	8.11	-0.9%	NEDC	Passenger Cars
Slovakia	6.78	6.47	-1.6%	NEDC	Passenger Cars
Slovenia	6.77	6.72	-0.3%	NEDC	Passenger Cars
South Africa	7.68	7.59	-0.4%	NEDC	Passenger Cars
Spain	6.69	6.38	-1.6%	NEDC	Passenger Cars
Sweden	8.35	7.49	-3.5%	NEDC	Passenger Cars
Thailand	8.33	7.62	-2.9%	NEDC	Passenger Cars
Turkey	7.24	6.67	-2.7%	NEDC	Passenger Cars
UK	7.31	6.82	-2.3%	NEDC	Passenger Cars
Ukraine	7.75	7.76	0.1%	NEDC	Passenger Cars
USA	9.68	9.13	-1.9%	FTP	PCs + LCVs
EU-27	7.00	6.61	-1.9%	NEDC	Passenger Cars
Global Average	**8.07**	**7.67**	**-1.7%**		
	2005	**2030**	Required Annual Change 2005-2030		
GFEI Objective	**8.07**	**4.03**	**-2.7%**		

It is notable that the two largest markets, the European Union and the United States, did not reach the target improvement for the period analysed; the tightening/enforcement of standards will hopefully help increase the rates of change in those markets in the near future. For all countries, strong policies and a long-term perspective will be needed to achieve and sustain rapid rates of improvement to 2030 and beyond.

Conclusion

This analysis compiled and used a large sample of registered vehicles in 21 countries to provide a picture of the status of the new vehicle characteristics, including fuel economy, worldwide. It also reported on changes between 2005 and 2008 models. The analysis indicates that in many countries, and for all countries on average, fuel economy improvements have occurred over the past three years, but the majority of this improvement was in OECD countries (though, these countries started with more energy-intensive vehicles). It also indicates that the global rate of fuel economy improvement is far too slow to meet the 2030 GFEI goal of achieving a 50% reduction in the fuel consumption of new vehicles by 2030 from 2005 levels.

To better understand how different factors interact and "explain" the resulting fuel economy levels and trends, this analysis should be deepened, for example, with multivariate analysis. It should also be updated regularly to assess the latest progress worldwide, analyse trends in an ongoing way, and track progress toward achieving GFEI objectives.

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Meyer T. and A. Clavel A. (2006), Place de la consommation de carburants dans les critères de choix des véhicules (Particuliers), PREDIT , Convention ADEME N° 03 66 C0035.

OICA, (2010) 2010 Production Statistics, http://oica.net/category/production-statistics/

Annex I: Official tested fuel economy resource database

Country		
US	**Name**	DoE / EPA Fuel Economy ratings
	Web	www.fueleconomy.gov/
China	**Name**	
	Web	www.gzly.miit.gov.cn:8090/datainfo/miit/babs2.jsp
UK	**Name**	Car Fuel Data Booklet
	Web	www.vcacarfueldata.org.uk/
France	**Name**	Consommation conventionnelles de carburant et émissions de gaz carbonique
	Web	www2.ademe.fr/servlet/getDoc?cid=96&m=3&id=52820&p1=00&p2=12&ref=17597
Australia	**Name**	Green Vehicle Guide Factsheets
	Web	www.greenvehicleguide.gov.au
Japan	**Name**	JIDOSHA NENPI ICHIRAN (in Japanese)
	Web	www.mlit.go.jp/jidosha/jidosha_mn10_000001.html
Mexico	**Name**	Indicadores de Eficiencia Energética y Emisiones Vehiculares
	Web	www.ecovehiculos.gob.mx/
Swiss	**Name**	Automobil Revue catalogue
	Web	www.katalog.automobilrevue.ch/

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