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BRAZIL PASSENGER VEHICLE MARKET STATISTICS

INTERNATIONAL COMPARATIVE ASSESSMENT OF TECHNOLOGY ADOPTION AND ENERGY CONSUMPTION

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EXECUTIVE SUMMARY

Brazil has been one of the world's top five vehicle markets for six consecutive years, and accounts for over half of all vehicles sold in Latin America. The Brazil Passenger Vehicle Market Statistics report provides detailed information about vehicle characteristics, technology adoption, and energy consumption for passenger vehicles – automobiles, sport utility vehicles (SUVs), pick-up trucks and minivans – sold in Brazil in 2013. This study examines the adoption of vehicle efficiency technologies and their aggregate impact on vehicle energy consumption.

Many countries have been investing heavily in vehicle technology development, some of which have a direct impact on improvements in energy consumption. This study provides a better understanding of how the Brazilian fleet compares to international fleets in the world's major vehicle markets – the European Union (EU), China, India, Japan, South Korea, and the United States (U.S.) – in terms of technology adoption and energy consumption.

There is currently a lack of vehicle data and analyses to support the adequate evaluation of public policies to encourage investments in vehicle technology and reductions in energy consumption in Brazil. The Inovar-Auto policy adopted in 2012 aims at fostering industrial competitiveness through technology development and improvements in vehicle efficiency. This study not only supports the strengthening of vehicle energy consumption targets set by Inovar-Auto, but it also recommends further investments in technology deployment and energy consumption improvements, and highlights the need for better data quality and availability.

Chapter 1 provides an overview of the Brazilian passenger vehicle market. Brazil was the world's fifth largest market of passenger car sales in 2013 after China, EU, U.S. and Japan, and ahead of India and South Korea. Similarly to many developing countries, vehicle sales in Brazil decreased in 2014 (by 7%) due to the economic downturn, but Brazil continues to be amongst the top five passenger vehicle markets worldwide.

Brazil's passenger fleet is unique in many aspects. Through a combination of national investment and fiscal incentives, Brazil's new fleet consists primarily of flex-fuel cars that can be powered by either ethanol or gasoline. In addition, Brazil has long incentivized sales of one-liter engine cars, which became the symbol of the Brazilian automotive industry in the 1990s, reaching over 70% of sales in 2001. Since then, the share of one-liter engine cars has been dropping consistently (i.e., 36% in 2013) in favor of medium-sized vehicles with larger engines.

Chapter 2 includes key characteristics of the Brazilian passenger vehicle fleet, including a comparison with other countries and regions, including the EU, China, India, Japan, South Korea, and the U.S. The report provides vehicle characteristics by segment and by the 20 largest manufacturers in Brazil. On average the Brazilian fleet is smaller in size, lighter, and less powerful than all countries evaluated, with the exception of India.

Chapter 3 examines the adoption of energy-saving technologies by segment and manufacturer, comparing it to other countries. This analysis concludes that Brazil lags behind most other vehicle markets in the adoption of such technologies (**Figure ES-1**), although its penetration appears to be increasing over time. These technologies, which have a large potential to reduce vehicle energy consumption, include hybrid engines, downsized engines (e.g., three cylinders), continuously variable transmissions (CVT), dual-clutch transmissions (DCT), higher gear ratio transmissions (e.g., six and above), dual overhead camshafts (DOHC), variable valve actuation (VVA) technologies, turbocharging, and gasoline direction injection (GDI). The combination of GDI technology, turbocharging, and downsizing can result in up to 15% savings in energy consumption over the more predominant technologies commercialized in Brazil today. Hybrid systems can achieve substantially larger savings in energy consumption, between 20% and 50%, with respect to similar-sized vehicles.

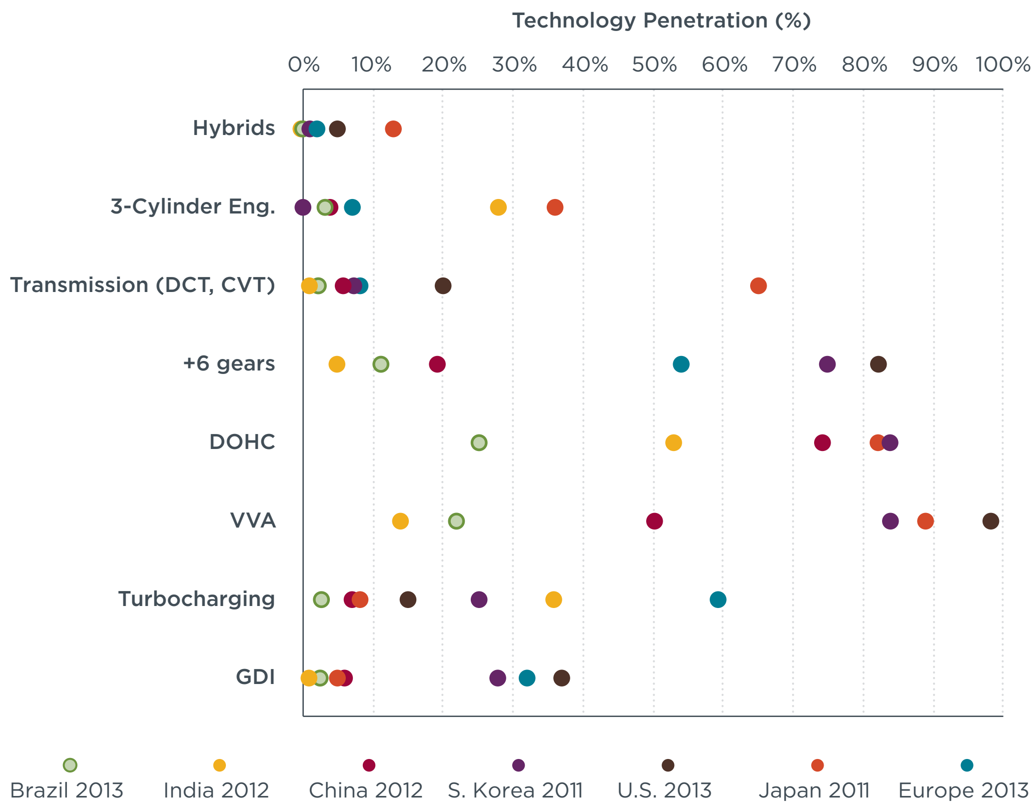

Figure ES-1 – International comparison of technology penetration in passenger vehicles.
Country labels indicate the dataset year.

Chapter 4 examines vehicle energy consumption in new passenger cars. Brazil's fleet is on average more efficient than fleets in the U.S., China, and South Korea. When compared to countries with vehicles of similar and even higher average weight, Brazil has relatively inefficient vehicles (**Figure ES-2**). Because of lower adoption rates of energy/fuel efficiency technologies, the average Brazilian vehicle consumes about 18% more energy than the average vehicle in Japan, even though Brazilian vehicles are, on average, 8% lighter than the average Japanese car. The Japanese fleet has a large penetration of fuel-efficiency technologies such as three-cylinder engines, variable valve actuation, dual overhead camshafts, and advanced transmissions, as well as a large market of gasoline hybrids. European vehicles also perform better, despite weighing more than vehicles in the majority of other countries with the exception of the U.S. and South Korea. The adoption of fuel-efficiency technologies (e.g., DCT, 6-speed transmissions, GDI, turbocharging) contributes to Europe's above average performance.

It is also important to note that this comparison is limited to type-approval and certification data, and does not include off-cycle or real-world adjustments.

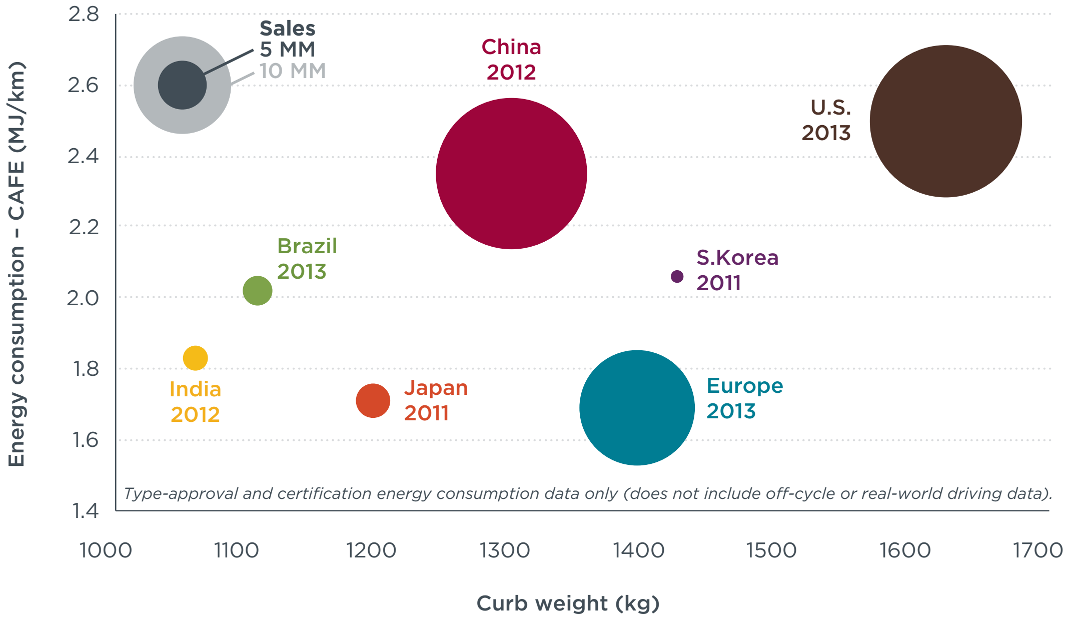

Figure ES-2 – International comparison of passenger fleet-average energy consumption.
Country labels indicate the dataset year.

This analysis suggests that there are potential reductions in vehicle energy consumption for the Brazilian fleet. For similar vehicles in terms of weight class, footprint, or engine rating, there is a significant range in energy consumption, indicating that there are vehicles performing much worse than the average. There is also a clear trend of some manufacturers performing much better than the average, while others have a lot more room for improvement. The international comparison clearly shows that Brazilian vehicles perform much worse in terms of energy consumption than vehicles of similar weight elsewhere, indicating a delay in the adoption of energy-efficient technologies among Brazilian vehicle manufacturers. Finally, a more detailed analysis of vehicle versions clearly illustrates a considerable number above the average energy consumption. This indicates potential improvements that would place those versions on par with the best performing vehicles with similar characteristics in Brazil.

Because of the wide gap between Brazil and other major vehicle markets, there is much potential for the introduction of energy-saving technologies. Future analyses will need to evaluate the potential of these energy-saving technologies to reduce fuel consumption and emissions in Brazil, together with a cost-benefit (payback) analysis of such technologies, and a better understanding of barriers to technology penetration. In addition, improvements in data quality and completeness will be essential to improve the accuracy of these analyses.

1. MARKET OVERVIEW

Brazil was the fifth largest market worldwide for sales of new passenger vehicles in 2013, after China, U.S., EU, and Japan (**Figure 1-1**). Although the Brazilian passenger vehicle market contracted by 8% in 2014 (with sales of 2.8 million new passenger vehicles), its relative ranking remained unaltered since other developing countries also experienced a decrease in sales. Annual average market growth rates during the last nine years for the group of BRIC countries remained strong, led by China (21%), and followed by India (15%), Brazil (10%) and Russia (10%). Although vehicle sales in developed markets, i.e., EU, U.S., and Japan, increased from 2013 to 2014, these three markets have also experienced an overall contraction of around 2% between 2005 and 2013.

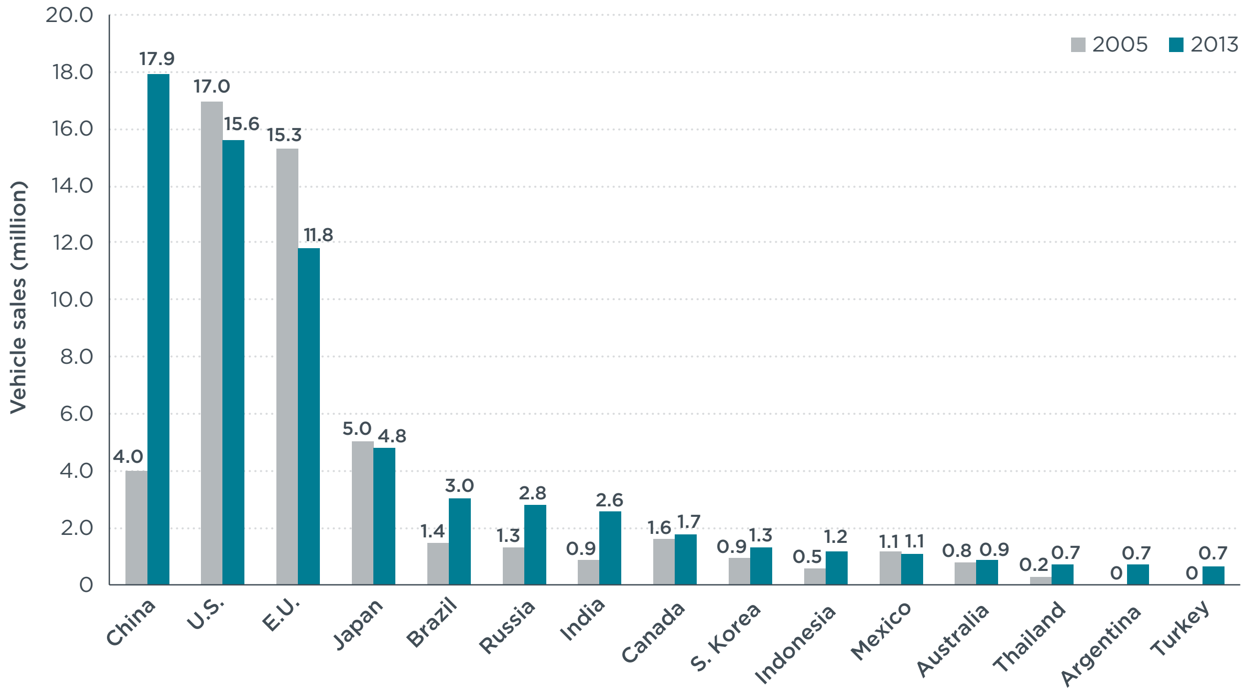

Figure 1-1 – Top 15 passenger vehicle markets worldwide.

U.S., Canada, and Mexico data include cars and light-duty trucks. Source: MarkLines vehicle databases.

The growth in passenger vehicle sales in Brazil over the past decade was driven by a combination of national economic growth, more favorable consumer credit policies, and fiscal incentives from the government. While gross domestic product (GDP) and vehicle sales have gone hand-in-hand from 1990 until the mid-2000s, vehicle sales growth remained robust even in 2009 and after 2011 when economic growth faltered (**Figure 1-2**). Slower economic growth following the international financial crisis was offset by credit expansion and fiscal incentives to encourage vehicle sales. Although there is much debate regarding the effects of such fiscal incentives on vehicle sales and GDP (Alves 2014, ANTP 2014, Mendonça 2014), it is widely acknowledged that fiscal incentives contributed to part of the recent growth in vehicle sales.

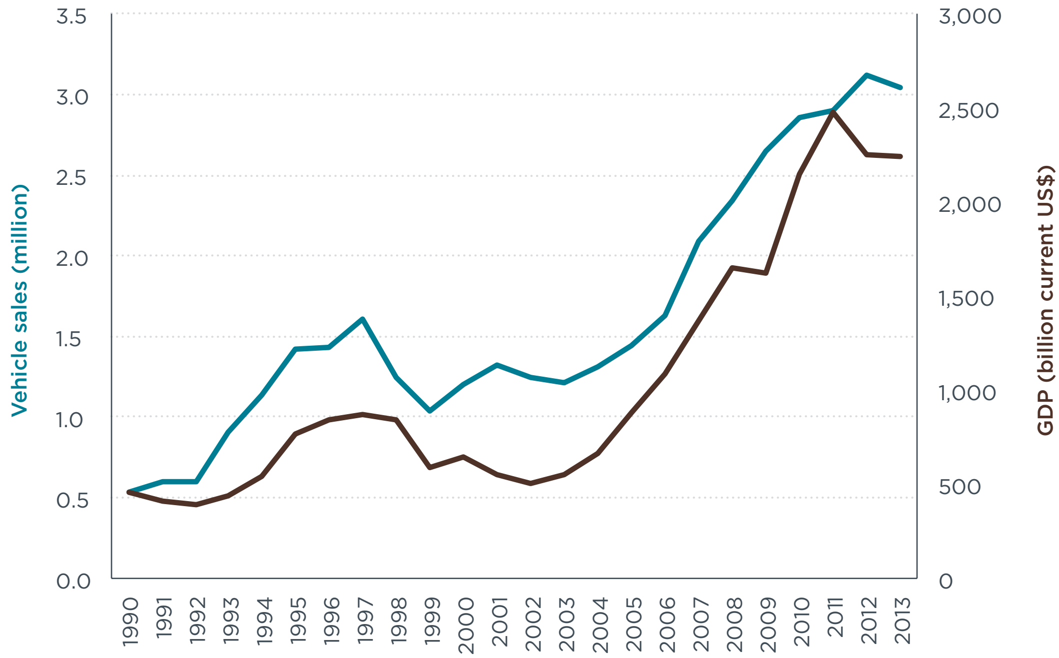

Figure 1-2 – Comparison of passenger vehicle sales and economic growth in Brazil.
Sources: ANFAVEA 2015, World Bank databases.

One-liter engine vehicles have consistently lost market share since 2001. Brazil has historically encouraged the sales of small-engine vehicles through lower sales taxes. From 1990 to 2001, one-liter engine automobiles became the symbol of the national automotive industry, and their share in total sales increased from 4% to over 70% (Anfavea 2015). In the 2000s, the number of vehicle manufacturers in Brazil increased from 15 to 46, and the government started to provide tax incentives to flex-fuel cars independently of engine size. Because of increasing competition amongst automakers, a narrower gap between taxes for one-liter engine cars and flex-fuel cars, and increasing consumer preference for more comfort and powerful engines, the share of one-liter engine cars decreased to 36% in 2013. While the relative participation of one-liter engine cars has decreased, total one-liter vehicle sales have increased continuously in the same period, from 780,000 units sold in 2001 to over 1.1 million in 2013 (**Figure 1-3**).

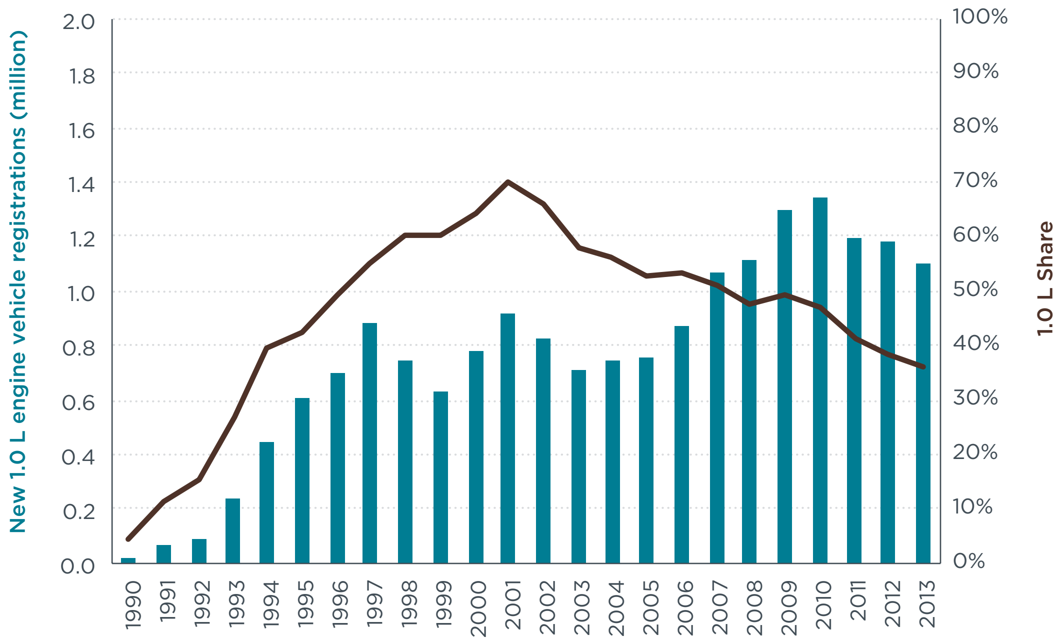

Figure 1-3 – New registrations of one-liter engine vehicles.
Source: ANFAVEA 2015.

Due to a long-standing national program to stimulate ethanol consumption, ethanol is sold as E100 (100% ethanol by volume), as well as being blended in gasoline. The government sets the ethanol blend in commercial gasoline, ranging from 20% to 27% ethanol depending on the current blend mandate (E20-E25 since 2011 and E27 in 2015). As a result, biofuels in Brazil account for about 25% of road transport fuel demand, compared to less than 3.5% globally (IEA 2015).

Ethanol availability at different blend levels has had a strong impact over consumer choices and technologies offered in the market by manufacturers. Until the 2000s, sales of gasoline or ethanol vehicles were driven primarily by fuel prices, with ethanol vehicles dominating sales in the 1980s, and very strong sales of gasoline engines in the 1990s. Today flex-fuel engines, those that can run on any combination of ethanol and gasoline, are currently ubiquitous in new passenger vehicles. Since their introduction in 2003, flex-fuel engines now dominate the passenger vehicle market, accounting for 94% of new sales in 2013 (**Figure 1-4**). Sales of new diesel passenger cars have been below 1% of total sales since 2005 (ANFAVEA 2015).

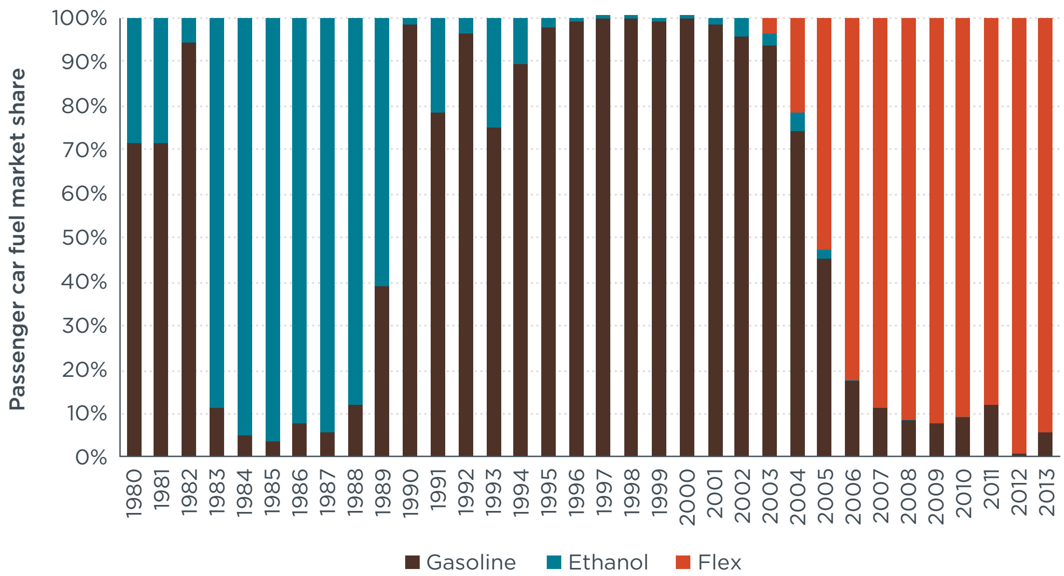

Figure 1-4 – Registrations of new passenger vehicles by fuel type.
Source: ANFAVEA 2015.

The top seven manufacturers – Fiat, General Motors (GM), Volkswagen, Ford, Renault, Hyundai and Honda – commanded a vast majority (83%) of the entire market in 2013, with the remaining manufacturers accounting for less than 4% of market sales each (**Figure 1-5**). The Volkswagen Gol is the most popular vehicle in Brazil, accounting for about 4.5% of all sales in 2013. Medium-sized vehicles dominate the market with 39% of all sales, followed by compact and subcompact vehicles, which together make up 84% of the entire market. In addition, domestically manufactured vehicles accounted for more than 83% of sales in 2013, which represented a small increase with respect to the previous year.

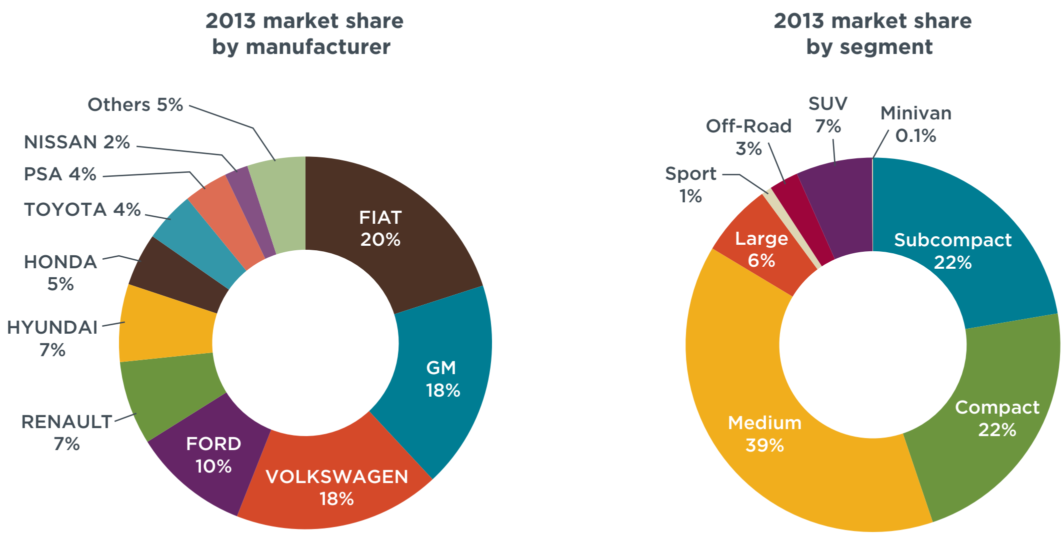

Figure 1-5 – Market share of new passenger vehicles by manufacturer and segment (2013).
Source: ADK.

Table 1-1 summarizes key indicators for the Brazilian passenger vehicle market in 2012 and 2013. Fiat remained the market leader in 2013, although with a small loss, and GM overtook Volkswagen in 2013. Amongst the companies that gained the most market share are Hyundai and Toyota, both of which doubled their market share between 2012 and 2013. On the other hand, PSA and Nissan lost market shares in this period. The market dominance of medium-sized vehicles in 2013 marks a significant shift in consumer preferences. Between 2012 and 2013 the subcompact segment lost the majority share (from 33% to 22%), and the larger compact and medium segments gained sizable shares.

Table 1-1 – Market characteristics of new Brazilian passenger vehicles.

Parameter	2012	2013
Sales (million)	3.11	3.04
Price (R$)*	$47,203	$47,446
Domestic market share	80.0%	83.4%
Engine 1.0 L share	38.6%	36.3%
Fuel share		
Flex	91.4%	93.6%
Gasoline	8.2%	5.9%
Hybrid	0.004%	0.014%
Diesel	0.4%	0.5%
Segment market share		
Subcompact	33.2%	22.3%
Compact	16.2%	22.5%
Medium	33.5%	38.8%
Large	7.9%	6.3%
Sport	0.7%	0.9%
Off-road	2.3%	2.5%
SUV	6.1%	6.6%
Minivan	0.1%	0.1%
Manufacturer market share		
Fiat	22.1%	20.0%
GM	17.6%	18.0%
Volkswagen	21.1%	17.9%
Ford	9.6%	10.1%
Renault	7.3%	7.3%
Hyundai	3.2%	6.8%
Honda	4.3%	4.6%
Toyota	2.4%	4.4%
PSA	4.4%	3.8%
Nissan	2.8%	2.0%
Mitsubishi	1.3%	1.2%
Kia	1.1%	0.8%
JAC	0.6%	0.5%
BMW	0.3%	0.5%
Land Rover	0.3%	0.3%
Mercedes-Benz	0.2%	0.3%
Others	0.2%	1.4%

*Sales-weighted average

2. VEHICLE FLEET CHARACTERISTICS

This chapter provides an overview of key vehicle fleet characteristics in Brazil. Number of cylinders, engine displacement, curb weight[1], length, footprint[2], engine power, and power-to-weight ratio (PTWR)[3] are relevant indicators to characterize a vehicle fleet and understand individual vehicle and fleet-average energy consumption.[4]

These key characteristics of passenger vehicles in Brazil experienced a small change in 2013, compared to 2012 (**Table 2-1**). With the exception of number of cylinders, all parameters increased in 2013, consistent with a trend of increasing market shares for larger and more powerful vehicles. The evaluation of minimum and maximum parameters also provides important insights. While the smallest vehicles continue to be sold in Brazil (since the minimum values did not change with the exception of footprint), it is evident that much larger vehicles started being sold in 2013, represented by the large variation in the maximum values of each parameter. Because sales of these recently introduced larger vehicles are relatively small, their effect on weighted average parameters is also modest.

Figure 2-1 illustrates key vehicle fleet characteristics by vehicle segment (see Appendix A for segment definition). Not surprisingly, most parameters get larger between the subcompact and large segments. Off-road vehicles, sports cars, and minivans tend to be the largest and most powerful vehicles across the fleet, while sport utility vehicles (SUVs) tend to be comparable with vehicles in the “large” segment. Because of their high performance (absolute and relative to vehicle size), sports cars have significantly larger engine power and PTWR compared to all other segments. Sports vehicles, primarily imported, are not sold in a flex-fuel configuration, and consume strictly gasoline. Flex-fuel vehicles have slightly higher engine power and PTWR than their gasoline counterparts in most segments. Detailed sales-weighted average data by segment are presented in **Table C-1** in Appendix C.

1 Based on norm ABNT NBR ISO 1176: 2006. Curb weight is the total weight of a vehicle with standard equipment, all necessary operating consumables (e.g., motor oil and coolant), a full tank of fuel, but not loaded with passengers or cargo.

2 Footprint (m^2) is the product of the distance between the axles of a vehicle (wheelbase) and the distance between the centerline of the tires (average trackwidth).

3 Power to weight ratio (PTWR) is defined as the rated power of the engine (kW) divided by the vehicle weight (kg). PTWR is a metric that describes vehicle acceleration and handling and it is thus used in Brazil as a criterion to classify sports vehicles (PTWR > 0.075 kW/kg).

4 Vehicle energy consumption is presented in megajoules per kilometer (MJ/km) for consistency with the vehicle energy consumption targets established by Inovar-Auto. Although E27 is currently being used, flex-fuel vehicles are tested with E22 fuel.

Table 2-1 – Fleet characteristics of new Brazilian passenger vehicles.

Vehicle characteristic		2012	2013	Variation
Number of cylinders	**Weighted average**	**4.02**	**4.00**	**-0.6%**
Displacement (cc)	Min	970	970	
	Max	6,498	6,749	
	Weighted average	**1,418**	**1,430**	**0.8%**
Curb weight (kg)	Min	800	800	
	Max	2,940	2,710	
	Weighted average	**1,102**	**1,106**	**0.4%**
Length (mm)	Min	2,695	2,695	
	Max	5,290	5,842	
	Weighted average	**4,089**	**4,100**	**0.3%**
Footprint (m^2)	Min	2.17	2.41	
	Max	5.23	8.74	
	Weighted average	**3.64**	**3.67**	**0.9%**
Engine power – gasoline (kW)	Min	33	33	
	Max	153	545	
	Weighted average	**74.3**	**75.7**	**1.8%**
Engine power – ethanol (kW)		49	49	
	Max	114	153	
	Weighted average	**71.5**	**74.0**	**3.4%**
PTWR - gasoline (kW/kg)		0.0455	0.0455	
	Max	0.4482	0.3344	
	Weighted average	**0.0658**	**0.0671**	**2.0%**
PTWR - ethanol (kW/kg)		0.0476	0.0477	
	Max	0.0935	0.1033	
	Weighted average	**0.0667**	**0.0683**	**2.4%**
Energy consumption – U.S. CAFE (MJ/km)		N/A	2.02	

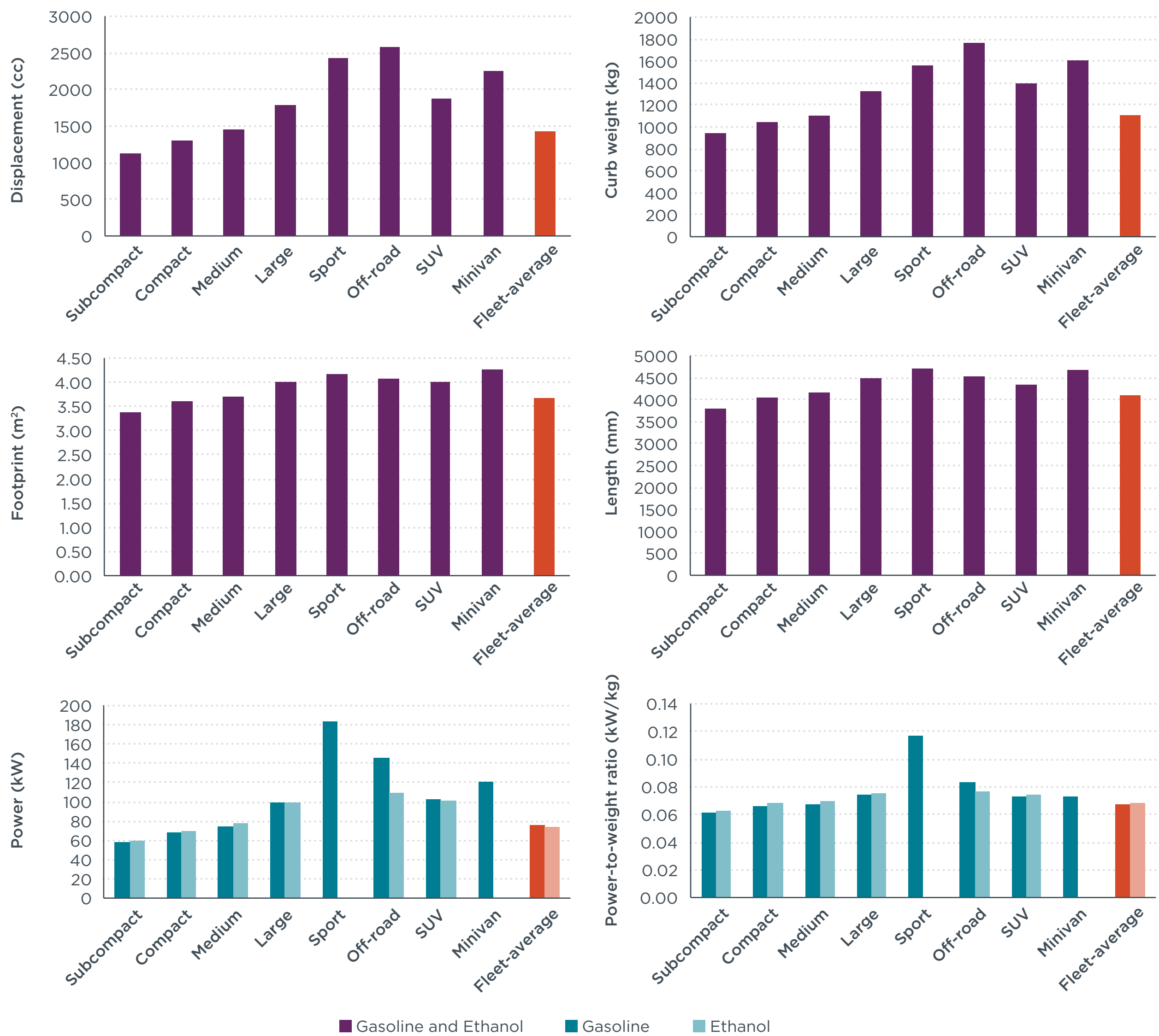

Figure 2-1 – Fleet characteristics of new Brazilian passenger vehicles by segment (2013).

Fleet characteristics for the top 20 vehicle manufacturers, responsible for more than 99% of passenger vehicle sales in 2013, are presented in **Figure 2-2**. The four top-selling manufacturers (Fiat, GM, Volkswagen, and Ford) produce on average lighter vehicles with smaller and less powerful engines. Average engine rated power is below 80 kW for the 10 largest manufacturers, except for Toyota and Honda, since each has a large share of off-road and SUV sales, respectively. Luxury manufacturers and off-road dominant manufacturers (Jeep and Mitsubishi) show the largest values of engine power. PTWR values seem evenly distributed below 0.070 kW/kg across the five largest manufacturers, plus PSA and Chery, and climb following the power trend for luxury and off-road oriented manufacturers. Most vehicles are rated with higher engine power and PTWR under ethanol (E100) than under gasoline (E22). Detailed sales-weighted average data by manufacturer are presented in **Table C-2** in Appendix C.

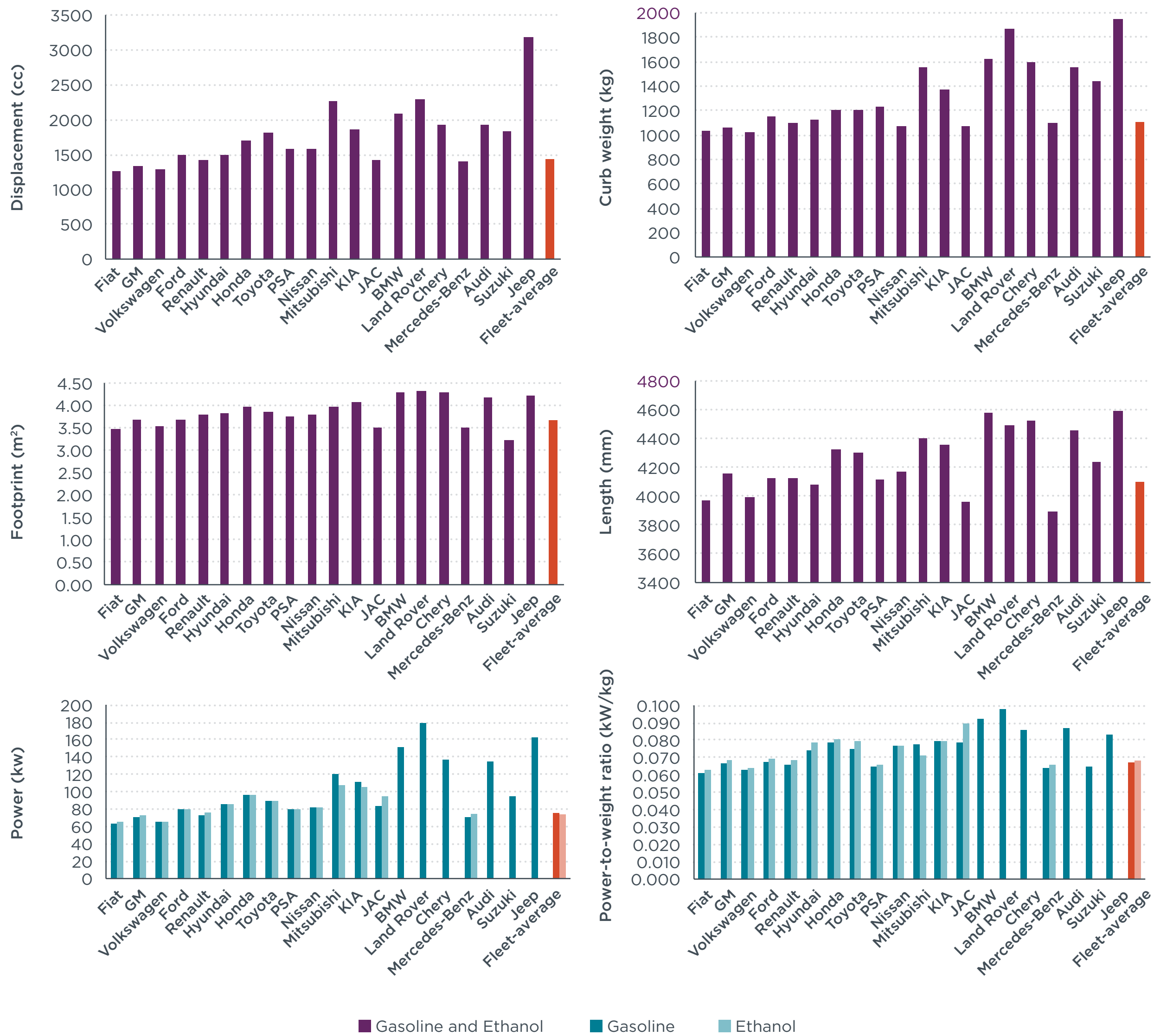

Figure 2-2 – Fleet characteristics of new Brazilian passenger vehicles by manufacturer (2013).
Manufacturers are organized by total sales in descending order.

Figure 2-3 illustrates vehicle fleet characteristics for domestic and imported vehicles. In general, imported vehicles are bigger and heavier than those nationally produced. The most remarkable contrast lies on engine power and PTWR. Imported vehicles are more powerful and have higher PTWR, but while domestic vehicles exhibit higher engine power and PTWR for ethanol than for gasoline, the opposite occurs for imported ones. A closer examination of available data on engine compression ratios shows that domestic producers are leveraging ethanol's higher octane rating and designing flex-fuel engines with much higher compression ratios (~12.5:1) than gasoline-only engines (around 10.5:1).[5] This confirms the special engine design/calibration for operation with high ethanol gasoline blends from manufacturers with local production. Detailed sales-weighted average data by origin are presented in **Table C-3** in Appendix C.

5 More information on the effect of ethanol on vehicle design characteristics can be found in Stein et al (2013).

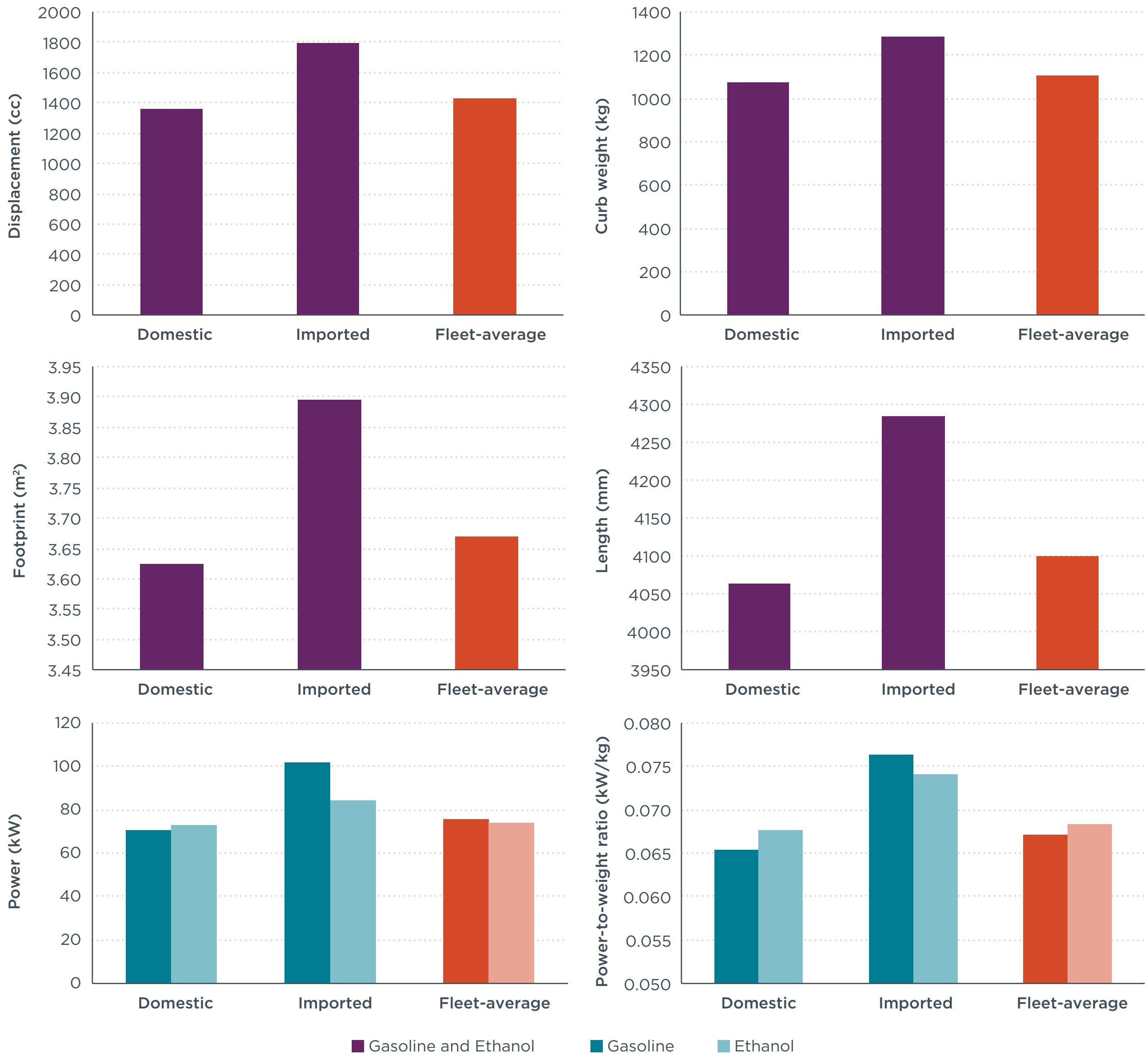

Figure 2-3 – Fleet characteristics of new Brazilian passenger vehicles by origin (2013).

Figure 2-4 compares Brazil's passenger vehicle fleet with those in China, the U.S., EU, Japan, India, and South Korea. For the energy consumption comparison, this analysis considers the U.S. corporate average fuel economy (CAFE) test cycle.[6] Average engine displacement, curb weight, footprint, and engine power in Brazil are the smallest with the exception of India (and Japan in the case of engine displacement). With respect to PTWR, the average Brazilian passenger car breaks the trend set by the power category, i.e., Brazilian cars are less powerful than those in China, Japan, and EU, due to their lower average weight, which drives the PTWR value above Chinese, Japanese and European cars. This suggests that the average Brazilian cars share the driving performance characteristics (e.g., acceleration times) of the U.S. and Korean vehicles despite their relative smaller engines. Detailed international data are presented in Appendix B.

6 Details on ICCT's methodology for comparing new vehicle fuel efficiency can be found at the Global PV Standards section in the ICCT's website: http://www.theicct.org/info-tools/global-passenger-vehicle-standards

Despite having the smallest, lightest, and least powerful vehicles on average (with the exception of India), Brazil's average energy consumption ranks fourth amongst the markets analyzed in this study. The Japanese fleet had the lowest energy consumption given the small and light vehicle characteristics of Japanese cars, and their relatively higher adoption of efficiency technologies (e.g., hybrids), followed by the EU (medium size/weight fleet with high technology penetration) and India (smaller and lighter fleet overall). The U.S. has the highest energy consumption on average due to the fleet's larger size, weight and power requirements. China and South Korea trail the U.S. as the most energy-consuming fleet, and these countries have fleets with large and heavy vehicles but relatively lower penetration of efficiency technologies. A detailed evaluation of energy consumption in Brazil and other markets is presented in Chapter 4.

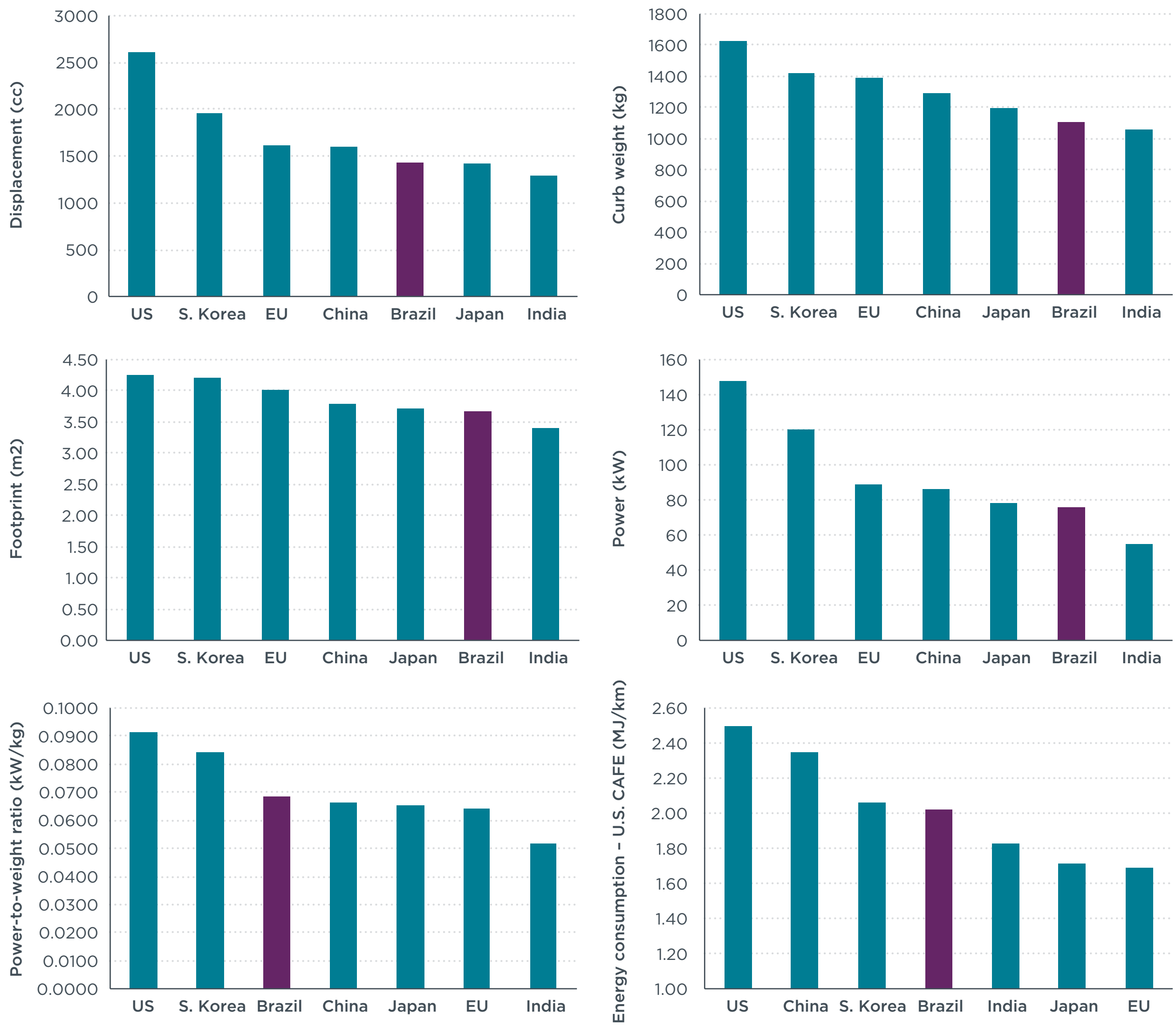

Figure 2-4 – International comparison of key new passenger vehicle characteristics.

3. VEHICLE TECHNOLOGY ADOPTION

This chapter provides an overview of current technology adoption, including fuel, engine and transmission technologies that affect vehicle energy consumption. The type and complexity of technologies vary across vehicle segments. To a large extent this is a function of vehicle size and weight and its intended performance, and, ultimately, cost. Fleet-average parameters presented in **Table 3-1** correspond to sales-weighted fleet-average values. This chapter is divided by technology type, with supporting information in Appendix C. An international comparison for each technology is also presented in this chapter. The data for this technology adoption analysis came from a diversity of sources listed in Appendix D. Also, note that for comparisons at the international level it was required to use information from different years, the most recent according to data availability.

Table 3-1 – Technology adoption in new Brazilian passenger vehicles.

	Year	2012	2013
Fuel type	**Flex**	91.4%	93.6%
	Gasoline	8.2%	5.9%
	Hybrid	0.004%	0.014%
	Diesel	0.4%	0.49%
No. of cylinders	**Three**	0.3%	2.5%
	Four	98.6%	96.6%
	Five	0.0%	0.0%
	Six	0.9%	0.8%
	Eight or more	0.1%	0.1%
Transmission	**Manual**	87.0%	83.3%
	Automatic	11.2%	14.7%
	CVT	1.4%	1.5%
	DCT	0.4%	0.5%
No. of gear ratios	**Four or fewer**	6.1%	5.9%
	Five	84.9%	83.1%
	Six	8.4%	9.8%
	Seven	0.3%	0.7%
	Eight or more	0.2%	0.5%
Drivetrain	**FWD**	95.0%	94.4%
	RWD	2.7%	2.9%
	4WD and AWD	2.3%	2.7%
No. of valves per cylinder	**Two**	66.4%	59.6%
	Multi valve	33.6%	40.4%
Valve camshaft configuration	**Single overhead camshaft**	69.6%	63.0%
	Dual overhead camshaft	17.6%	24.5%
Valve actuation	**Fixed**	82.2%	78.3%
	VVT	12.4%	15.9%
	VVT+VVL	5.4%	5.8%
Fuel systems for gasoline vehicles	**Multi-point fuel injection**	98.2%	97.6%
	Gasoline direct injection	1.8%	2.4%
Air induction systems for gasoline vehicles	**Naturally aspirated**	98.4%	97.3%
	Supercharger, turbocharger or twin-turbo	1.6%	2.7%

FUEL TYPE

Flex-fuel vehicles (FFVs) are designed to run on gasoline (E22), ethanol (E100), or any combination of both fuels. Except for a few engine and fuel system modifications, FFVs are identical to gasoline-only models.[7] FFVs experience no loss in performance when operating on E100. However, since ethanol contains less energy per volume than gasoline, FFVs typically get about 25% fewer kilometers per liter when fuelled with E100.

Flex-fuel is the dominant technology across all vehicle segments, with the exception of sports cars, off-road vehicles, and minivans (**Figure 3-1**). All top 10 manufacturers produce primarily flex-fuel engines, and those manufacturers with a larger share of gasoline and diesel engines typically import most of their vehicles (**Figure 3-2**). The predominance of FFVs, responsible for almost 94% of vehicle sales in 2013, is unique to Brazil (**Figure 3-3**).

Hybrid-gasoline vehicles achieve reduced fuel consumption by incorporating in the drivetrain a battery and an electric motor in addition to an internal combustion (IC) engine. This technology permits the IC engine to shut down when the vehicle is decelerating and is stopped, braking energy to be recovered, and the IC engine to be downsized and operated at more efficient operating points. Depending on the level of complexity, hybrid systems can achieve 15% to 35% reductions in fuel consumption with respect to similar-sized vehicles.

Despite having very limited penetration, sales of new hybrid vehicles have increased three-fold from 131 units in 2012 to 432 in 2013, primarily in the medium and sports segments. Two manufacturers sell the most gasoline hybrid models (not flex-fuel) in Brazil, including the Toyota Prius and the Ford Fusion Hybrid.

Diesel engines offer 20% to 25% reduction in fuel consumption over traditional gasoline multi-point fuel injection (MPFI) engines due to higher compression ratios, reduced pumping losses, and 12% higher energy content per liter of fuel. The challenge for further commercialization is twofold: the complexity and additional cost of advanced exhaust after-treatment technologies that reduce emissions of particulate matter and oxides of nitrogen to levels comparable to those of gasoline and FFV engines.

Sales of diesel passenger vehicles are not allowed in Brazil, with the exception of vehicles with some off-road characteristics. Despite having a small penetration (around 0.5%), sales of diesel passenger vehicles increased by 16% in 2013. Toyota sells the most diesel passenger vehicles, followed by Mitsubishi, Land Rover, GM, and Mercedes-Benz. The light-duty diesel market in Brazil is equivalent to the U.S. and China in terms of market penetration, and much below the penetration in Europe and South Korea, although air quality concerns in Europe might trigger lower sales of diesel vehicles in coming years.

7 Most of the modifications with respect to a gasoline-only vehicle (E00) include changes to fuel system's materials that are compatible with the oxygen content of ethanol blends and changes to air and fuel ratio management systems (mainly software based).

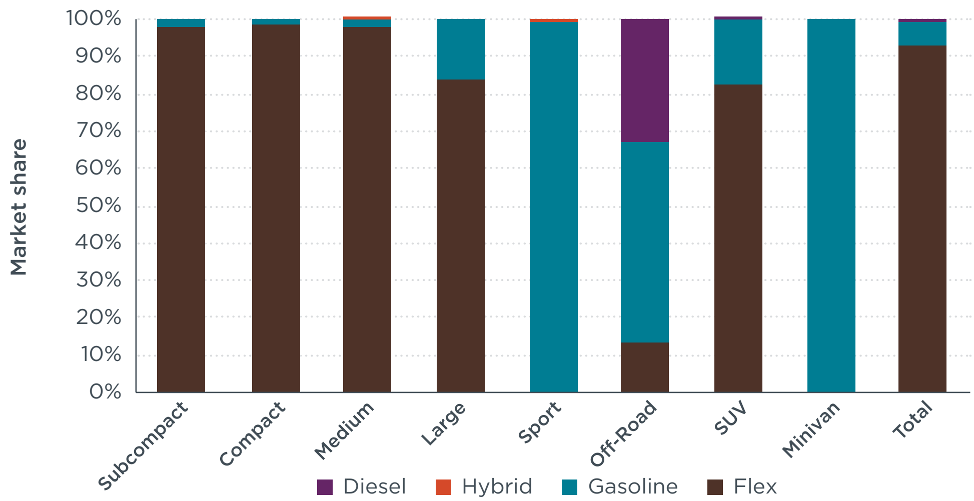

Figure 3-1 – Fuel type by segment.

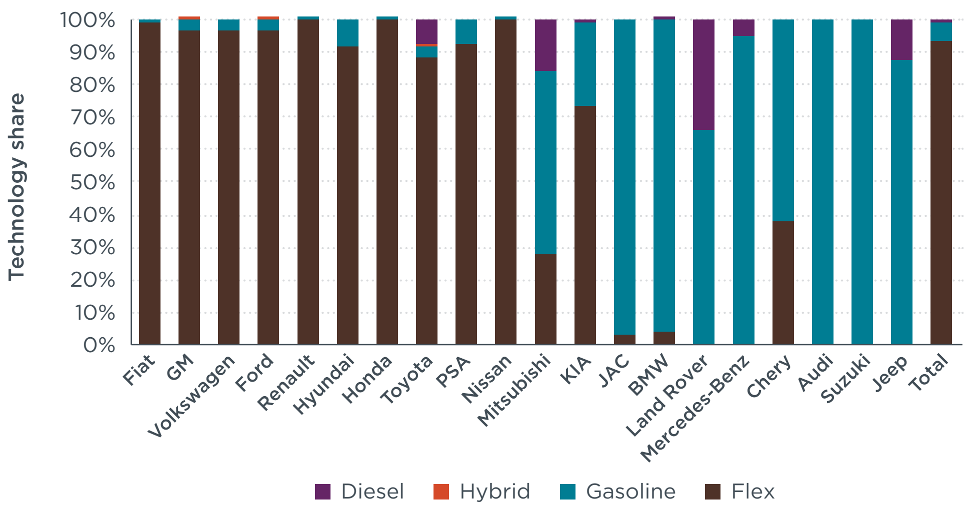

Figure 3-2 – Fuel type by manufacturer.

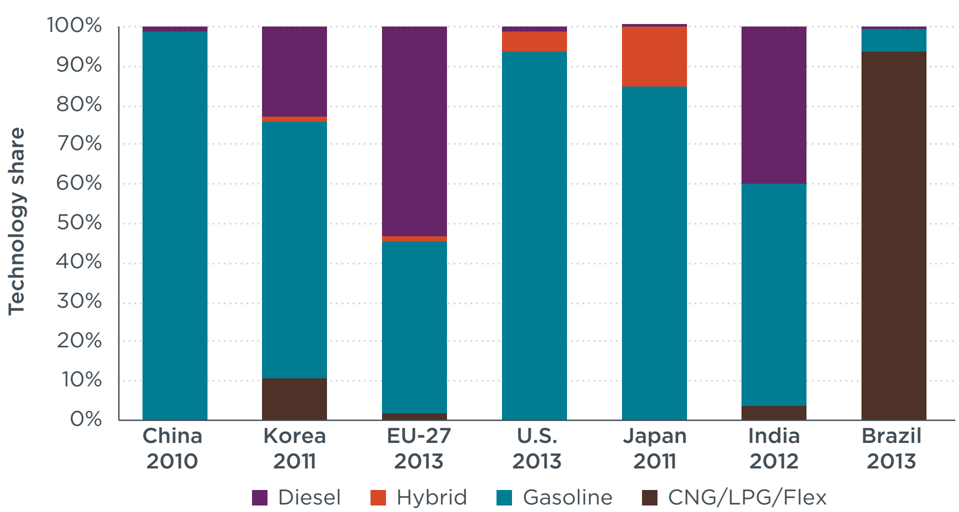

Figure 3-3 – Fuel type: international comparison.

NUMBER OF CYLINDERS

Across all vehicle markets, 4-cylinder engines are the most common design in automobile engines with displacements below 2.5 liters. This engine configuration presents the right balance between complexity and performance for the target vehicle segments (small to mid-size sedans, SUVs, and some off-road vehicles). Engines with six and more cylinders are designed to provide a smoother vehicle driving experience, with lower vibration and noise than 4-cylinder engines can provide, and with higher power output. This better overall performance comes at a higher cost, driving their widespread use in large and luxury vehicles, and heavier SUVs and off-road vehicles.

The need to attain better energy consumption has resulted in a recent wave of 3-cylinder engines from a handful of manufacturers in vehicles that typically used 4-cylinder engines, achieving similar or better performance. This practice is known as engine downsizing. Downsizing can also be applied to larger engines, from V-8s to V-6s, and from V-6s to I-4s. In most cases engine downsizing is accompanied with turbocharging and changes to the fuel delivery system.

Four-cylinder engines dominate the passenger vehicle market in Brazil, and are sold in more than 90% of new vehicles among all segments except the sports, off-road, and minivan segments (**Figure 3-4**). Despite its predominance, sales of 4-cylinder engines fell from over 3.07 to 2.93 million units between 2012 and 2013, equivalent to a 4% reduction. 4-cylinder vehicles represent the majority of sales among the 20 top manufacturers, except for Hyundai and Jeep (**Figure 3-5**). Although 4-cylinder engines represent the dominant technology in all countries analyzed, Brazil still has the largest market share (**Figure 3-6**).

The most significant shift in market preferences in Brazil occurred with 3-cylinder engines. This technology is becoming more popular, with almost eight times more vehicles sold in 2013 compared to 2012, reaching almost 75,000 units in 2013. Almost all 3-cylinder engines are being sold as compact vehicles, instead of the smaller subcompact segment. Hyundai is the technology leader in sales of 3-cylinder high-efficiency Kappa engines.[8] Japan and India have relatively high penetration of 3-cylinder engine technology. In India, the popularity of 2- and 3-cylinder vehicles is primarily driven by lower price tags (< USD $8,000).

Six-cylinder engines are third in sales after 4- and 3-cylinder engines, with absolute numbers close to 25,000 units sold in 2013; its market share reduced by 13% with respect to 2012. Six-plus cylinder engines are being sold mostly in the sports, off-road, and minivan segments. Manufacturers that cater to the most expensive models and segments dominate the market of vehicles with six-plus cylinder engines, such as Land Rover, BMW, and Mercedes-Benz. The penetration of 6-plus-cylinder engines in Brazil is very low compared to other countries.

Five-cylinder engines are not very common in Brazil or other countries, and are losing market with respect to 2012 sales, by 56%. Volkswagen, Audi, and Volvo are the only manufacturers that offered 5-cylinder engines in Brazil in 2013.

8 Hyundai's 3-cylinder Kappa engine: http://worldwide.hyundai.com/WW/Showroom/Cars/HB20/PIP/index.html

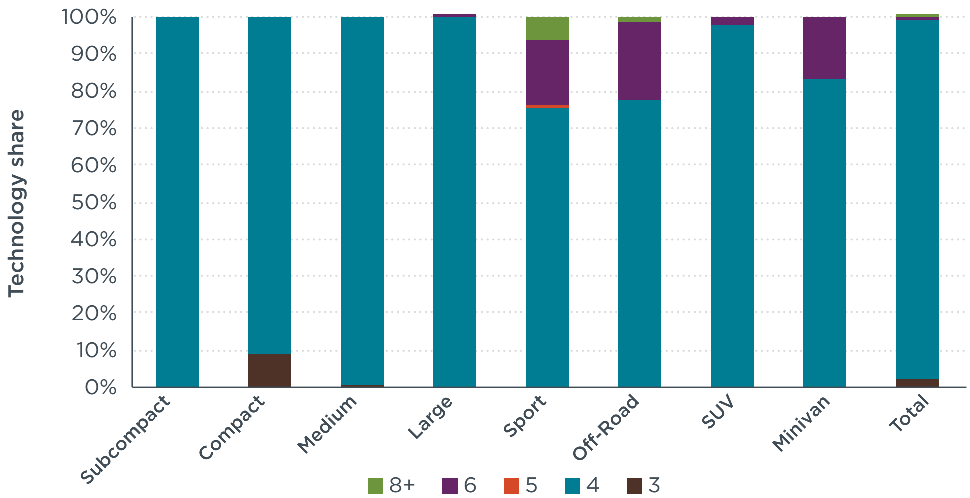

Figure 3-4 – Number of cylinders by segment.

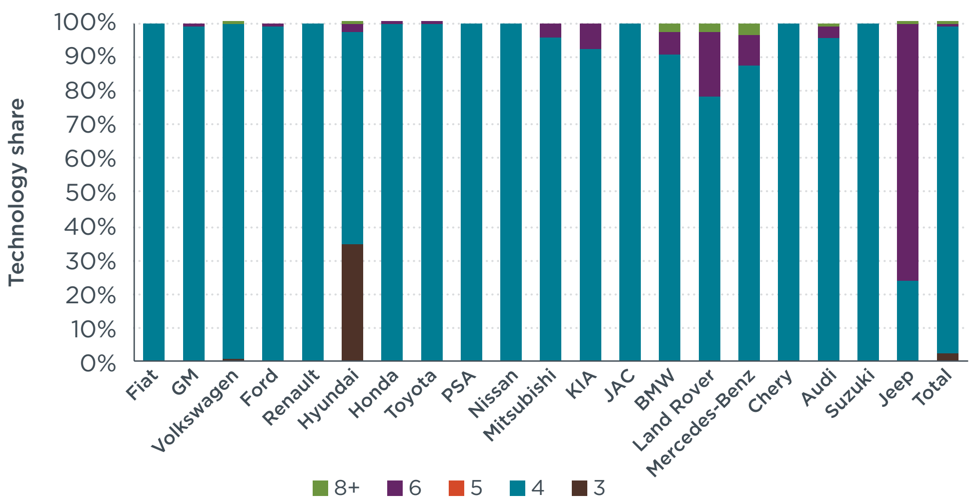

Figure 3-5 – Number of cylinders by manufacturer.

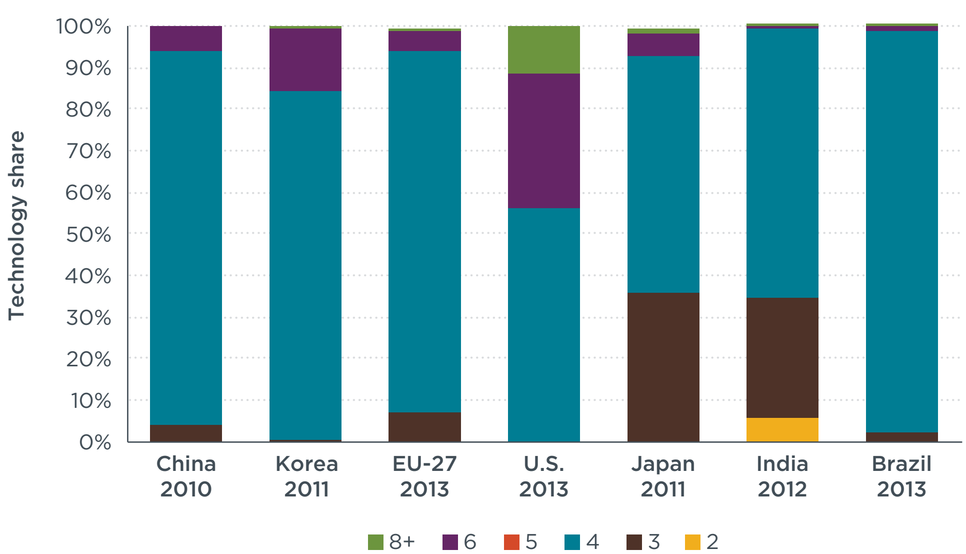

Figure 3-6 – Number of cylinders: international comparison.

TRANSMISSION

Transmission technologies can reduce energy consumption in two ways: First, by allowing engine operation on a more efficient region of the engine map and, second, by reducing the mechanical losses within transmissions. Traditionally, manual transmissions have offered better energy consumption than traditional automatic transmissions (with 4 or 5 speeds) due to lower friction losses. However, new generation of automatic transmissions with higher number of gears, lower friction, better materials and computer-controlled shift points have not just closed the gap between manual and automatic transmission performance, but even exceed manual transmission performance.

New technologies such as dual-clutch transmissions (DCTs) and continually variable transmissions (CVTs) are gaining market share due to the need for lower vehicle energy consumption. DCTs can be defined as manual transmissions with electro-hydraulically operated dual-clutch systems, allowing for faster shifting times and selective automatic or "manual" operation. As opposed to manual, automatic and DCT transmissions, which have a discrete number of gear ratios, CVTs have a theoretically infinite choice of ratios between fixed limits, which allows engines to be further optimized for minimizing energy consumption. CVT technology has been used in lower-horsepower vehicles because of maximum-torque limitations with the most common metal-belt design (NAS 2011). These advanced transmission technologies offer significant benefits in energy consumption compared to traditional manual or automatic technologies. According to the U.S National Academy of Sciences, a 6-speed DCT provides 6% to 9% lower energy consumption than a 4-speed automatic transmission. Note that a traditional 6-speed automatic transmission provides an estimated 3% to 5% benefit. The energy consumption benefit of CVT depends on the application, and is estimated to be 1% to 7% (NAS 2011).

Although vehicle sales with manual transmissions are predominant in Brazil, the penetration of automatic transmissions, CVTs, and DCTs is increasing, resulting in a market share loss for manual transmissions of about 6% between 2012 and 2013 (**Table 3-1**). With the exception of sports and off-road segments, manual transmission technology has the largest market share in all segments, but it tends to become less predominant as vehicles grow in size and comfort level (**Figure 3-7**). The top five manufacturers sell most of their vehicles with manual transmissions, but their market share is somewhat smaller for other high-selling manufacturers that cater to a more affluent market (**Figures 3-8**).

Automatic transmissions are becoming increasingly popular in Brazil, experiencing an increase of 28% in sales between 2012 and 2013. Automatic transmissions dominate the sports and off-road segments. Kia, BMW, Land Rover, Mercedes-Benz, and Jeep adopt this type of transmission technology for most of their vehicle sales.

DCT transmissions are entering the Brazilian market mostly through the sports segment, via imported models. The sales of DCT equipped vehicles increased in 2013 by 22% with respect to 2012. DCT technology is being offered mainly by manufacturers that sell sports vehicles, such as Audi in more than 67% of their vehicles, and Mercedes-Benz in more than 15% of their vehicles. The global leader in DCT adoption is Europe, followed by the U.S. (**Figure 3-9**).

CVT technology market is still relatively small, being sold by small volume manufacturers like Jeep, Audi, and Mitsubishi, with more than 25% of new vehicle sales each. Nissan, Renault, Honda, and Toyota also sell vehicles with CVT technology. CVT penetration in Brazil is similar to Europe's. CVT is the leading transmission technology in Japan with more than 65% of the market.

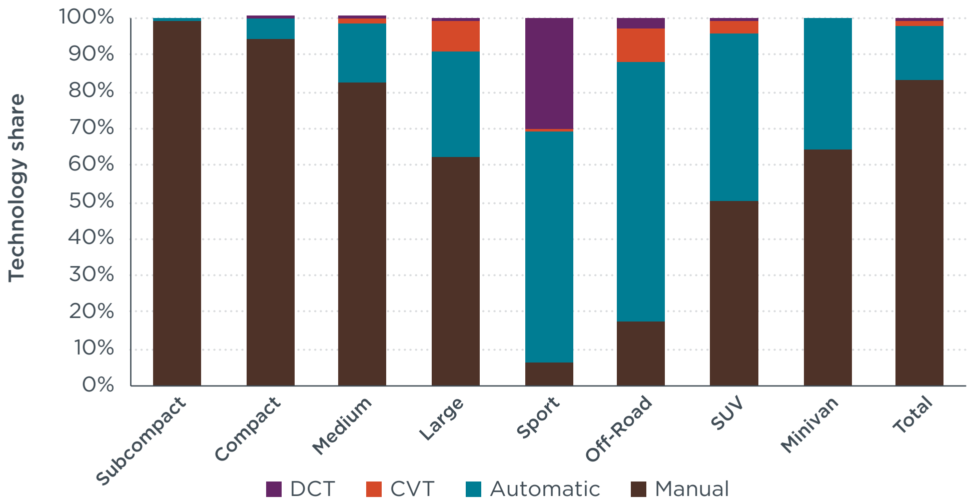

Figure 3-7 – Transmission by segment.

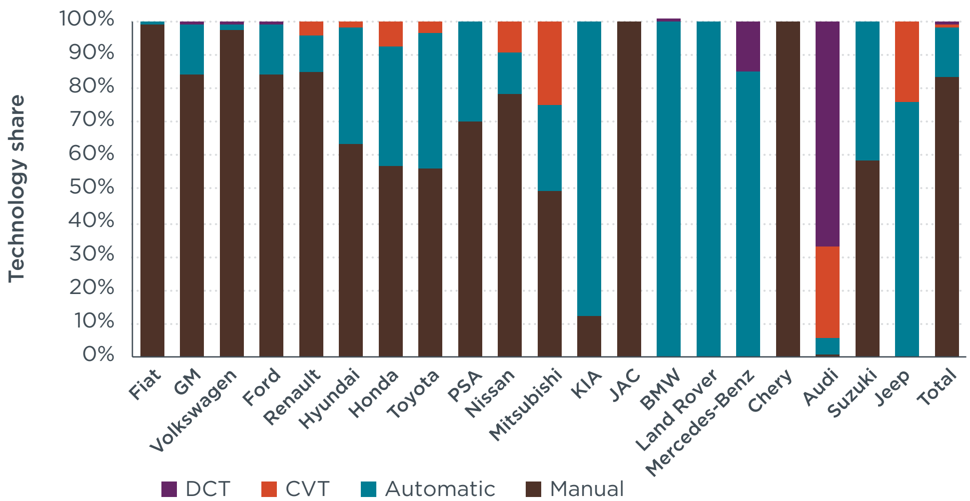

Figure 3-8 – Transmission by manufacturer.

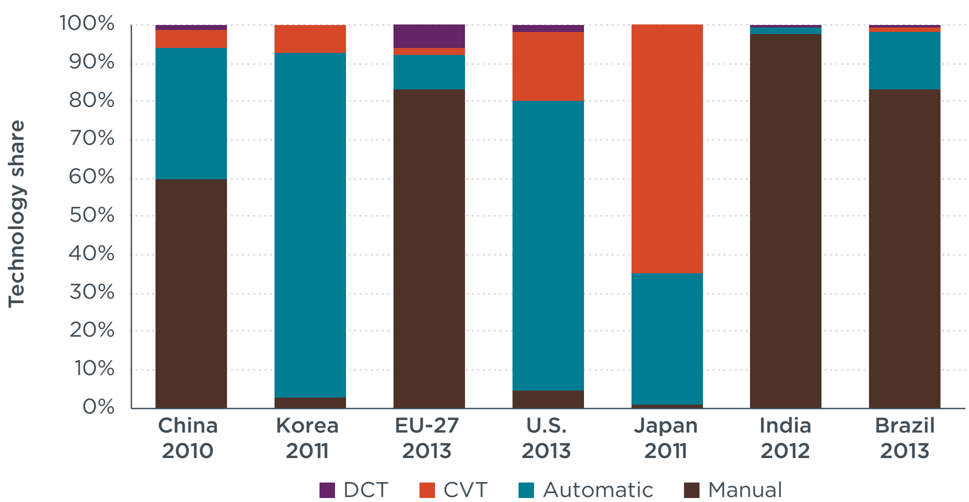

Figure 3-9 – Transmission: international comparison.

NUMBER OF GEAR RATIOS

As mentioned in the previous section, increasing the number of gear ratios (whether manual, automatic, dual-clutch, or continuously variable) allows the engine to be operated in the best efficiency region resulting in energy consumption benefits. Compared to an automatic four-gear ratio transmission (also known as 4-speed transmission), higher ratio automatic transmissions could reduce energy consumption from 2% to 3% (for a five-gear ratio) to 6% to 8% (for an eight-gear ratio) (EPA/NHTSA 2010).

Four-gear ratio transmissions are losing market share in Brazil, by more than 5% between 2012 and 2013 (**Table 3-1**). These transmissions are particularly high sellers in the SUV and minivan segments, which suggest that some models in these more expensive segments are being sold with outdated technologies (**Figure 3-10**). Most manufacturers are phasing out this type of transmission (**Figure 3-11**), although Jeep, Suzuki, and Toyota are lagging behind other manufacturers. The four-gear ratio transmission technology has been losing market share in most countries; even in India, where smaller and inexpensive cars dominate the market, 4-speed transmissions have the smallest market share (**Figure 3-12**).

Five- and six-gear ratio transmissions were predominant in the Brazilian market in 2013. Five-gear ratio transmissions are dominant in all segments, except for the off-road and sports segments, which have adopted six-gear ratio transmissions in most sales. The significant market share of five- and six-gear ratio transmissions is similar to most countries, although the U.S., Europe, and South Korea show higher shares of six and more gear ratios.

Seven- and eight-gear ratio transmissions, which are considered emerging technologies, have experienced an increase in sales in Brazil with over twice as many sales in 2013 compared to 2012. Seven- and eight-gear ratio transmissions are popular among the large, sports, and off-road segments, all of which are imported models. Luxury manufacturers such as Mercedes-Benz and Audi are selling the most seven-gear vehicles as a share of their sales; Volkswagen and Toyota are also selling similar numbers of seven-gear ratio vehicles, although for Volkswagen and Toyota it represented less than 3% of their brand sales. BMW and Land Rover are the leaders in eight-gear ratio vehicles.

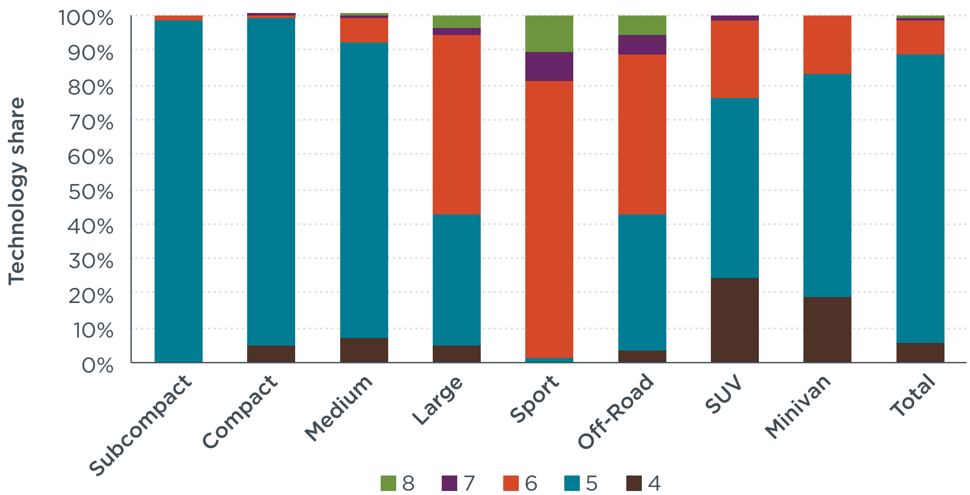

Figure 3-10 – Number of gear ratios by segment.

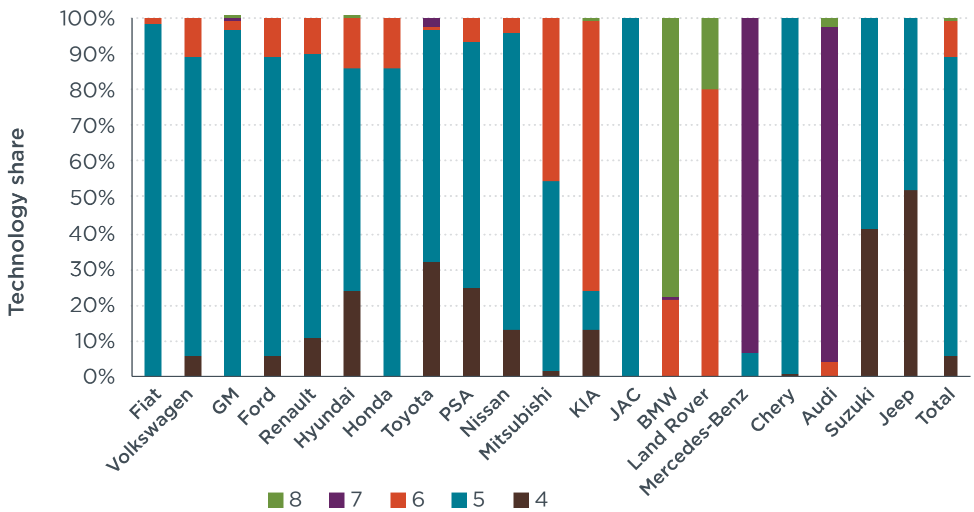

Figure 3-11 – Number of gear ratios by manufacturer.

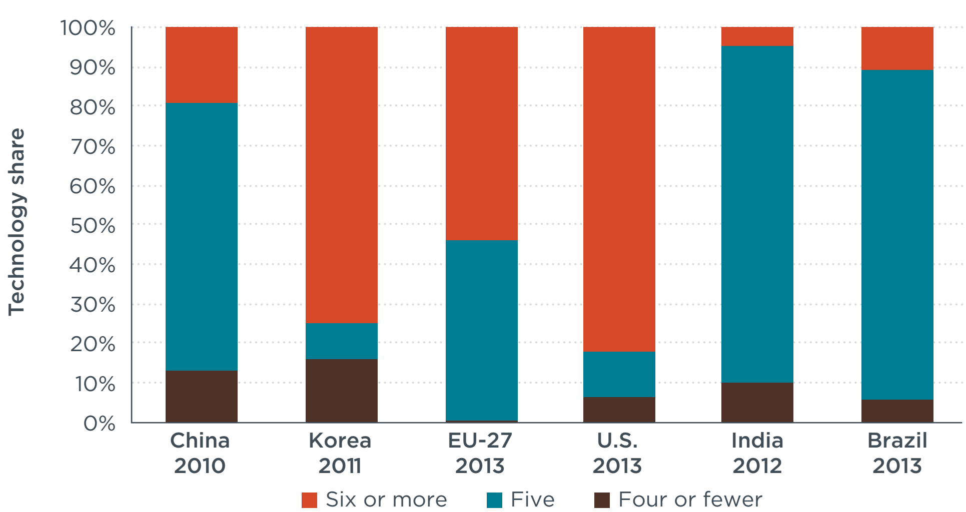

Figure 3-12 – Number of gear ratios: international comparison.

DRIVETRAIN

Drivetrain technology includes front-wheel drive (FWD), rear-wheel drive (RWD), and all-wheel drive (AWD) vehicles. For the same vehicle size, FWD vehicles provide more interior space and better energy consumption than RWDs due to lower weight, as it avoids the added weight of and space for the driveshaft and differential that RWD requires. Because the weight of the engine and transmission is located close to the wheels, FWD vehicles have better traction than RWDs. RWDs, however, show better handling, as the weight distribution between the front and rear wheels is more uniform and the tasks of turning and acceleration are split between the front and rear wheels. Also, directing large amounts of power through the front wheels can create "torque steer". Thus, RWD is the adequate technology for the sports segment. AWD drivetrains are intended for specific driving applications that imply loss of traction, such as off-road terrains, snow, or towing.

FWD vehicles dominate all segments of the Brazilian passenger car market (**Table 3-1**), with the exception of the off-road segment (**Figure 3-13**). Among the 20 largest manufacturer sellers, most, except for BMW, Land Rover, Mercedes-Benz, and Suzuki offer FWD technology (**Figure 3-14**). Brazil has the highest market share of FWD vehicles of all countries analyzed (94.4%), although FWD has at least 50% market share in all seven countries (**Figure 3-15**).

AWD market share increased by 15% between 2012 and 2013 due to a tri-fold increase in the sports segment sales. Off-road vehicle sales with AWD also increased to more than 76,000 units in 2013. Amongst the largest ten manufacturers, Toyota is the AWD market leader, followed by Ford and Volkswagen. Note that Land Rover sells only AWD vehicles in Brazil. Among non-luxury manufacturers, Mitsubishi and Suzuki are selling more than 50% of their vehicles with AWD technology.

RWD technology is offered mostly in large and sports vehicles, and in SUVs. Among the 10 largest manufacturers, RWD is offered mainly by GM and Toyota, while an extended examination of the 20 largest manufacturers by sales, show that AWD and RWD is focused among the more expensive brands (**Figure 3-14**). Mercedes-Benz and BMW sell close to 90% of their vehicles with RWD technology traditionally associated with engine performance and responsiveness.

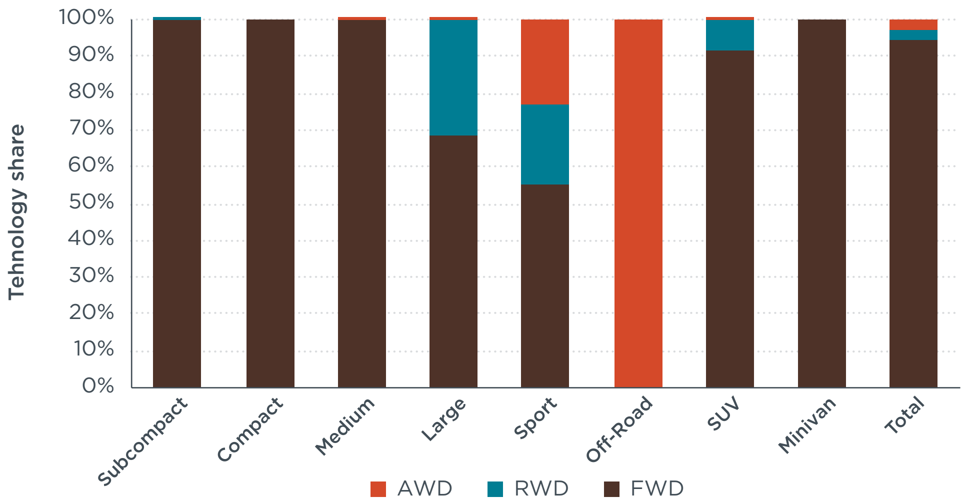

Figure 3-13 – Drivetrain by segment.

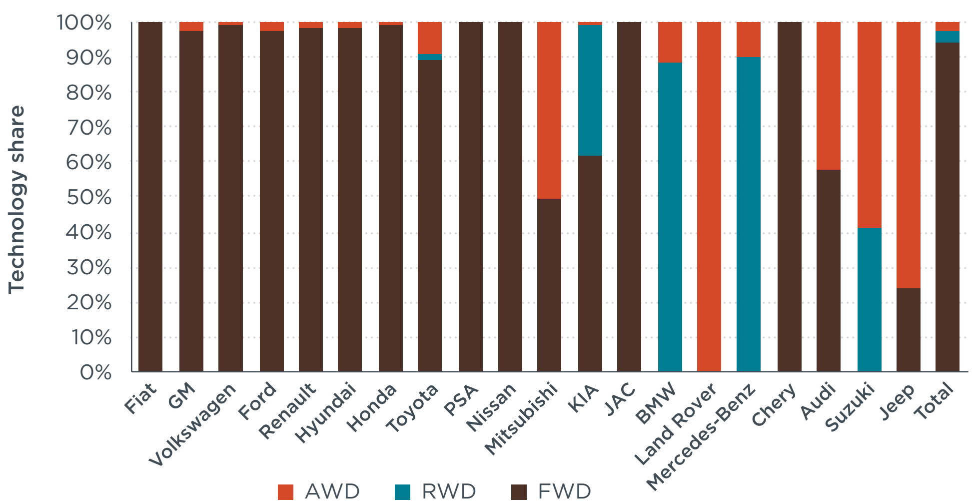

Figure 3-14 – Drivetrain by manufacturer.

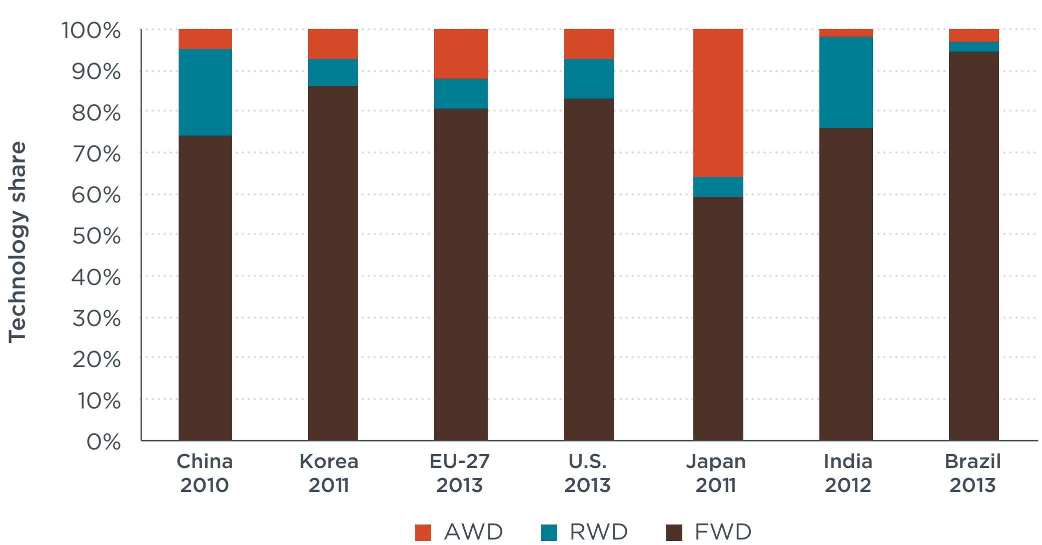

Figure 3-15 – Drivetrain: international comparison.

VALVE CAMSHAFT CONFIGURATION (DOHC VS. SOHC)

The engine camshaft governs the timing, duration, and lift of valve operation, controlling the intake of air and the exhaust of combustion gases. This report focuses on single overhead camshafts (SOHC) and dual overhead camshafts (DOHC), as these configurations have almost completely replaced the older overhead valve configuration (OHV). SOHC design places a single camshaft above the cylinder head that governs all the valves, intake, and exhaust. In the case of SOHC V-engines, there is one single camshaft per head. DOHC designs use separate camshafts for intake valves and exhaust valves. DOHC engines achieve increased airflow at high-engine speeds, improve volumetric efficiency, and reduce the valvetrain's moving mass. Such engines typically develop higher power at high-engine speeds. The U.S. Environmental Protection Agency (EPA) and National Highway Traffic Safety Administration (NHTSA) estimate the effectiveness of DOHC over SOHC to be between 1% and 2.5% (EPA/NHTSA 2010).

Although DOHC produce more power and provide lower fuel consumption, the Brazilian fleet is still mostly composed of SOHCs vehicles (**Table 3-1**). SOHC technology is predominant among the subcompact, compact, and medium segments (**Figure 3-16**). Among manufacturers, SOHC technology is predominant among the five largest, least expensive brands (**Figure 3-17**). Sales of vehicles with more advanced DOHC technology grew in 2013 by almost 36% with respect to 2012, albeit from a relatively smaller base. This increase was experienced in all vehicle segments, but in different magnitudes.

Although global data on this technology are scarce, **Figure 3-18** indicates that most countries are moving away from SOHC, with Brazil being the only country analyzed where SOHC is still predominant. No data were available for the U.S. or Europe.

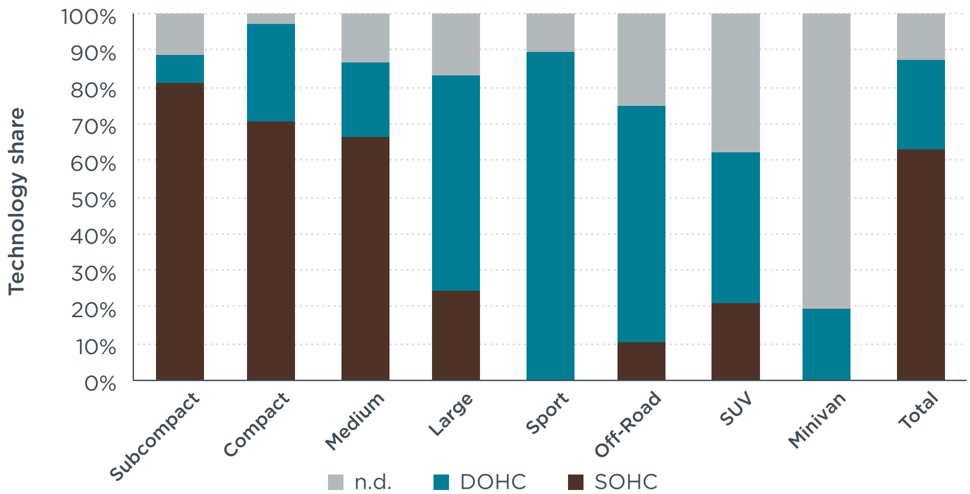

Figure 3-16 – Valve camshaft configuration by segment. *(n.d.: no data.)*

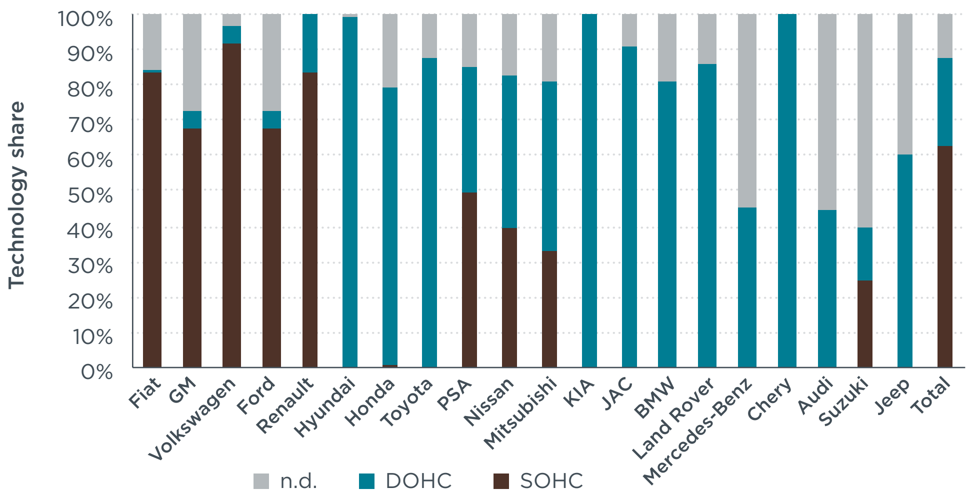

Figure 3-17 – Valve camshaft configuration by manufacturer. *(n.d.: no data.)*

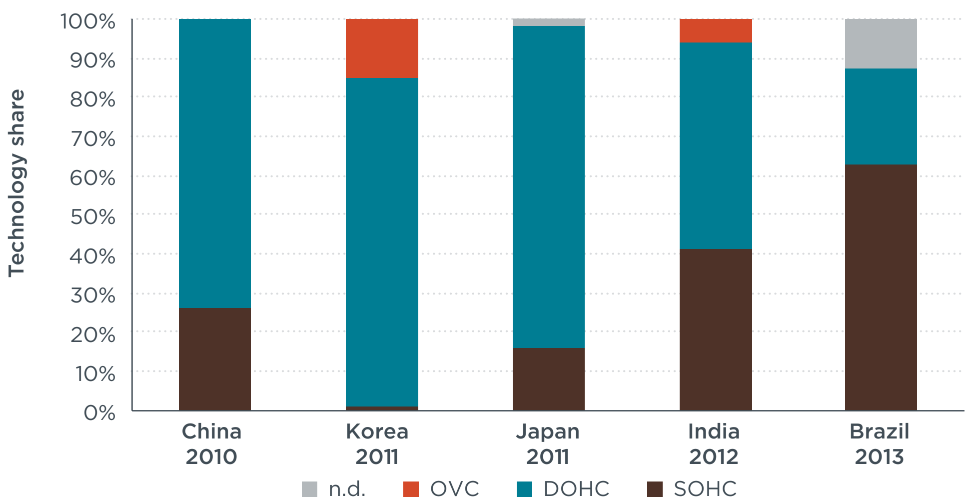

Figure 3-18 – Valve camshaft configuration: international comparison. *(n.d.: no data.)*

VALVE ACTUATION

Improved valvetrain systems with variable valve actuation (VVA) technology, either variable valve timing (VVT) or variable valve timing and lift (VVT+VVL) improves the engine's volumetric and thermodynamic efficiency. They also enable further engine improvements such as internal exhaust gas recirculation and cylinder deactivation. VVT alters the timing of the intake valve, exhaust valve, or both, primarily to reduce pumping losses, increase specific power, and control residual exhaust gases. VVL increases efficiency by optimizing airflow over a broader range of engine operation, which reduces pumping losses and increases specific power. VVL is accomplished by controlled switching between two or more cam profile lobe heights. The most advanced technology, VVT+VVL yields a wide range of performance optimization and volumetric efficiency, including enabling the engine to be valve-throttled (no need for intake throttle). VVT provides energy consumption gains of 3% to 5%, while the more flexible and complex VVT+VVL system can reach 4% to 8% (EPA & NHTSA, 2010).

VVA technology, either VVT or VVT+VVL, are emerging technologies in Brazil, where most vehicles still have fixed-valve timing designs (**Table 3-1**). Fixed technology is predominant among the smaller vehicle segments, as well as SUVs and minivans (**Figure 3-19**). The five largest manufacturers sold more than 90% of their vehicles with fixed-valve technology in 2013 (**Figure 3-20)**. The international comparison indicates that only Brazil and India have not yet adopted VVA technologies for most of their light-duty fleet (**Figure 3-21**).

VVT and VVT+VVL are being adopted across all segments, including the subcompact segment, but tend to be more predominant in high-end manufacturers. A closer examination by manufacturer shows that most are offering some vehicles with either one of the VVA systems, while Honda and Hyundai offer this technology in almost all vehicles (**Figure 3-20**). Honda is the technology leader in variable valve actuation, with the adoption in the early 1990s of the VTEC system (Valve Timing Electronic Control). VVT technology's market share grew by about 25% in 2013, primarily due to Hyundai's sales, from 80,000 units in 2012 to almost 200,000 units in 2013. Hyundai offered the continuously variable valve technology (CVVT) in the large majority of vehicle sold in 2013. The sports segment is the one where VVT dominates the market. Mitsubishi, BMW, and Audi are also selling a large share of their vehicles with the VVT+VVL technology.

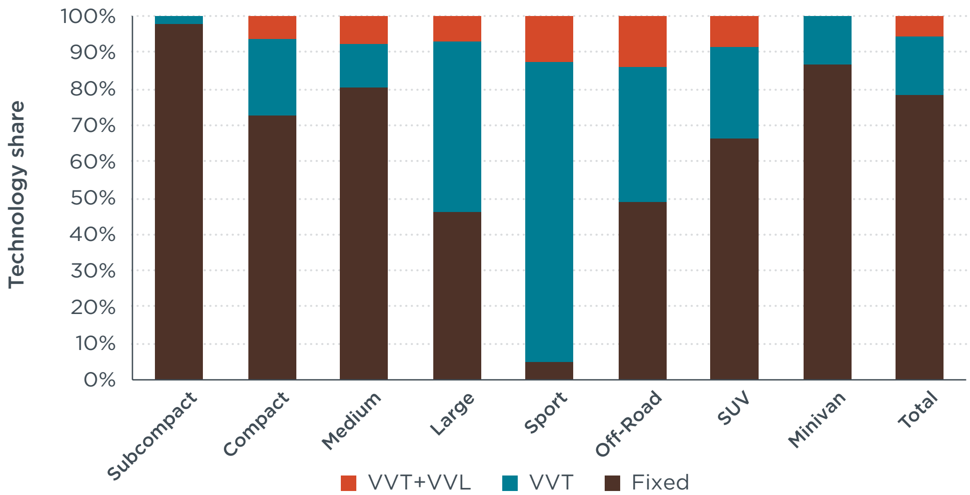

Figure 3-19 – Valve actuation by segment.

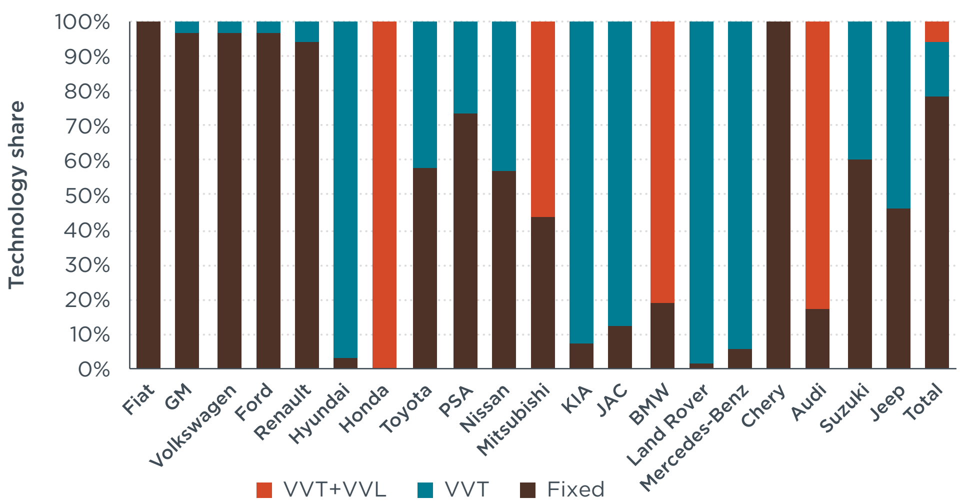

Figure 3-20 – Valve actuation by manufacturer.

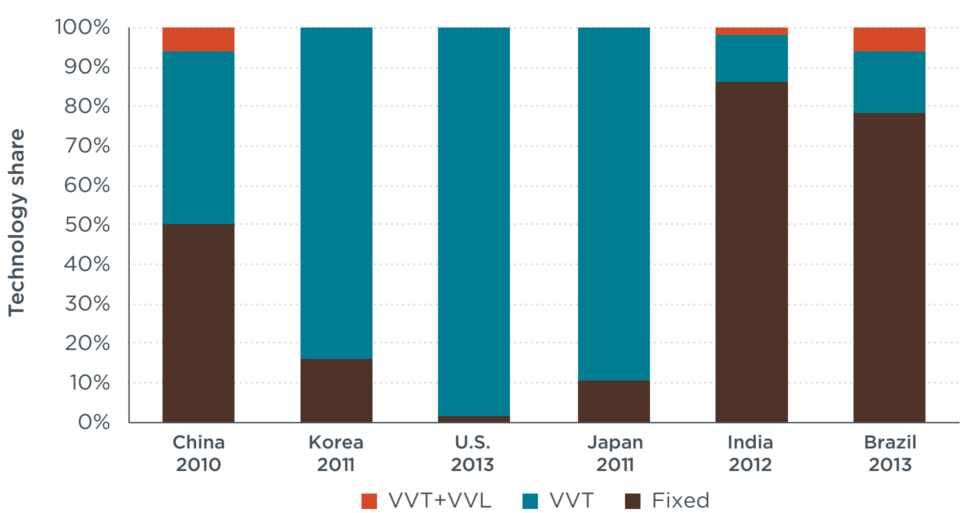

Figure 3-21 – Valve actuation: international comparison.

FUEL SYSTEMS FOR GASOLINE VEHICLES

Vehicle fuel systems describe the technology required to deliver fuel into the engine combustion chamber. This section examines two gasoline/flex technologies, namely multi-point fuel injection (MPFI) and gasoline direct injection (GDI). MPFI is now the most common fuel-delivery system for gasoline engines used in passenger vehicles worldwide. In sequential MPFI engines, fuel is injected into the air stream next to the intake valve port while the intake valve is open to draw the air-fuel mixture into the cylinder. Some of the fuel is vaporized on the surface of the hot intake valve, expanding, and thus reduces the volumetric efficiency. On GDI engines, fuel is injected at high pressure directly into the combustion chamber, improving volumetric efficiency and providing cooling of the air/fuel charge within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency. GDI technology alone offers benefits of 2% to 5% with respect to MPFI engines, but bigger benefits rely on the synergy between GDI, turbocharging and downsizing, which can reach 12% to 15% energy consumption reduction with respect to a MPFI, naturally aspirated engine (EPA 2012).

Table 3-1 illustrates that MPFI is still the most common fuel injection technology for gasoline/flex vehicles in Brazil, which is reflected in its dominant share across most segments, except for sports and off-road vehicles. In Brazil, GDI has found a niche market in the sports and off-road segments, with more than 90% of sport vehicles fitted with GDI technology (**Figure 3-22**). Within the overall gasoline market, the GDI technology is still an emerging technology, representing just 2.4% of new sales. GDI's market share increased by 31% in 2013, with all but 4,000 units being imported. Among the 10 largest manufacturers, the adoption of GDI is extremely low, below 5% for Volkswagen, Ford, Hyundai, and PSA (**Figure 3-23**). High-end European brands (Audi, Land Rover, Mercedes-Benz, and BMW) are the technology leaders in terms of GDI adoption rates, echoing the trend of turbocharging technology sales. Volkswagen vehicles with GDI systems account for less than 3.5% of their sales in 2013, but their absolute numbers (around 19,000 vehicles) place the company as one of the leaders in GDI technology in the Brazilian market.

From a global market perspective, the penetration of GDI technology in Brazil is low, compared to all other markets in **Figure 3-24**, except for India and Japan. It should be noted that the later has the largest share of hybrid vehicles around the globe.

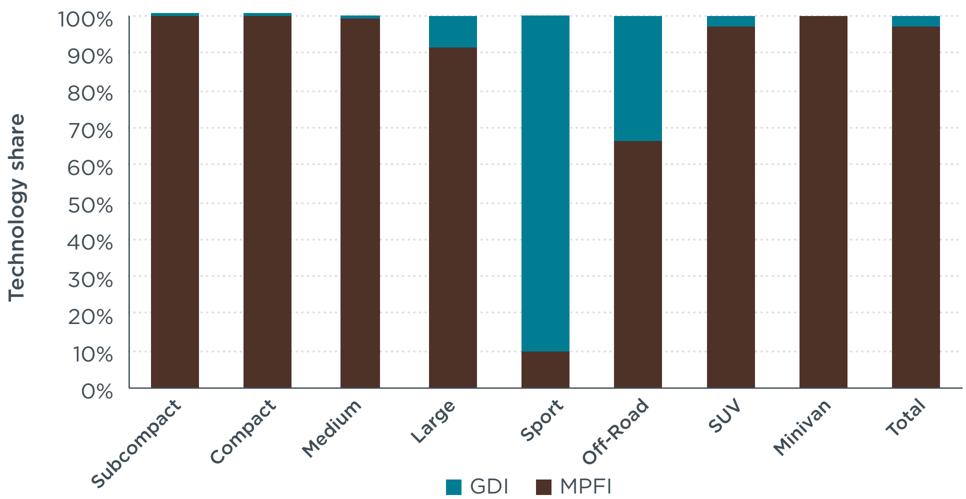

Figure 3-22 – Gasoline/flex fuel system by segment.

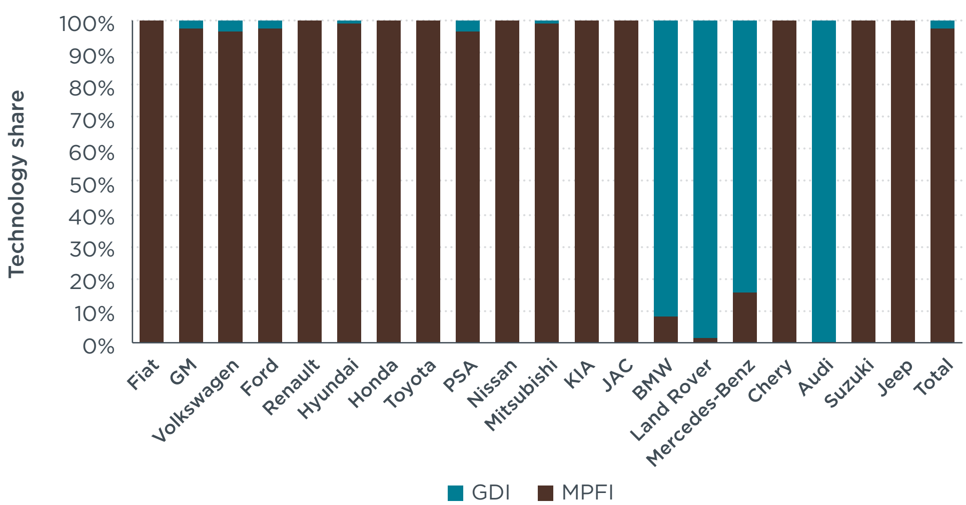

Figure 3-23 – Gasoline/flex fuel system by manufacturer.

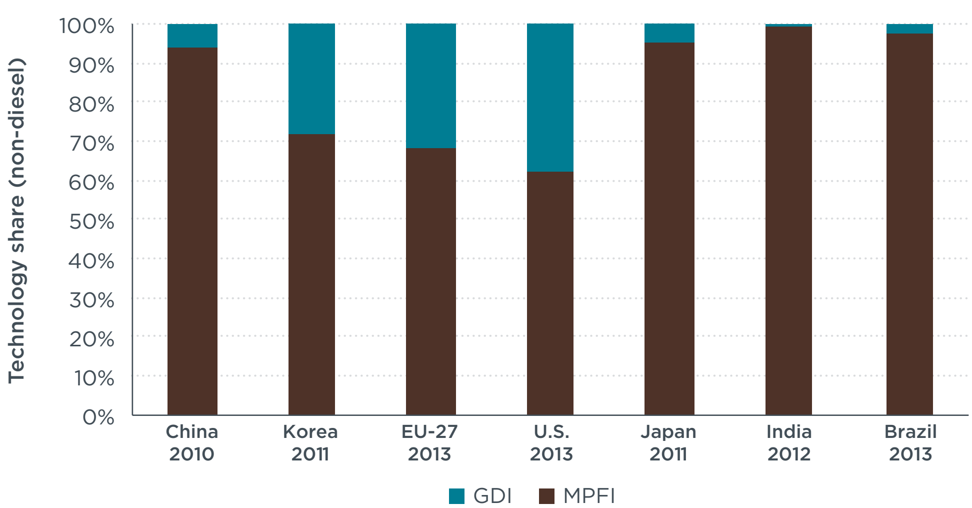

Figure 3-24 – Gasoline/flex fuel system: international comparison.

TURBOCHARGING

Engine power is primarily limited by the rate at which the engine is able to draw air into the combustion chamber. Turbocharging and supercharging are two methods to increase the amount of air drawn into the engine above the level of what is possible with the naturally aspirated process (through the expansion of the cylinders). By increasing the amount of air into the engine, the amount of fuel can be proportionally increased, resulting in increased power output level, and with it, the ability to reduce engine displacement while maintaining performance. The combination of turbocharging and downsizing in spark ignited (gasoline and flex-fuel) vehicles can provide energy consumption improvements between 2% to 6% with respect to a direct-injected GDI engine (EPA & NHTSA, 2010). Turbocharging technology is the cornerstone for achieving better energy consumption in vehicles as the basis for downsizing and reducing the engine weight while keeping the same or better vehicle performance (i.e., acceleration or time to reach certain speed). Although turbochargers are used in diesel and gasoline/flex vehicles, the analysis in this report focuses on turbocharging for spark-ignited gasoline/flex vehicles only.

Turbocharging is one of the most important emerging technologies in Brazil, where most vehicles are still naturally aspirated (NA) (**Table 3-1**). Turbocharging technology has increased the market share significantly between 2012 and 2013, by more than 65%, albeit from a small base (from about 49,000 to 81,000 vehicles).

Most vehicles with turbocharging are sold in the sports and off-road segments, as this technology also produces superior engine power output (**Figure 3-25**). Among the 10 largest manufacturers, turbocharging is still below 10% of their sales (**Figure 3-26**). Volkswagen and Ford, despite having small relative sales of vehicles with turbocharging (less than 3.5%), are the manufacturers with the highest total sales of vehicles with turbocharging. Audi, Land Rover, Mercedes-Benz, and BMW are the technology leaders with more than 90% of vehicle sales in 2013.

The penetration of turbo and supercharging technologies in Brazil is lower than in other countries with a larger gasoline fleet, such as the U.S., China, and Japan (**Figure 3-27**). In Brazil, 95% of diesel passenger vehicle sales have turbocharging technology.

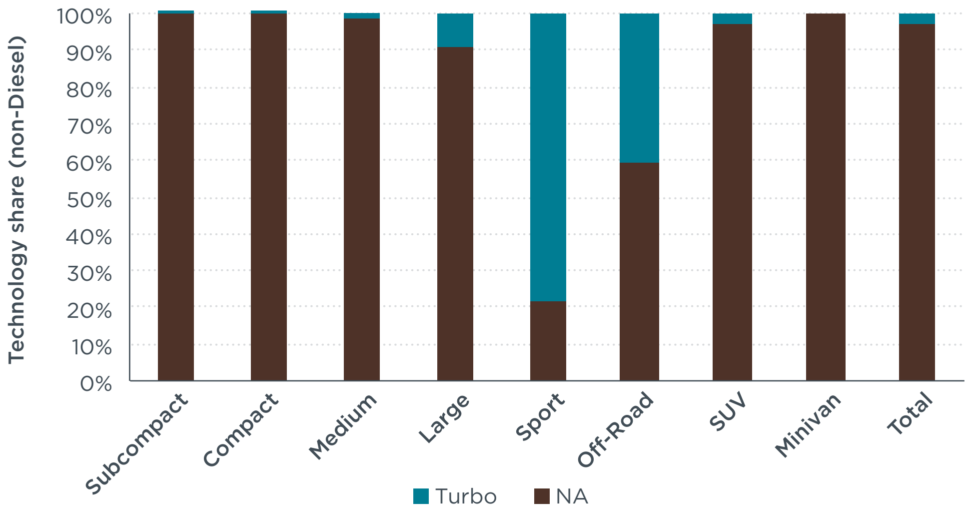

Figure 3-25 – Turbocharging for gasoline/flex fuel vehicles by segment. (*NA: naturally aspirated.*)

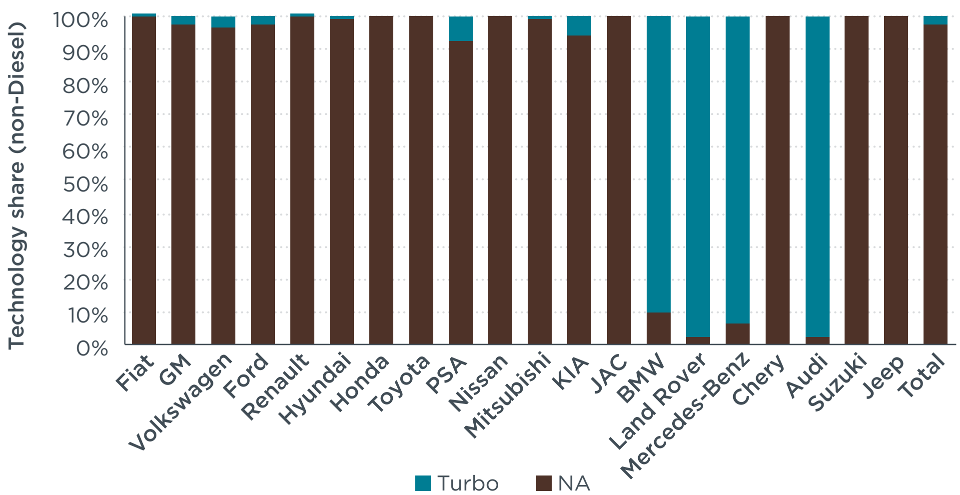

Figure 3-26 – Turbocharging for gasoline/flex fuel vehicles by manufacturer. (*NA: naturally aspirated.*).

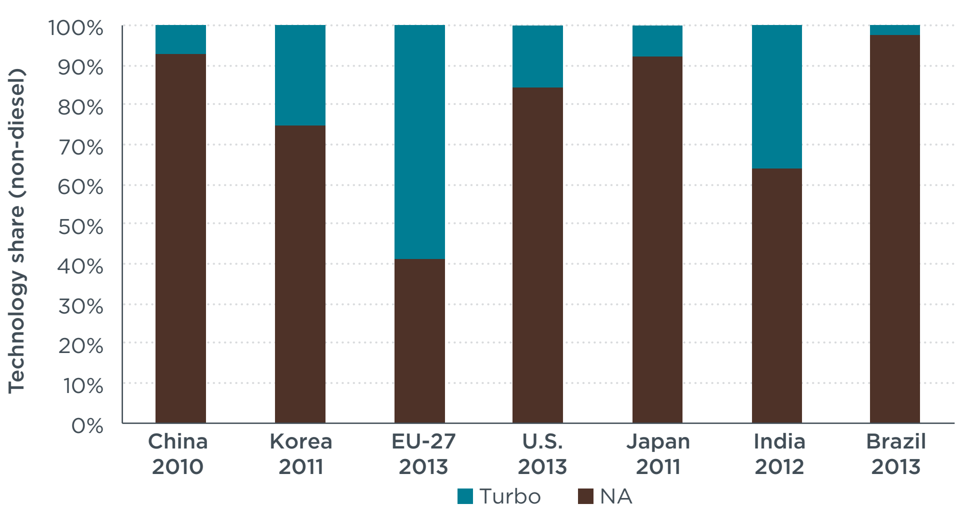

Figure 3-27 – Turbocharging for gasoline/flex fuel vehicles: international comparison. (*NA: naturally aspirated.*)

4. VEHICLE ENERGY CONSUMPTION

This section analyzes the Brazilian new passenger vehicle energy consumption in 2013. Although other metrics are more common (see box), vehicle energy consumption is presented in megajoules per kilometer (MJ/km) for consistency with Brazil's Inovar-Auto policy. In 2012, Brazil's Ministry of Development Industry and Foreign Trade (MDIC) adopted the Inovar-Auto policy with the aim of fostering industrial competitiveness through technology investments. The policy includes a target for corporate average energy consumption (in MJ/km, with vehicle curb weight as the attribute parameter) for vehicles sold in 2017.

In the U.S., Canada, Mexico, and Saudi Arabia, fleet-average fuel economy standards are defined as a function of vehicle footprint. In the EU, China, Japan, South Korea, and India, vehicle weight is the attribute for the calculation of fleet-average targets. In Brazil, Inovar-Auto has defined its fiscal targets for vehicle energy consumption, measured in megajoules per kilometer (MJ/km), as a function of vehicle weight.

VEHICLE ENERGY MEASUREMENT UNITS

Many metrics can be used to describe the amount of fuel, energy, or emissions generated by unit of distance traveled.

Fuel economy measures distance traveled per unit of fuel consumed. In Brazil, kilometers per liter (km/L) is the most common metric to describe vehicle efficiency, but other units are used in different countries, such as miles per gallon (mpg) in the U.S.

Fuel consumption is the reciprocal of fuel economy, and measures fuel consumed per distance traveled. It is usually expressed in liters per 100 kilometers (L/100 km), and it is used in Europe, for example.

GHG/CO_2 emissions measures GHG or CO_2 emissions per distance traveled, expressed as grams of pollutant per kilometer or mile.

Energy consumption (EC) measures the energy consumed per distance traveled, for example in megajoules per kilometer. Despite being a less common metric, it is sometimes preferred for being a fuel-neutral metric across different types of fuel and vehicle technologies. Vehicle energy consumption in MJ/km is the metric used in Brazil's Inovar-Auto policy to quantify the corporate average energy consumption target for each manufacturer. Values for energy consumption in Brazilian spark-ignited vehicles are provided for E22, since that is the fuel mixture used in vehicle tests.

Vehicle energy consumption in this report is calculated from CO_2 emissions data in the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) Nota Verde program (IBAMA 2014), which reports official emissions data from homologation tests. Data are limited to passenger cars sold by the top 10 manufacturers, with light commercial vehicles being excluded. Appendix D presents a description of data sources and calculation methodologies, as well as a discussion of vehicle energy consumption data quality and completeness in Brazil.

Not surprisingly, vehicle energy consumption increases with vehicle footprint and engine rated power, the two parameters that define vehicle segments in Brazil (**Figure 4-1**). Subcompact and compact vehicles, which accounted for about 45% of new sales in 2013, have average energy consumption below the fleet average, while medium-sized vehicles, which hold the largest market share (38.8%), have energy consumption just above the fleet average. Larger, more powerful vehicles consume more energy than the fleet average, but have a considerably smaller market share (combined share of 16.3%). Data availability for these segments is not as extensive as the data available for the subcompact, compact, and medium segments, which could affect the relative rankings of each segment.

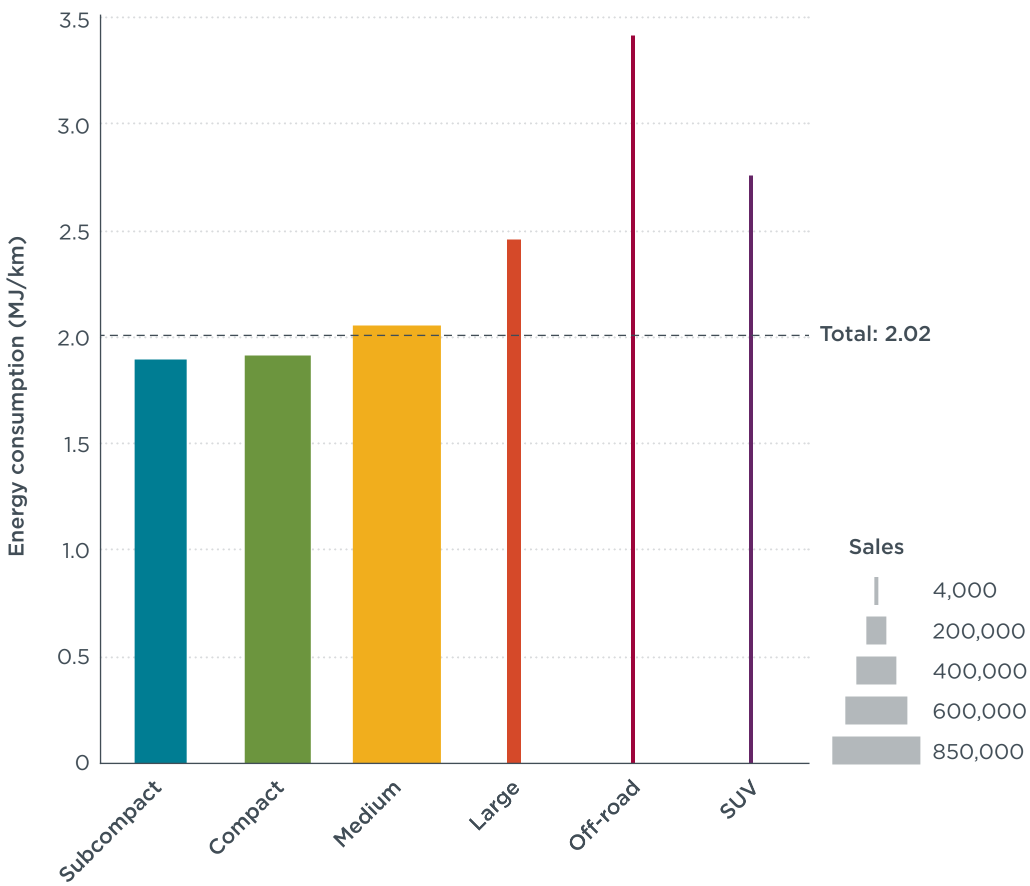

Figure 4-1 – New vehicle sales-weighted average energy consumption by segment (2013).

Figures 4-2 and **4-3** illustrate new vehicle energy consumption for multiple weight and footprint bins. For each weight bin (in 100 kg increments), and footprint bin (in 0.1 m^2 increments), sales-weighted averages of energy consumption for each vehicle version are presented (dashes), generating energy consumption ranges for each bin (cream areas). Vehicle sales by bin are presented for reference in the lower charts.

The strong correlation between vehicle energy consumption and weight follows from the strong physical relationship between the weight of the vehicle and the energy required to accelerate it and overcome resistances[9] (**Figure 4-2**). Data dispersion within each bin suggests that energy consumption varies due to other vehicle characteristics that affect vehicle aerodynamics and rolling resistance, as well as the adoption of technologies that affect engine and transmission efficiency (e.g., friction reduction technologies, GDI, VVT).

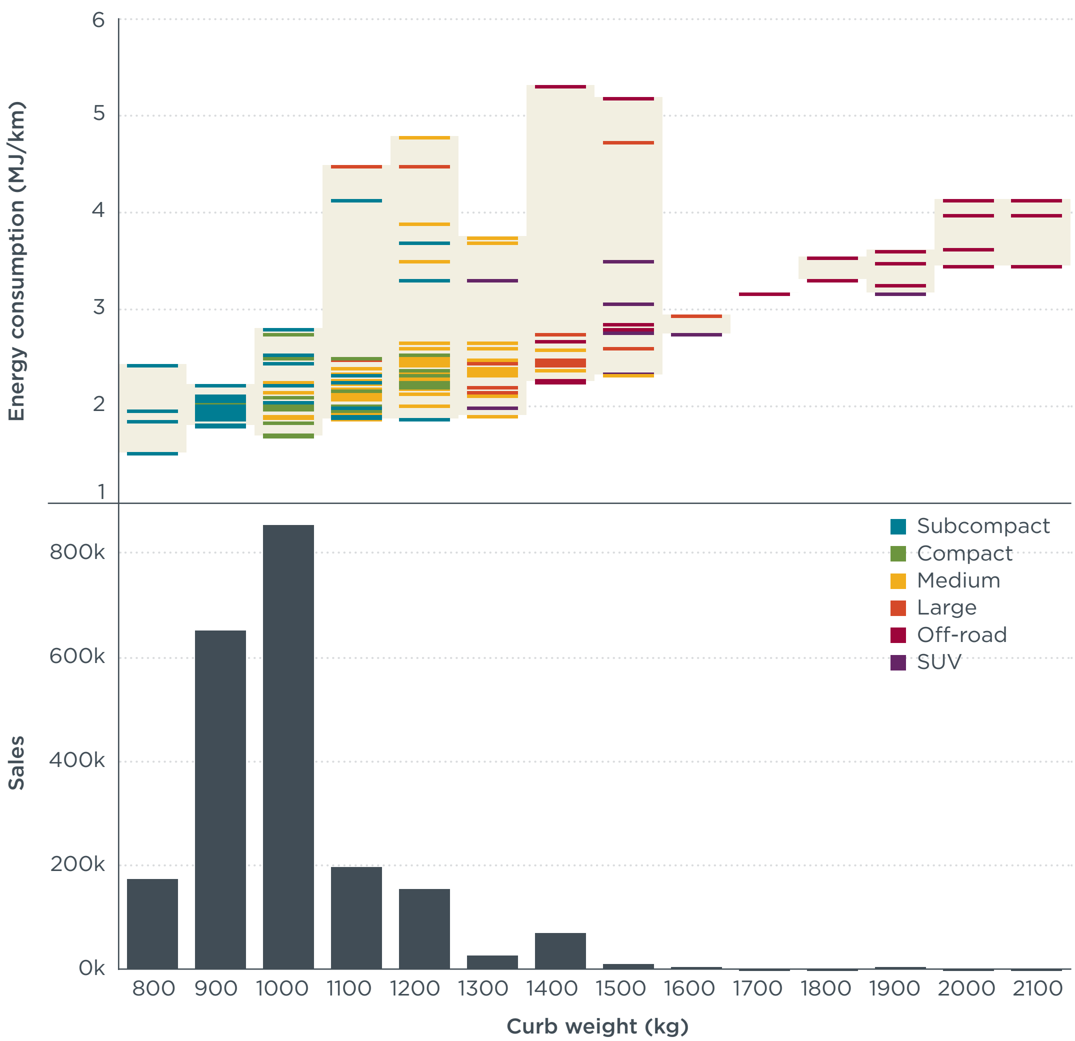

Figure 4-2 – New vehicle energy consumption by vehicle weight (2013).

9 On a plain surface the sum of resistances of a vehicle is: acceleration resistance + rolling resistance + aerodynamic resistance = $c_1 * m * a + c_2 * frr * m + c_3 * c_w * A * v^2$, with mass (m) as an integral part of both acceleration and rolling resistance, which are most relevant for inner-city driving situations. Other factors are: acceleration (a), rolling resistance of tires (frr), aerodynamic coefficient of the vehicle (c_w), frontal area of vehicle (A), velocity (v), and constants (c_x)

Footprint has a reasonable correlation with energy consumption (**Figure 4-3**), i.e., larger vehicles tend to consume more fuel than smaller vehicles. However, the correlation is not as strong as with vehicle weight. Similar to the previous figure, the broad spread of energy consumption values suggests a combination of different vehicle characteristics (e.g., weight, engine displacement, rated power) and technologies (e.g., transmissions, fuel systems), as well as the presence of SUVs and off-road vehicles among the medium- and large-sized footprint values, respectively.

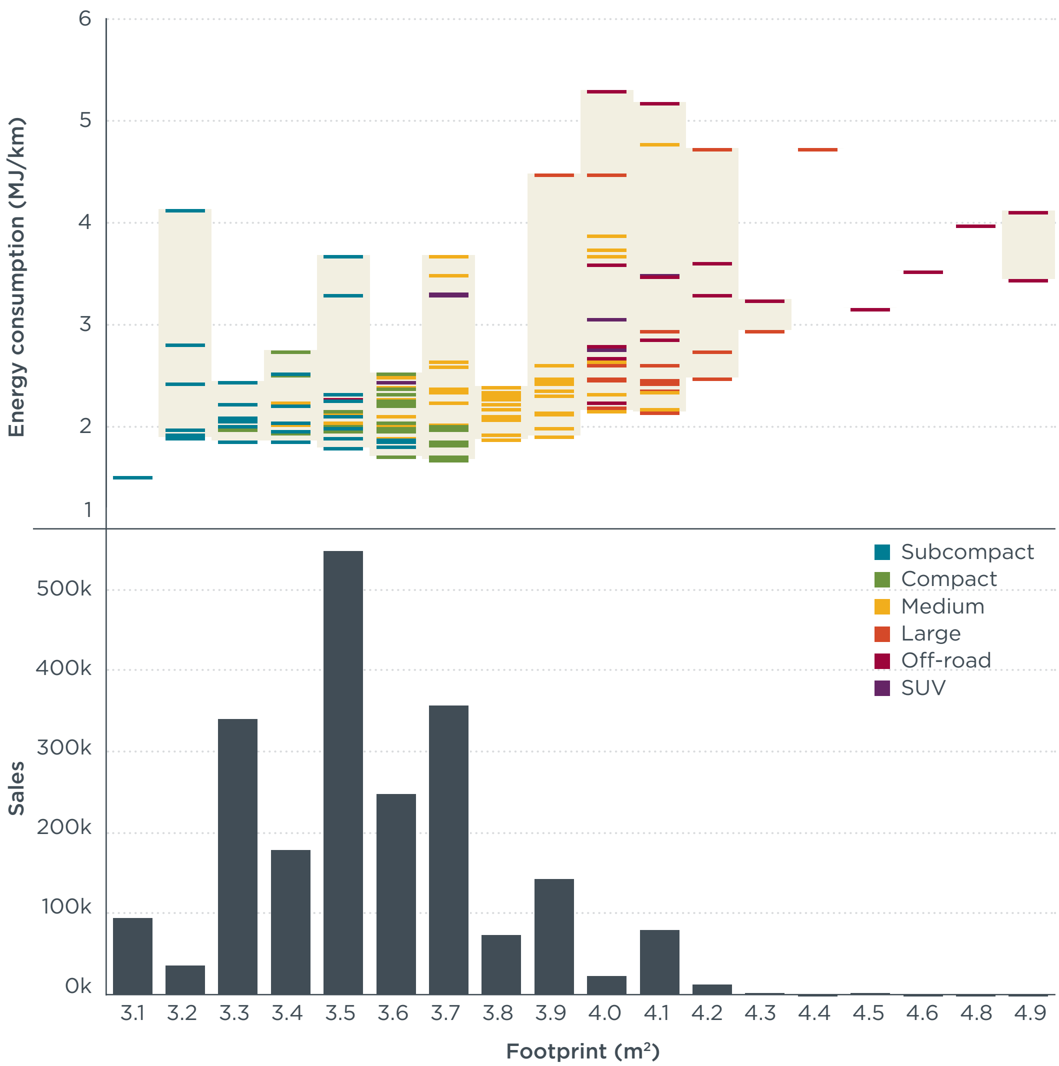

Figure 4-3 – New vehicle energy consumption by vehicle footprint (2013).

Figure 4-4 illustrates sales weighted average for new vehicle energy consumption by mass for the top 10 manufacturers in Brazil in 2013. Bubble sizes are proportional to total vehicle sales. Manufacturers in the lower-left quadrant produce the lightest and most efficient vehicles, with Hyundai presenting the best overall average energy consumption. Renault, in the upper-left quadrant, produces vehicles that are equivalent in weight, but on average with higher energy consumption. In the lower-right quadrant are manufacturers that produce relatively heavier vehicles, but with lower energy consumption in their weight class. Despite producing heavier vehicles on average than many manufacturers, Honda achieves lower energy consumption on average. In the upper-right quadrant are manufacturers that produce on average the heavier and least efficient vehicles, with PSA (Citroen and Peugeot) producing the heaviest and least efficient cars on average. A regression line correlating vehicle energy consumption and mass highlights the best performers (Hyundai, Honda, and Nissan), average performers (Fiat, Volkswagen, GM, and Toyota), and those performing worse than average (Renault, Ford, and PSA).

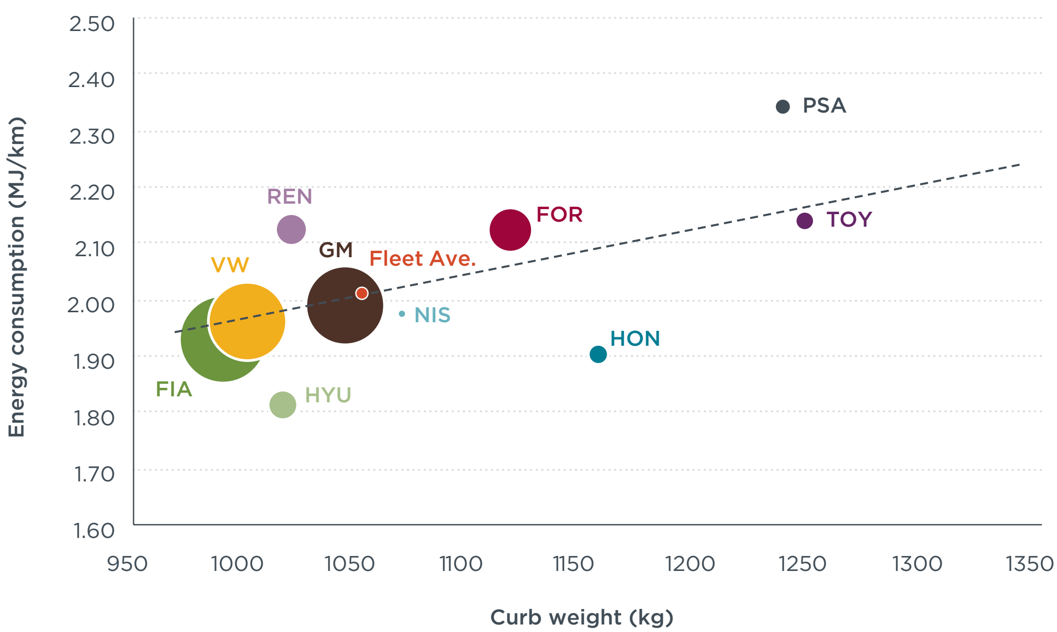

Figure 4-4 –Average new vehicle sales-weighted energy consumption by manufacturer (2013).

Figure 4-5 shows fleet-average energy consumption based on certification and type approval data for new vehicles in multiple countries, converted to the U.S. CAFE combined driving cycle. Bubble sizes represent total sales of new passenger cars. Because of data availability in different countries, the country comparison is based on different calendars years for different countries: 2011 for South Korea and Japan, 2012 for China and India, and 2013 for Europe, the U.S., and Brazil. Given annual improvements in vehicle energy consumption triggered by regulatory efficiency standards and fiscal incentives, those countries with older data could be at a slight disadvantage in this comparison.

With the heaviest vehicles on average, the U.S. fleet is also the most energy consuming of all countries. China and South Korea have similar average energy consumption, but since South Korean vehicles are heavier on average, they are relatively more efficient than Chinese vehicles. Although Brazil's fleet consumes less fuel on average than those from the U.S., China, and South Korea, its fleet is relatively inefficient when compared to countries with vehicles of similar weight (Japan and India). The average Brazilian vehicle consumes about 34% more energy than the average vehicle in Japan, whose fleet has a large penetration of gasoline hybrid and advanced fuel-efficiency technologies, such as three-cylinder engines, VVA, DOHC, and 6-plus speed transmissions. European vehicles are the best performing on average, despite being heavier than all countries with the exception of the U.S. and South Korea. The adoption of fuel-efficiency technologies (e.g., DCT, 6-plus-speed transmissions, GDI, turbocharging) contributes to Europe's better than average performance.

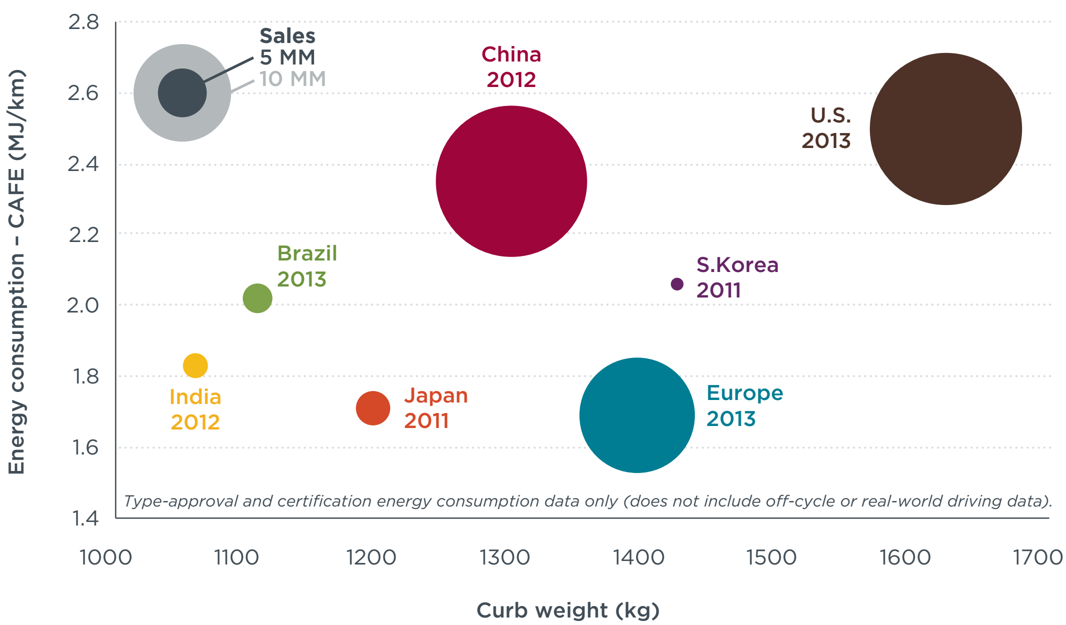

Figure 4-5 – International comparison of passenger car energy consumption.
Country labels indicate the dataset year.

Figure 4-6 provides a more detailed country comparison by illustrating average vehicle energy consumption by vehicle (curb) weight bin. Vehicle sales in each bin are shown for reference. The U.S. is not shown due to lack of detailed model-by-model data. Brazil's vehicles on average have the highest energy consumption in most weight bins, with China being the second highest in most bins. Because China has higher fuel consumption than Brazil on the 1,000 bin, which represents the highest share of vehicle sales, fleet-average energy consumption in China is still higher than in Brazil, as illustrated in the previous figure. Europe consistently performs best in terms of vehicle energy consumption in most weight bins, with Japan also performing relatively well.

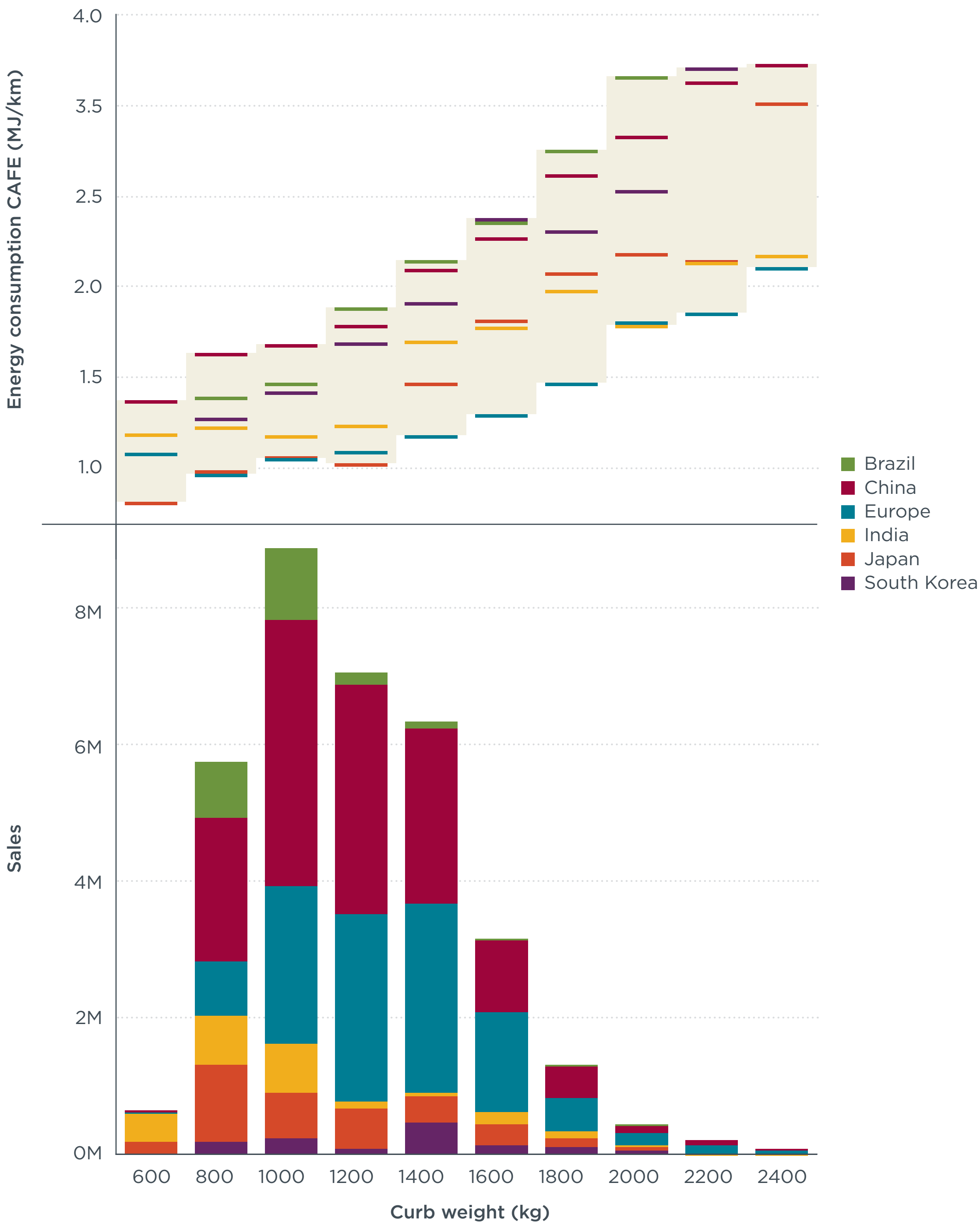

Figure 4-6 – International comparison of average vehicle energy consumption by vehicle weight.

Type-approval and certification energy consumption data only (does not include off-cycle or real-world driving data).

Figure 4-7 illustrates the distribution of energy consumption data in Brazil for each vehicle version by mass and segment. Bubble sizes represent total sales of each version. Data were limited to flex-fuel vehicles in the subcompact, compact, medium, and large segments due to its relatively better data quality and representativeness (i.e., they represented over 87% of sales in 2013). While most vehicles follow a predictable trend that correlates energy consumption and vehicle mass, there are a large number of versions with energy consumption substantially higher than the trend line. This suggests there is substantial room for improvements in their energy consumption, since there are vehicles in similar weight classes with substantially superior energy consumption performance.

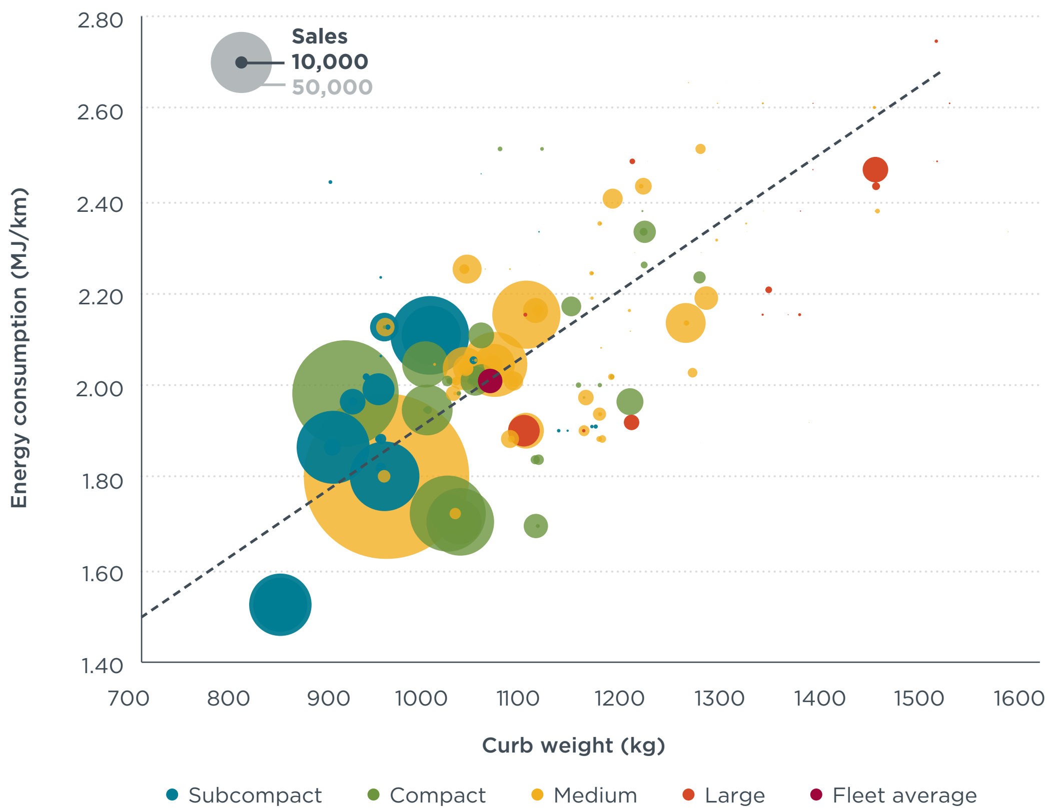

Figure 4-7 – Distribution of new Brazilian passenger vehicle energy consumption data by vehicle weight and segment (2013).

This chapter suggests that there are potential improvements in vehicle energy consumption for the Brazilian fleet. For similar vehicles in terms of weight class, footprint, or engine rating, there is substantial dispersion in energy consumption, indicating that there are vehicles performing much worse than the average. Across manufacturers, there is also a clear trend of some manufacturers performing much better than the average, while others have a lot more room for improvement. The international comparison clearly shows that Brazilian vehicles perform much worse in terms of energy consumption than vehicles of similar weight, suggesting a delay in the adoption of energy efficient technologies among Brazilian vehicle manufacturers.

Finally, a more detailed analysis of vehicle versions clearly illustrates a considerable number of vehicle versions significantly above average, thus indicating potential improvements in energy consumption that would place them on par with better performing vehicles with similar characteristics.

Deficiencies in data quality and completeness prevent more definite conclusions about vehicle energy consumption. Gasoline-only vehicles in particular have poor energy consumption data quality, although they represent a relatively small fraction (6%) of total vehicles sold in 2013. Because some vehicle segments are primarily composed of gasoline-only vehicles (e.g., sports, minivans), this chapter excludes these segments from the analysis. There are also concerns about the gap between energy consumption data reported by IBAMA's Nota Verde and Brazil's National Institute of Metrology Standardization and Industrial Quality's (INMETRO) labeling program (PBEV, using its acronym in Portuguese), with the latter reporting consistently lower values of vehicle energy consumption.

Finally, the availability of energy consumption data was not adequate for many manufacturers beyond the top 10 sales group, which prevented their inclusion in this analysis. Despite the data quality and lack of completeness, the energy consumption data in this chapter include data that are reasonably accurate and representative, thus supporting its interpretation.

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LIST OF ACRONYMS

4WD	Four-wheel drive
ANFAVEA	Brazilian Association of Automobile Manufacturers
AWD	All-wheel drive
BRIC	Brazil Russia India China
CAFE	Corporate average fuel economy
CBG	Compressed biogas
CO_2	Carbon dioxide
CVT	Continuously variable transmission
CVVT	Continuously variable valve technology
DCT	Dual-clutch transmission
DOHC	Dual overhead camshaft
EC	Energy consumption
EPA	U.S. Environmental Protection Agency
EU	European Union
FFV	Flex-fuel vehicle
FTP	Federal test procedure
FWD	Front-wheel drive
GDI	Gasoline direct injection
GDP	Gross domestic product
GHG	Greenhouse gas
GM	General Motors
IBAMA	Brazilian Institute of the Environment and Renewable Natural Resources
IC	Internal combustion
ICCT	International Council on Clean Transportation
INMETRO	National Institute of Metrology, Standardization and Industrial Quality
Kg	Kilogram
Km	Kilometer
Kw	Kilowatt
LDV	Light-duty vehicle
LPG	Liquified petroleum gas
MDIC	Ministry of Development Industry and Foreign Trade
MJ	Megajoule
MPFI	Multi-point fuel injection
Mpg	Miles per gallon
NAS	U.S. National Academy of Sciences

NHTSA	U.S. National Highway Transportation Safety Administration
OHV	Overhead valve
PBEV	Brazilian Vehicle Labeling Program
PSA	PSA Peugeot Citroën
PTWR	Power-to-weight ratio
PV	Passenger vehicle
RWD	Rear-wheel drive
SOHC	Single overhead camshaft
SUV	Sport utility vehicle
U.S.	United States
USD	U.S. dollar
VTEC	Valve timing electronic control
VVA	Variable valve actuation
VVL	Variable valve lift

APPENDIX A. SEGMENT DEFINITIONS

Table A-1 – Segment definitions.

Segment	Power (kW)	PTWR (kW/kg)	Area (m^2)	Other characteristics	Examples
Subcompact	< 140	< 0.075	≤ 6.5	—	Mini Cooper, Chevrolet Celta, Smart ForTwo
Compact	< 140	< 0.075	6.5 < Area ≤ 7.0	—	Honda Fit, Hyundai HB20, Volkswagen, Polo
Medium	< 140	< 0.075	7.0 < Area ≤ 8.0	—	Honda Civic, Nissan Tiida, Peugeot 308
Large	< 140	< 0.075	> 8.0	—	Audi A4, BMW 3 series, Mercedes C-Class
Sports	> 140	> 0.075	—	4 seats max	Jaguar XF, Lamborghini Gallardo, Ferrari California
Off-road	—	—	< 8.0	Traction = 4WD	Jeep Cherokee, Honda CR-V, BMW X3, Hyundai Santa Fe
SUV	—	—	< 8.0	Based on ADK's default classification	BMW X1, Ford Ecosport, Hyundai Tucson
Minivan	—	—		Passengers: 6-12	Citroen Grand Picasso, KIA Carnival

APPENDIX B. INTERNATIONAL MARKET DATA

Table B-1 – International market comparison of new fleet characteristics.

Parameters	China	S. Korea	EU	U.S.	Japan	India	Brazil
Year	2012	2011	2013	2013	2011	2012	2013
Sales (million)	15.5	1.3	11.8	15.6	3.52	2.56	3.04
Price (USD)	$21,008	$21,383	$24,439	—	$20,637	$11,717	$22,015
No. of cylinders	—	4.3	4.0	4.7	3.8	3.6	4.0
Displacement (cc)	1,605	1,960	1,613	2,606	1,425	1,294	1,430
Curb weight (kg)	1,296	1,421	1,391	1,623	1,193	1,059	1,106
Length (mm)	4,323	4,531	4,263	—	4,013	3,859	4,100
Footprint (m^2)	3.8	4.20	4.0	4.25	3.71	3.41	3.67
Engine power (kW)	86	120	89	148	78	55	76
PTWR (kW/kg)	0.0664	0.0844	0.0640	0.0912	0.0654	0.0519	0.0671
Energy consumption – U.S. CAFE (MJ/Km)[1]	2.35	2.06	1.69	2.50	1.71	1.83	2.02

[1] Energy consumption data presented here for countries other than Brazil were obtained from local official sources in its original metric and drive cycle, and then converted to MJ/km under the U.S. CAFE drive cycle using the methodology described in Yang (2015). Mode details and historical fuel consumption data on their original metrics is presented in the ICCT's Global PV standard website: http://www.theicct.org/info-tools/global-passenger-vehicle-standards

Data Sources:

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Brazil: ICCT Brazil Vehicle Database (2013)

Table B-2 – International market comparison of technology adoption in new vehicles.

Technology adoption	China	S. Korea	EU	U.S.	Japan	India	Brazil
Year	2010	2011	2013	2013	2011	2012	2013
Fuel type							
CBG/LPG/Flex	0%	11%	2%	0%	0%	4%	94%
Gasoline	99%	65%	44%	93%	86%	56%	6%
Hybrid	0%	1%	1%	5%	13%	0%	0%
Diesel	1%	23%	53%	1%	0%	40%	0%
No. of cylinders							
Two	0%	0%	0%	0%	0%	6%	0%
Three	4%	0%	7%	0%	36%	28%	3%
Four	90%	84%	87%	56%	57%	65%	97%
Five	0%	0%	1%	0%	0%	0%	%
Six	6%	15%	4%	32%	5%	0%	1%
Eight or more	0%	0%	0%	12%	1%	0%	0%
Transmission							
Manual	60%	3%	83%	5%	1%	98%	83%
Automatic	34%	90%	9%	75%	34%	2%	15%
CVT	5%	7%	2%	18%	65%	0%	1%
DCT	1%	0%	6%	2%	—	0%	1%
Number of gear ratios							
Four or fewer	13%	16%	1%	7%	—	10%	6%
Five	68%	9%	45%	11%	—	85%	83%
Six or more	19%	75%	54%	82%	—	5%	11%
Drivetrain							
FWD	74%	86%	81%	83%	59%	76%	0%
RWD	21%	7%	7%	10%	5%	22%	0%
4WD and AWD	5%	7%	12%	7%	36%	2%	100%
No. of valves per cylinder							
Two	17%	—	—	2%	4%	25%	60%
Multi valve	83%	—	—	98%	95%	75%	40%
Valve camshaft configuration							
Single overhead camshaft	26%	1%	—	—	16%	41%	63%
Dual overhead camshaft	74%	84%	—	—	82%	53%	25%
Overhead camshaft	—	15%	—	—	0%	6%	—
Valve actuation							
Fixed	50%	16%	—	2%	11%	86%	78%
VVT	44%	84%	—	98%	89%	12%	16%
VVL	6%	—	—	—	—	2%	6%
Fuel systems for gasoline vehicles							
Multi-point fuel injection	94%	72%	68%	62%	95%	100%	98%
Gasoline direct injection	6%	28%	32%	37%	5%	0%	2%
Air induction systems for gasoline vehicles							
Naturally aspirated	93%	75%	41%	85%	92%	64%	97%
Supercharger, turbocharger or twin-turbo	7%	25%	59%	15%	8%	36%	3%

APPENDIX C. NEW VEHICLE CHARACTERISTICS AND TECHNOLOGY ADOPTION DATA IN BRAZIL

Table C-1 – Fleet characteristics of new Brazilian passenger vehicles by segment (2013).

Parameters	Subcompact	Compact	Medium	Large	Sports	Off-road	SUV	Minivan
Sales (thousands)	678.5	684.3	1179.0	192.0	27.3	76.8	199.7	2.3
Market share (%)	22.3%	22.5%	38. 8%	6.3%	0.9%	2.5%	6.5%	0.1%
Price (R$)	$30,103	$38,732	$45,496	$66,508	$148,834	$151,284	$75,164	$82,284
No. of cylinders	4.00	3.91	3.99	4.00	4.62	4.48	4.04	4.33
Displacement (cc)	1128	1293	1447	1794	2430	2586	1884	2244
Curb weight (kg)	940	1037	1102	1329	1561	1772	1395	1604
Length (mm)	3804	4026	4163	4499	4711	4516	4352	4658
Footprint (m^2)	3.39	3.61	3.71	4.02	4.18	4.09	4.02	4.27
Engine power – gasoline (kW)	58	68	75	99	183	146	103	120
Engine power – ethanol (kW)	59	70	77	98	—	109	101	—
PTWR – gasoline (kW/kg)	0.0614	0.0655	0.0671	0.0742	0.1173	0.0828	0.0731	0.0732
PTWR – ethanol (kW/kg)	0.0630	0.0678	0.0697	0.0757	—	0.0766	0.0745	—

Table C-2 – Fleet characteristics of new Brazilian passenger vehicles by manufacturer (2013).

Parameters	Fiat	GM	Volkswagen	Ford	Renault	Hyundai	Honda	Toyota	PSA	Nissan	Mitsubishi	KIA	JAC	BMW	Land Rover	Mercedes-Benz	Chery	Audi	Suzuki	Jeep
Sales (thousands)	608.7	548.6	544.8	307.4	220.7	205.5	139.2	133.4	116.3	62.1	36.8	25.5	15.8	14.1	10.6	9.4	8.0	6.7	6.3	3.6
Market share (%)	20.02%	18.04%	17.92%	10.11%	7.26%	6.76%	4.58%	4.39%	3.83%	2.04%	1.21%	0.84%	0.52%	0.46%	0.35%	0.31%	0.26%	0.22%	0.21%	0.12%
Price (R$)	$35,017	$42,259	$38,701	$46,174	$43,447	$50,112	$67,078	$68,922	$103,001	$44,035	$100,696	$87,009	$37,654	$165,111	$221,943	$153,281	$30,821	$142,799	$74,769	$139,039
No. of cylinders	4.00	4.01	4.00	4.02	4.00	3.70	4.00	4.00	4.00	4.00	4.08	4.16	4.00	4.24	4.48	4.31	4.00	4.11	4.00	5.52
Displacement (cc)	1250	1340	1287	1497	1423	1495	1691	1808	1575	1579	2262	1856	1411	2095	2281	1934	1398	1912	1831	3182
Curb weight (kg)	1033	1060	1020	1156	1102	1122	1210	1201	1231	1069	1556	1377	1079	1624	1868	1598	1097	1551	1444	1945
Length (mm)	3965	4155	3993	4120	4127	4078	4319	4299	4116	4171	4401	4357	3956	4574	4487	4527	3896	4454	4234	4584
Footprint (m^2)	3.45	3.70	3.54	3.68	3.78	3.83	3.97	3.87	3.76	3.79	3.95	4.07	3.51	4.29	4.33	4.29	3.49	4.17	3.23	4.20
Engine power – gasoline (kW)	64	71	65	79	73	86	96	90	80	82	120	112	83	151	179	138	71	136	94	162
Engine power – ethanol (kW)	65	72	65	79	76	85	97	90	81	82	107	106	95	—	—	—	75	—	—	—
PTWR – gasoline (kW/kg)	0.0613	0.0662	0.0631	0.0674	0.0657	0.0739	0.0788	0.0745	0.0646	0.0766	0.0779	0.0792	0.0784	0.0921	0.0977	0.0856	0.0638	0.0870	0.0649	0.0835
PTWR – ethanol (kW/kg)	0.0629	0.0681	0.0642	0.0693	0.0685	0.0781	0.0800	0.0795	0.0660	0.0768	0.0710	0.0798	0.0896	—	—	—	0.0659	—	—	—

Table C-3 – Fleet characteristics of new Brazilian passenger vehicles by origin (2013).

Parameters	Domestic	Imported
Sales (thousands)	2,537	504
Market share (%)	83.4%	16.6%
Price (R$)	$41,739	$76,049
No. of cylinders	3.97	4.12
Displacement (cc)	1,359	1,791
Curb weight (kg)	1,070	1,289
Length (mm)	4,063	4,285
Footprint (m^2)	3.62	3.90
Engine power – gasoline (kW)	70	102
Engine power – ethanol (kW)	73	84
PTWR – gasoline (kW/kg)	0.065	0.076
PTWR – ethanol (kW/kg)	0.068	0.074

Table C-4 – Technology adoption in new Brazilian passenger vehicles by segment (2013).

Technology adoption	Subcompact	Compact	Medium	Large	Sport	Off-road	SUV	Minivan
Fuel type								
Flex	98.2%	98.8%	98.2%	83.7%	0.0%	13.4%	82.6%	0.0%
Gasoline	1.8%	1.2%	1.7%	16.3%	99.6%	54.0%	17.4%	100.0%
Hybrid	0.000%	0.000%	0.028%	0.000%	0.396%	0.001%	0.000%	0.000%
Diesel	0.0%	0.0%	0.0%	0.0%	0.0%	32.6%	0.0%	0.0%
No. of cylinders								
Three	0.1%	9.1%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Four	99.9%	90.9%	99.0%	99.8%	75.8%	77.5%	97.9%	83.3%
Five	0.0%	0.0%	0.0%	0.2%	0.3%	0.0%	0.0%	0.0%
Six	0.0%	0.0%	0.0%	0.0%	17.5%	21.1%	2.1%	16.7%
Eight or more	0.0%	0.0%	0.0%	0.0%	6.3%	1.3%	0.0%	0.0%
Transmission								
Manual	99.3%	94.4%	82.6%	62.2%	6.2%	17.4%	50.5%	64.1%
Automatic	0.7%	5.5%	16.1%	28.3%	62.9%	70.7%	45.1%	35.9%
CVT	0.0%	0.0%	1.2%	8.9%	0.9%	9.3%	3.4%	0.0%
DCT	0.0%	0.1%	0.2%	0.6%	29.9%	2.5%	1.0%	0.0%
No. of gear ratios								
Four or fewer	0.4%	4.7%	7.2%	5.1%	0.0%	3.4%	24.7%	19.3%
Five	98.4%	94.3%	84.8%	37.8%	1.5%	39.2%	51.6%	64.1%
Six	1.2%	0.9%	7.3%	51.5%	79.6%	46.2%	22.5%	16.7%
Seven	0.0%	0.1%	0.6%	2.3%	8.7%	5.3%	1.2%	0.0%
Eight or more	0.0%	0.0%	0.1%	3.2%	10.2%	5.9%	0.0%	0.0%
Drivetrain								
FWD	99.8%	100.0%	99.7%	68.8%	55.0%	0.0%	91.6%	100.0%
RWD	0.2%	0.0%	0.3%	31.1%	22.1%	0.0%	8.4%	0.0%
AWD	0.0%	0.0%	0.0%	0.1%	22.9%	100.0%	0.0%	0.0%
No. of valves per cylinder								
Two	80.6%	69.4%	58.4%	19.5%	0.0%	0.0%	25.8%	0.0%
Multi valve	19.4%	30.6%	41.6%	80.5%	100.0%	100.0%	74.2%	100.0%
Valve camshaft configuration								
Single overhead camshaft	83.9%	78.6%	70.9%	30.9%	0.0%	21.2%	37.5%	0.0%
Dual overhead camshaft	2.4%	15.8%	16.1%	54.6%	88.0%	51.7%	44.6%	25.5%
Valve actuation								
Fixed	98.2%	72.9%	80.7%	46.1%	4.9%	49.3%	66.4%	86.8%
VVT	1.8%	21.1%	11.5%	47.0%	82.7%	36.7%	25.2%	13.2%
VVT+VVL	0.0%	6.1%	7.8%	6.8%	12.4%	14.0%	8.4%	0.0%
Fuel systems for gasoline vehicles								
Multi-point fuel injection	99.9%	99.8%	99.7%	94.9%	97.9%	14.3%	76.6%	100.0%
Gasoline direct injection	0.1%	0.2%	0.3%	5.1%	2.1%	85.7%	23.4%	0.0%
Air induction systems for gasoline vehicles								
Naturally aspirated	99.9%	99.7%	99.5%	94.3%	97.4%	36.9%	54.3%	100.0%
Supercharger, turbocharger or twin-turbo	0.1%	0.3%	0.5%	5.7%	2.6%	63.1%	45.7%	0.0%

Table C-5 – Technology adoption in new Brazilian passenger vehicles by manufacturer (2013).

Technology adoption	FIAT	GM	VOLKSWAGEN	FORD	RENAULT	HYUNDAI	HONDA	TOYOTA	PSA	NISSAN	MITSUBISHI	KIA	JAC	BMW	LAND ROVER	MERCEDES
Fuel type																
Flex	99.0%	98.7%	96.5%	96.6%	99.7%	92.1%	99.9%	88.6%	92.8%	99.8%	28.3%	73.9%	3.1%	4.2%	0.0%	0.0%
Gasoline	1.0%	0.9%	3.5%	3.4%	0.3%	7.9%	0.1%	3.5%	7.2%	0.2%	55.7%	25.5%	96.9%	95.7%	66.3%	95.0%
Hybrid	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Diesel	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	7.7%	0.0%	0.0%	16.0%	0.6%	0.0%	0.0%	33.7%	5.0%
No. of cylinders																
Three	0.0%	0.0%	0.5%	0.0%	0.0%	34.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Four	100.0%	99.6%	99.4%	98.9%	100.0%	62.6%	99.9%	99.8%	100.0%	100.0%	95.8%	92.2%	100.0%	90.6%	78.7%	87.8%
Five	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Six	0.0%	0.2%	0.1%	1.1%	0.0%	2.6%	0.1%	0.2%	0.0%	0.0%	4.2%	7.8%	0.0%	6.8%	18.5%	8.7%
Eight or more	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.6%	2.8%	3.5%
Transmission																
Manual	99.2%	87.8%	98.5%	84.6%	85.3%	63.2%	56.6%	56.5%	70.3%	78.5%	49.3%	12.0%	100.0%	0.2%	0.0%	15.1%
Automatic	0.8%	10.3%	0.0%	13.7%	6.2%	28.5%	35.5%	16.0%	29.7%	12.1%	11.8%	79.3%	0.0%	57.5%	1.8%	1.4%
CVT	0.0%	1.9%	1.5%	1.6%	4.1%	7.0%	0.1%	24.6%	0.0%	0.0%	13.9%	8.7%	0.0%	42.3%	98.2%	83.6%
DCT	0.0%	0.0%	0.0%	0.0%	4.3%	1.3%	7.8%	3.0%	0.0%	9.4%	25.1%	0.0%	0.0%	0.0%	0.0%	0.0%
No. of gear ratios																
Four or fewer	0.2%	0.4%	0.0%	5.5%	10.4%	23.7%	0.0%	32.3%	24.9%	13.2%	1.7%	13.3%	0.0%	0.0%	0.0%	0.0%
Five	98.1%	81.1%	96.3%	83.9%	79.7%	62.3%	86.1%	64.3%	68.4%	82.8%	53.0%	10.7%	100.0%	0.0%	0.0%	6.4%
Six	1.7%	18.5%	2.9%	10.6%	9.9%	14.0%	13.9%	0.7%	6.7%	4.0%	45.3%	75.4%	0.0%	21.7%	80.0%	0.0%
Seven	0.0%	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%	2.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	93.6%
Eight or more	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	77.5%	20.0%	0.0%
Drivetrain																
FWD	100.0%	90.2%	98.9%	97.2%	98.7%	98.5%	99.0%	89.2%	100.0%	100.0%	49.6%	62.3%	100.0%	0.0%	0.0%	0.0%
RWD	0.0%	9.1%	0.0%	0.0%	0.0%	0.0%	0.0%	1.6%	0.0%	0.0%	0.0%	37.0%	0.0%	88.2%	0.0%	90.0%
AWD	0.0%	0.6%	1.1%	2.8%	1.3%	1.5%	1.0%	9.2%	0.0%	0.0%	50.4%	0.7%	0.0%	11.8%	100.0%	10.0%
No. of valves per cylinder																
Two	81.1%	86.4%	98.8%	74.5%	22.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Multi Valve	18.9%	13.6%	1.2%	25.5%	78.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Valve camshaft configuration*																
SOHC	83.6%	75.5%	91.4%	67.5%	83.2%	0.0%	0.4%	0.0%	49.7%	39.8%	33.1%	0.0%	0.0%	0.0%	0.0%	0.0%
DOHC	0.7%	10.8%	5.6%	5.0%	16.8%	99.2%	78.6%	87.5%	35.2%	42.8%	47.7%	100.0%	90.7%	81.0%	86.0%	45.3%
Valve actuation																
Fixed	100.0%	89.8%	96.5%	96.6%	94.0%	2.9%	0.0%	57.4%	73.6%	57.3%	43.5%	7.6%	12.4%	18.7%	1.8%	5.5%
VVT	0.0%	10.2%	3.5%	3.4%	6.0%	97.1%	0.0%	42.6%	26.4%	42.7%	0.0%	92.4%	87.6%	0.0%	98.2%	94.5%
VVT+VVL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	56.5%	0.0%	0.0%	81.3%	0.0%	0.0%
Air Induction System																
Naturally aspirated	99.7%	99.4%	96.6%	97.7%	99.7%	98.8%	100.0%	92.3%	92.2%	100.0%	83.5%	93.6%	100.0%	9.7%	3.7%	10.1%
Supercharger, turbocharger or twin-turbo	0.3%	0.6%	3.4%	2.3%	0.3%	1.2%	0.0%	7.7%	7.8%	0.0%	16.5%	6.4%	0.0%	90.3%	96.3%	89.9%
Fuel systems for gasoline vehicles																
Multipoint fuel injection	100.0%	99.5%	96.5%	97.2%	100.0%	98.9%	100.0%	100.0%	96.7%	100.0%	99.4%	100.0%	100.0%	7.8%	1.5%	15.8%
Gasoline Direct Injection	0.0%	0.5%	3.5%	2.8%	0.0%	1.1%	0.0%	0.0%	3.3%	0.0%	0.6%	0.0%	0.0%	92.2%	98.5%	84.2%

* Note: Difference between 100% and summation of SOHC and DOHC market share values corresponds to data not available

APPENDIX D. DATA SOURCES AND COMPLETENESS

The basis of the statistics shown in this report is a database compiled by the ICCT with vehicle sales, technical information (e.g., fleet characteristics, technology content), and energy consumption (converted from either CO_2 emissions or fuel economy) from various data sources outlined in Table D-1.

Table D-1 – Brazilian data sources.

Parameters	Sales	Technical	Energy consumption
ADK (2014, 2015)	x	x	
MarkLines (2015)	x		
IBAMA (2014)			x
INMETRO (2014)			x
UOL (2014)		x	
Icarros.com (2014)		x	

This analysis examined energy consumption data from two public sources: the Nota Verde Program by the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA), and the Brazilian Vehicle Labeling Program (PBEV) by the National Institute of Metrology, Standardization and Industrial Quality (INMETRO). Table D-2 summarizes key differences between these two data sources.

Table D-2 – Energy consumption data sources.

	IBAMA	INMETRO
Program	Nota Verde[1]	Brazilian Vehicle Labeling Program (PBEV)[2]
Program description	Mandatory program that reports emissions of CO_2, CO, NO_x, and NMHC as part of emissions certification program.	Voluntary program since 2009 that allows the comparison of fuel economy across vehicle models.
Unit	gCO_2/km	km/L
Test cycle	Chassis testing under urban (FTP) driving cycle, based on NBR 6601:2005	Chassis testing under urban (FTP) and highway (HWYFE) driving cycles, based on NBR 7024:2010.[3]
Adjustment	No adjustment for real-world driving conditions. Because reported CO_2 emissions are assumed to be zero for ethanol, adjustments were made to account for tailpipe CO_2 emissions for vehicles running on ethanol.	Since 2010, published values include real-world adjustment factors to chassis test data, a method adopted by the U.S. EPA in 2008.
Conversion to MJ/km	IBAMA's data are reported as FTP (city test) CO_2 data in gCO_2/km. Conversion to CAFE test cycle and to a different metric (MJ/km) involves four steps as presented in Figure D-1.	INMETRO's data in km/L are presented separately by fuel type (E22, E100) and driving cycle (urban, highway). Conversion to MJ/km was done by applying a conversion factor (2,167 gCO_2/L for E22 and 1,428gCO_2/L for E00). CAFE values are obtained by using a 55/45% weighting for the urban (FTP) and highway cycles, respectively.

1 IBAMA (2014). Nota Verde program. Available at: http://www.mma.gov.br/cidades-sustentaveis/qualidade-do-ar/controle-de-emissoes-veiculares/nota-verde
2 INMETRO (2014). Programa Brasileiro de Etiquetagem Veicular (PBEV). Available at: http://www.inmetro.gov.br/consumidor/tabelas_pbe_veicular.asp
3 INMETRO (2014). Metodologia Para Divulgação De Dados De Consumo Veicular. Available at: http://www.inmetro.gov.br/consumidor/pbe/Metodologia_Consumo_Veicular.pdf

Step 1. Correcting the original IBAMA CO_2 reported data – FTP CO_2 g/km

IBAMA's CO_2 reported values are corrected to account for tailpipe emissions from ethanol (tailpipe CO_2 emissions are reported as zero in IBAMA's data):

- E22: FTP reported CO_2 data are reduced by 17.7%
- E100: FTP reported CO_2 data are reduced by 100%

Flex fuel vehicles are tested with E22 and E00; the final values is calculated as the average of both fuels:

CO_2 IBAMA_Flex_FTP= 0.5*(1-0.177)*CO_2_E22_test_FTP + 0.5*0*E100_FTP = 0.5*0.823*CO_2_E22_FTP

For Gasoline only vehicles the tests are carried out only with Gasoline E22:

CO_2 IBAMA_Gasoline_FTP = (1-0.177) *CO_2_E22_Test_FTP

Where in the previous equations,

CO_2_E22_FTP means CO_2 emissions values obtained under FTP testing

CO_2 IBAMA_Flex_FTP means IBAMA's Corrected FTP values for flex vehicles

CO_2 IBAMA_Gasoline_FTP means IBAMA's Corrected FTP values for gasoline only (E22) vehicles

Step 2. Convert FTP CO_2 values to CAFE CO_2 values

INNOVAR AUTO is based on energy consumption data obtained as the combined CAFE test cycle. This requires a weighted average of energy consumption data obtained from FTP testing (city driving) and Highway fuel economy testing (HWFET). In mathematical form, CAFE=f(FTP,HWFET).

Given that IBAMA data is provided for only the first aprt, the FTP testing, then it is required to find a way to calculate CAFE combined values through FTP -75 only data. A linear function was thus developed from data with FTP and HWY values (INMETRO data) is used to convert FTP only values to CAFE CO_2 values, i.e., CAFE=f(FTP). The function used for this conversion is :

CO_2_CAFE= (CO_2_FTP+4.4756)/1.1572

Step 3. Convert U.S. CAFE CO_2 values to MJ/km values

Converting CO_2 values to MJ/km values is done by using the energy density of E22. Note that all the previous calculations for CO_2 come from E22-based data.

- The energy density of E22 is 28.94 MJ/LE22
- E22 emits 2,167gCO_2/LE22
- CAFE (MJ/km) = CAFE (gCO_2/km) * (28.94 MJ/LE22 / 2,167 gCO_2/LE22)

Figure D-1 – Conversion of emission to energy consumption data.

Energy consumption values calculated from IBAMA and INMETRO data differ greatly. Figure D-1 illustrates energy consumption data for those models in both databases. IBAMA data are on average 12.6% higher than INMETRO data, with a standard deviation of 8.9% and a maximum deviation of 39%.

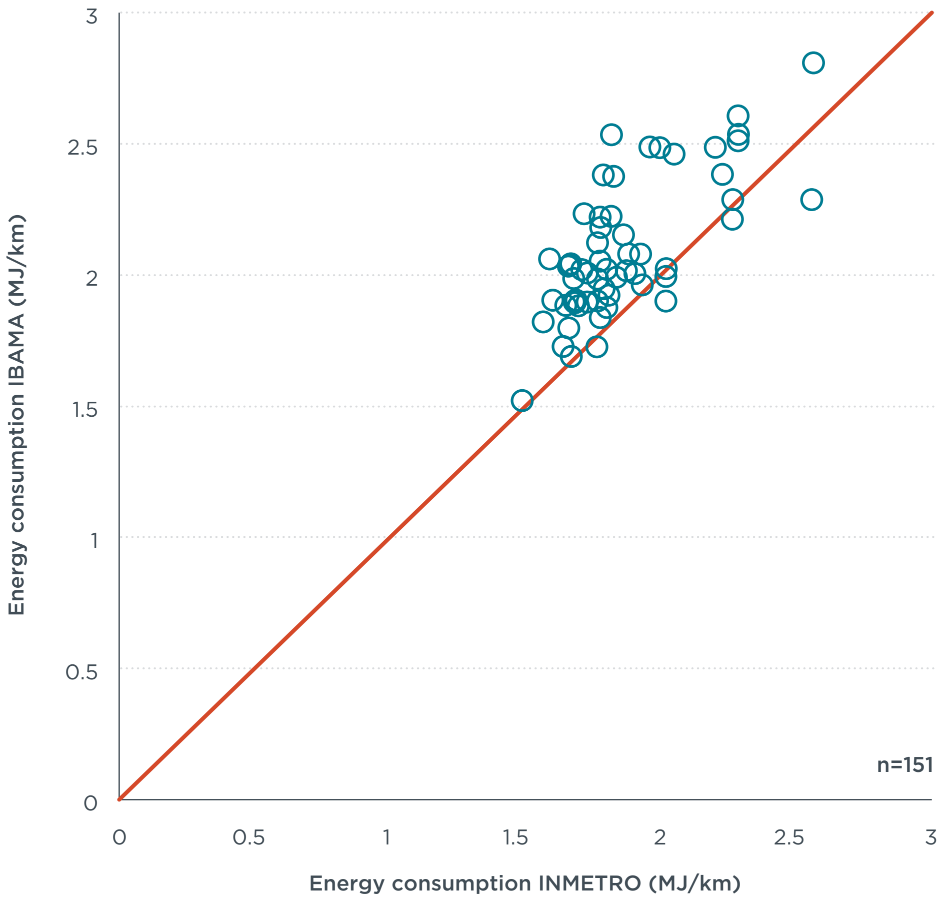

Figure D-2 – Comparison between energy consumption data from INMETRO and IBAMA.
151 vehicles tested under both programs.

Although INMETRO data are more transparent as it breaks down fuel economy by fuel and test cycle, it is still a voluntary program that allows manufacturers to select which models will participate. In addition, not all manufacturers participate in the program. In turn, IBAMA data only include CO_2 data for the urban cycle, and thus energy consumption in the combined cycle had to be estimated from correlations using international data. In addition, corrections had to be made for gasoline-only engines, since it seems that a CO_2 discount, in theory only applicable to flex-fuel engines, was also applied to gasoline-only engines. Despite these data quality issues, IBAMA data were considered the most adequate data source for energy consumption because it is a mandatory program that requires data reporting by all vehicle models and manufacturers.