Working paper
2011–13

Sustainable Management of Two- and Three-Wheelers in Asia

Authors: Francisco Posada, Fanta Kamakate, Anup Bandivadekar

Date: December 2011

Paper number: 2011-13

Keywords: two- and three-wheelers, Asia, fuel efficiency, fuel economy, emissions

Abstract: The large share of two- and three-wheelers in Asian countries pose significant challenges to air-quality, public health and road safety. Emission standards and technologies that have been applied for decades to control pollution from passenger cars have not fully migrated to two- and three-wheelers. Fuel economy standards, which offer great potential for reducing transportation sector energy consumption, have not been implemented in most countries/regions for this mode of transportation. Robust regulatory programs, such as compliance and enforcement programs, in-use control, OBD and evaporative controls that guarantee optimum performance have been employed only sparsely and most Asian regions lack such safeguards. This paper identifies the most effective technologies for CO_2, emissions and safety measures and maps the status of regulatory programs for two- and three-wheeler management in Asian countries. Best practice policy recommendations for emissions reduction, fuel economy standards and safety are provided.

Introduction

Rapid economic growth in Asia has resulted in a substantial increase of new vehicle sales in recent years, predominantly motorized two- and three-wheelers. The region has the highest concentration of two- and three-wheelers in world. This rapid expansion of vehicles has put extra stress on air quality and public health. And while motorcycles are considered among the most fuel-efficient personal modes of transportation, the cumulative affects of the large fleet have a significant impact on overall energy use and road safety.

Ensuring good air quality, energy sustainability, road safety and greenhouse gas reductions requires a comprehensive transportation management strategy that treats all modes, including two- and three-wheelers, as a system. While numerous reports focus principally on improvements and regulations for passenger and heavy-duty vehicles, two- and three-wheelers are frequently omitted. National and local decision makers require well-designed policy tools, including regulations and incentives, to improve the environmental and energy footprint of these popular vehicles. Safety and noise concerns raised by motorcycles also deserve attention as part of a comprehensive strategy. The objective of this paper is to identify how Asian nations can best manage the growing fleet of two- and three-wheelers.

Background

In the 10 largest Asian vehicle markets motorized two- and three-wheelers comprise roughly an average of 66 percent of the total vehicle population (Table 1). By 2010 the fleet of two- and three-wheelers in major Asian countries had surpassed the 200 million mark and by 2035 there will be more than 550 million two- and three-wheelers, assuming a 4.2 percent annual growth (CAI-Asia, 2011). India and China have experienced new motorcycle sales growth at an average rate of 11 percent each of the past 5 years; countries like Indonesia and Philippines have witnessed even larger annual growth rates.

Several factors have accelerated the surge in motorcycle (two-wheeler) ownership in Asia. Primary influences include public transport systems that are unable to respond to increasing demand, the perceived loss of productivity due to traffic congestion, the lower purchase cost and greater fuel efficiency of two- and three-wheelers and a good economy (CAI-Asia, 2011).

Table 1. Top Ten Largest Markets of 2- and 3- Wheelers in Asia and their Growth. Data from World Road Statistics (WRS, 2010)

Country/ Region	Year	Other Vehicles	Motorcycles and Mopeds	Percent Motorcycles	Average Annual Growth* Other Vehicles	Average Annual Growth* Motorcycles
China	2009	62,136,896	95,805,176	60.7%	30.9%	10.4%
India	2009	21,200,140	82,402,105	79.5%	10.7%	12.1%
Indonesia	2009	18,281,437	52,433,132	74.1%	22.6%	20.9%
Vietnam	2007	1,146,312	21,779,919	95.0%	ND	ND
Thailand	2006	8,923,447	15,674,941	63.7%	6.8%	2.6%
Taiwan Province of China	2009	6,718,746	14,604,330	68.5%	2.3%	3.3%
Malaysia	2008	9,030,292	8,487,451	48.5%	7.1%	7.5%
Pakistan	2009	2,170,430	3,383,493	60.9%	10.4%	13.0%
Philippines	2009	2,990,743	3,200,968	51.7%	2.0%	23.5%
Sri Lanka	2009	951.362	2,339,916	71.1%	ND	8.0%

* Average increase per year is calculated for data available between 2003 and 2009

Motorized two- and three-wheelers, like all internal combustion engine powered vehicles, emit the combustion products of air, fuel and lubricants. Tailpipe emissions associated with air pollution are carbon monoxide (CO), nitrogen oxides (NOx), particulate matter (PM), hydrocarbons (HC), and sulfur oxides (SOx). Many of these emissions undergo further reactions in the atmosphere, which may increase ground level ozone (O3) and smog levels.

The resulting effects of increased air pollution on human and environmental health are substantial. An evaluation of traffic-related air pollution by the Health Effects Institute (HEI) concluded that there is sufficient evidence that exposure to traffic can cause exacerbation of asthma, especially in children, and suggestive evidence of other health effects including premature mortality, decreased lung function, and respiratory problems (HEI, 2010), (WHO, 2005). Regional or city-level air pollution inventories identify emission sources and help policy makers develop effective regulations to improve air quality and human health.

There are a limited number of studies evaluating the contribution of motorcycles to conventional urban air pollution inventories and exposure in Asia. Studies from the early 2000's show significant contributions of HC, CO and PM from carbureted and uncontrolled motorcycles. Motorcycle's share of HC and CO pollution accounts for 60 to 90 percent and 30 to 70 percent of pollution from the total vehicle inventory while PM emitted by diesel three-wheelers accounts for 14 to 42 percent of the total (ICCT, 2009). It should be noted that in all the cases presented, motorcycle fleet share was greater than 70 percent during the study.

In India the share of HC and CO from two- and three-wheelers is also higher than HC and CO from other motor vehicles. According to ICCT's India Emissions Model, in 2010 the share of HC and CO are 92 and 74 percent respectively (Figure 1). It is evident that recent measures taken by the Indian government have helped reduce the contribution of two- and three-wheeler pollution. However, given the large growth of this market, the emission standards require further tightening to prevent an upswing in emissions.

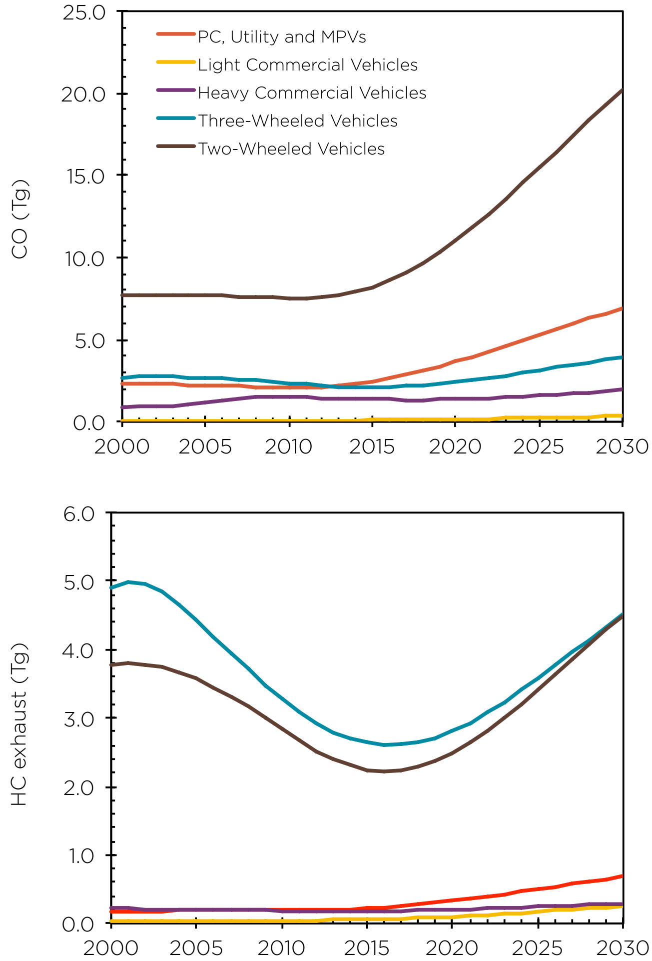

Figure 1. Emission Share by Transportation Mode for India. Source: ICCT India Emissions Model.

By contrast, in other countries and regions where motorcycle standards have been tightened during the last 10 years, the emission share from two- and three-wheelers is smaller than the emission share of other vehicles even when two- and three-wheelers comprise more than 60 percent of the entire vehicle fleet. In China, results from the national mobile source emission inventory released by the Chinese Ministry of Environmental Protection show that two- and three-wheelers, which compose nearly 56 percent of the vehicle fleet, account for only about 22 percent of total HC and CO produced and less than 2 percent of total NOx (MEP-China, 2010).

Although most studies do not differentiate between pollution impacts by motorcycle categories, the impact from three-wheelers on urban air quality is considerably more significant than two-wheeler's influence. According to a study by the Center for Science and Environment (CSE), Indian three-wheelers were found to contribute between 6 and 24 percent of total automotive PM in five large cities, significantly more than their share of vehicle population (Roychowdhury, Chattopadhyaya, Shad, & Chandola, 2006). The large share of two-stroke engines combined with poor maintenance practices contribute to such large emissions from three-wheelers.

Even in countries and regions where the motorcycle fleet is certified to Euro 3 levels, the intense regulatory work and advances in light-duty and heavy-duty vehicle emission control result in an increase in motorcycle emission share. A report by Ntziachristos et al. (2009) studying the future impact of two- and three-wheelers on the European emissions inventory concludes that if no further emission standards are established for these vehicles, the emission share of HC, CO and PM from two- and three-wheelers will increase significantly. Total HC emissions would reach 62.4 percent in 2020, up from 38 percent in 2007, with mopeds being the most significant contributor. CO emissions share would increase from 20 percent to 36 percent during the same period and the PM share would pass the 5 percent mark after 2013 due to the adoption of diesel particulate filters in heavy-duty vehicles (Ntziachristos et al., 2009).

In addition to emission problems, safety has been identified as a concern given the alarming fatality rates associated with this transportation mode. Figure 2 presents road traffic fatalities by mode for Asian countries where data is available. It is evident that in most places the fatality rate is significantly higher for two- and three-wheelers compared to other transportation modes, due largely to their sheer numbers.

Technology Roadmap for Sustainable Management

New two- and three-wheeler vehicle technology is being shaped by tighter standards, restrictions on two-stroke use and fuel economy requirements. This section presents available technologies for improved emissions controls for two- and four-stroke engines, better fuel economy and advanced technology-electrification.

Two-Stroke Engines

Two-stroke engines have been phased out of motorcycles in several countries (e.g. India, Japan, China), but are still offered in mopeds, small scooters, some motorcycles and three-wheelers. Their low cost and easy maintenance compared to four-stroke engines have helped the two-stroke engine keep some share of the two- and three-wheeler market. However, high tailpipe emissions associated with the exhaust scavenging process on two-stroke engines requires special measures. During scavenging, exhaust gases are pushed out of the cylinder partially assisted by the intake flow. The intake flow carries not only air, but also premixed fuel, which result in high emissions of unburned hydrocarbons (HC) and lubricating oil. Technologies to help minimize emissions from two-stroke engines include air-fuel control, after treatment and quality lubricants.

Air-assisted Direct Fuel Injection for two-stroke engines

Air-assisted direct fuel injection redesigns the conventional two-stroke cycle in such a way that only air pushes the exhaust gases out during the scavenging process. The mixture of fuel and lubricant is added directly into the combustion chamber once the exhaust valve is closed. Air-assisted direct fuel injection uses compressed air for this task. Proper control for this redesign is achieved with the help of an on-board microprocessor.

Air-assisted direct fuel injection system allows the engine to run on lean air-fuel mixtures leading to reduced HC and CO emissions as well as reduced fuel consumption. Tests performed by Gambino and Iannaccone (2001) on

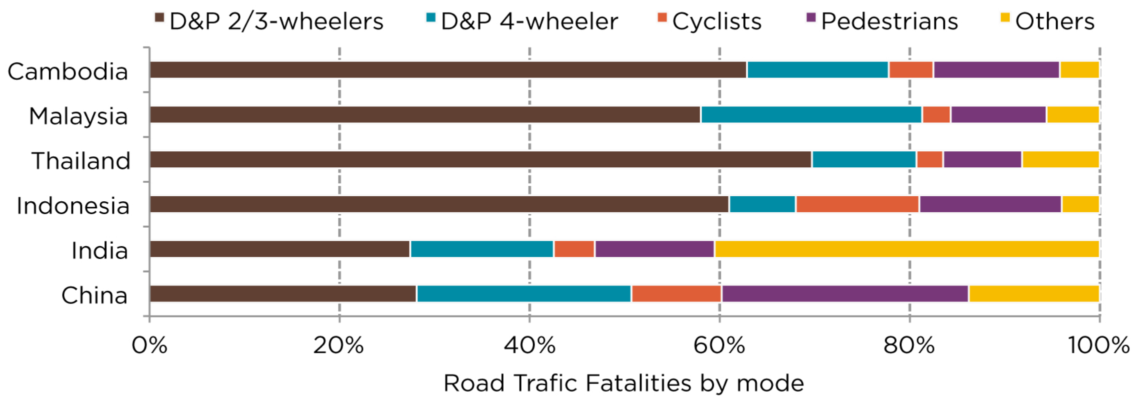

Figure 2. Road Traffic Fatalities for Selected Countries in Asia, Classified by Road User Group. Source: WHO (2009). Note: D&P = Driver and Passenger.

a 50cc engine (under the ECE 47 test cycle) show that CO and HC+NOx emissions were reduced by more than 80 and 62 percent respectively over the original carbureted two-stroke 50cc engine.

Air assisted direct injection improves fuel consumption by 30 to 60 percent over carbureted engines depending upon engine size and duty cycle (Gambino & Iannaccone, 2001), (Archer & Bell, 2001), (Govindarajan, 2005).

Direct injection is currently available in small motorcycles in Europe and is being developed for the Indian market (Iyer, 2011). The cost of a direct injection system for small two-stroke engines has been estimated at around $40 (Meszler, 2007). Direct injection is also available as a retrofit for two-stroke three-wheelers (ICCT, 2009).

Catalytic converters for two-stroke engines

HC, CO and PM emissions from two-stroke vehicles can further be controlled through oxidation catalysts. Oxidation catalysts are widely used in motorcycles in Europe, Asia and North America. It is expected that oxidation catalysts, a proven and cost effective solution, will continue to be used to meet future standards. The cost of these catalysts ranges from $20 to $50 (Meszler, 2007).

The use of oxidation catalysts to control emissions from two-stroke engines presents durability challenges. Prior to the wide adoption of durability standards, oxidation catalysts failed to control HC emission after 15,000 km (Bovonsombat, 1998). With the adoption of durability requirements, the performance of oxidation catalyst was improved for HC conversion (approximately 60 percent) after 30,000 km (Coultas, 2001). As the average motorcycle life is well beyond 30,000 km, durability requirements and inspection programs for two-stroke vehicles would be necessary to ensure that performance is maintained at the original emission rates.

Lubricant Quality for two-stroke engines

Lubricant quality and its mixing with fuel in two-stroke engines has a significant impact on emissions. In conventional two-stroke engines, lubricant oil is dispensed to the engine by mixing it directly with the fuel. Lubricant is thus burned along with the fuel. The inefficiency of this process can lead to large amounts of PM and heavy unburned hydrocarbons that manifest as white smoke. Thus, using high quality lubricants in the right proportions can help reduce HC and PM emissions.

Special lubricants with suitable burning qualities have been developed for two-stroke engines. The burning quality is defined by its Smoke Index, as defined by the Japanese specifications (JASO FA, FB and FC) for two-stroke engine lubricating oils. To conform with JASO specifications, lubricants are required to have a certain minimum Smoke Index. JASO FC has the highest Smoke Index. In general, synthetic oils have a better burning quality.

Improper mixtures of fuel and oil can lead to significant emissions increase and even to catalyst poisoning. Emissions testing on three-wheelers recruited from the Dhaka taxi fleet show that an 8 percent oil-fuel mix increased PM emissions by 160 percent compared with the recommended 3 percent of JASO FB oil-fuel mix (Kojima, 2002). The misuse of lubricant oil worsens emissions from two-stroke vehicles as the wrong lubricant oil can deactivate the catalyst in just 500 km of travel (Quin, 2001).

Four-Stroke Engines

Four-stroke engines are an improvement over two-stroke engines. This technology is more complex and heavier per power output than two-stroke technology, but offers better air-fuel control options and a separation of lubricants, exhaust and intake gas flows. As a result the four-stroke engine technology offers considerable benefits for emissions compliance. Technologies that improve fuel economy and emissions of four-stroke engines include air-fuel management devices such as the electronic carburetor and port fuel injection, combustion improvements such as dual spark plugs and aftertreatment with catalytic converters.

Air-fuel management: Electronic Carburetor

Traditional four-stroke engines use inexpensive mechanically operated carburetor technology for air-fuel control. Future regulations, however, may require more precise electronic technologies for fuel control. The electronic carburetor is an evolutionary step between the carburetor and port fuel injection. Electronic carburetors provide better fuel control through a solenoid valve. An oxygen sensor feedback signal is used to keep the air-fuel ratio close to complete combustion conditions. Because the air-fuel is well controlled, electronic carburetors allow the use of three-way catalytic after-treatment, which is fundamental for NOx control. Electronic carburetor costs are estimated around $40 (Iyer, 2011).

Emissions tests on electronic carburetors have shown significant improvements over mechanic carburetors. Tests conducted on two- and three-wheelers with 150cc engines show that under the test cycle ECE R40, the electronic carburetor reduced HC and NOx by about 75 and 40 percent respectively (Colombo, 2010).

Air-fuel management: Electronic Port Fuel Injection

More stringent emission and fuel economy regulations are projecting port fuel injection (PFI) technology to replace the carburetor as the fueling technology in the two- and three-wheeler market, even for small engines. PFI is the most promising technology for four-stroke engines for both motorcycles and three-wheelers. The use of PFI technologies in motorcycles started with large engines and has more recently been adapted to small engines. The introduction of more stringent emission standards in China, Japan, Taiwan Province of China, Thailand and India has led to the adoption, simplification and cost reduction of PFI in two- and three-wheelers. The estimated manufacturer's cost of electronic port fuel injection ranges from $85 to $170, depending on engine size (Meszler, 2007).

Compared with carburetors, electronically controlled port fuel injection offers improved precision of fuel delivery and better response to driver demands. PFI employs sensors to measure engine operational conditions and deliver the optimal according to fueling maps stored in the on-board computer. Spark ignition and fueling rates can be optimized for improved fuel economy and emissions performance. PFI enables the use of three-way catalysts. Electronic port fuel injection cost is estimated at $111 for a system without catalyst and $166 for systems with a catalyst and oxygen sensor (Meszler, 2007).

Experiments conducted by Leighton and Ahern (2003) in a 150cc motorcycle shows that PFI reduced CO by 20 percent and HC+NOx by 70 percent. It also reported a 20 percent reduction in fuel consumption. In 2010 Hero Motors in India introduced a 125cc motorcycle offered in both PFI and carbureted versions. According to the manufacturer, the PFI version delivers 85.8 km/l, 6 percent more than the carbureted version (Iyer, 2011). These benefits are not restricted by size. Honda introduced the first PFI 50cc engine in 2003. For this scooter, a 10 percent fuel economy improvement was reported (Honda, 2003).

Combustion improvements

Emissions and fuel economy improvements can also be achieved through in-cylinder combustion improvements. Measures associated with combustion improvements include the use of swirl-control valves, dual spark plugs and variable ignition timing.

The experience gained from passenger car technology shows that improving the way air and fuel mix just before combustion can have a significant benefit to fuel economy. Adding a swirl-control valve on the intake port can create turbulence for improved combustion and reduce unburned fuel in the exhaust. Tests under the ECE 40 test cycle on a 125cc motorcycle show that a swirl control valve increases fuel economy by 7 percent, while increasing maximum power by 8 percent compared to a conventional intake engine (Iijima, Kubota, & Kikuchi, 2009).

Dual spark plug technology is a technical challenge given the reduced space conditions on two- and three-wheeler engines, but it has proven beneficial for emissions and fuel economy. Tests conducted on commercial motorcycles with engines ≥15cc show that under the Indian Driving Cycle, the dual spark system reduces HC and CO by 28 percent and 40 percent respectively and fuel consumption by 12.8 percent over equivalent motorcycles with singe spark. (Iyer, 2011).

Variable ignition timing is intended to optimize the torque delivered by the engine for different driver demands and speed conditions. Using a throttle sensor position and the engine speed sensor, the load can be estimated and the spark timing adjusted for better fuel economy (Iyer, 2011).

Aftertreatment

Engine-out emission control from four-stroke engines requires aftertreatment control via oxidation catalyst or three-way catalyst, depending on emission standards requirements. Oxidation catalysts, as explained in the previous section, can provide some level of emission control on two-stroke engines, and perform even better on four-stroke engines. Engines running lean air-fuel ratios have very low HC and CO emissions, capable of achieving Euro 2 standards. However, if the engine is run rich, with little oxygen left in the exhaust, a secondary air injection system is required to obtain similar benefits. Experimental results on a 125cc four-stroke two-wheeler engine presented by Cursetji (2008) show that CO and HC emissions were reduced significantly with oxidation catalyst and with additional secondary injection. The oxidation catalyst alone reduced CO and HC by 25 and 20 percent respectively over to emission levels from engines without aftertreatment. The addition of secondary air injection in addition to the catalyst, reduced CO and HC by 90 and 56 percent respectively. It should be stressed that secondary air injection is not required in motorcycles tuned for lean combustion. However oxidation catalyst cannot control NOx emissions, which requires a three-way catalyst. Oxidation catalysts including secondary air injection systems have estimated costs around $61 (Meszler, 2007)

Further emission reduction requirements for NOx necessitate the implementation of three-way catalysts in four-stroke engines. Improved fuel control through port fuel injection with a feedback system in the exhaust ensures the necessary stoichiometric conditions in the three-way catalyst for adequate conversion efficiencies. Emission reductions compared to an uncontrolled carburetor four-stroke engine are estimated at 90 percent for CO, 85 percent for HC and 25 percent for NOx (Meszler, 2007). Given that three-way catalysts systems require stoichiometric combustion, the fuel economy may be affected. Compensation on fuel economy is achieved through further engine calibration enabled by the electronic control system and the flexibility of PFI systems. Estimated three-way catalysts costs are around $35 for a typical motorcycle excluding the oxygen sensor, which adds an additional $10-$15 (Meszler, 2007).

OBD Systems

On-board diagnostic technologies are designed to track and report vehicle components that affect emissions performance. Catalyst deterioration poses serious adverse impact on emissions, as the catalyst controls a majority of pollutant emissions, approximately 90 percent in passenger vehicles. The increase in emissions due to the deterioration of the catalyst could be greater than that caused by normal engine wear. Additionally, since there is no apparent deterioration of engine power or fuel efficiency a damaged or malfunctioning catalyst cannot be noticed by the vehicle user, except when the vehicle is equipped with the OBD.

In order to determine malfunctions in emission control systems, manufacturers must correlate component and system performance with exhaust emissions to determine when deterioration will cause emissions to exceed a certain threshold. The threshold is determined by the regulatory program and varies by pollutant. In passenger cars the threshold is set to 1.5 times the standard. This may require extensive testing and calibration for each engine model.

OBD sensing components can be added with minimal incremental costs to existing on-board computers that are part of the electronic fuel injection system. Experiences in port-fuel injected motorcycles indicate that the original ECU can be redesigned with additional capabilities for OBD sensing. This system, developed by Infineon and Tianjin University, has the capability to detect engine crankshaft position, sense throttle position, calculate mass airflow from air temperature, control fuel injection timing and amount, and control spark timing (Xie, Hu, Zhou, Hao, Tan, & Tan, 2006).

Evaporative Emission Control Technology

Evaporative emissions are caused by volatile components of gasoline that escape in gaseous form from the fuel system. There are four types of evaporative emissions. Diurnal evaporative emissions are caused by changes in ambient temperature during the day. Running loss emissions are vapor fuel emission caused by heating fuel in the gas tank and lines while the vehicle is in operation. Hot soak emissions occur after the vehicle is turned off and engine heat continues to heat up the tank and fuel system. Refueling emissions occur when the liquid gasoline displaces the vapors inside the tank and pushes them out into the air.

The main strategy to control evaporative emissions is the application of a system to capture the vapors. There are two main technologies, carbon canisters and system sealing. Carbon canisters are very effective at capturing vapors from the tank and fuel system when the engine is not running. When it runs, the engine draws the captured vapors from the canister and combusts them. System sealing includes the use of better materials and designs for sealants, connectors and fuel tank caps. Hydrocarbon evaporation may become a significant contributor to total HC emissions as exhaust concentrations decrease with more stringent standards.

One technology that has indirectly helped in reducing HC evaporative emissions is the port fuel injection, discussed earlier. Given that the PFI requires a pressurized system for fuel delivery, it is designed as a sealed system. Compared to carburetor motorcycles, PFI motorcycles emit around 60 percent less evaporative emissions (Ntziachristos, Geivanidis, Samaras, & Xanthopoulos, 2009). The use of carbon canisters and sealed tank and fuel lines produces a 95 percent reduction in diurnal losses (Geivanidis et al., 2008). The cost of canister and sealed tank and fuel lines was estimated around $15 to $70 depending on engine size, which ranges from 50 to 500cc (Geivanidis, Ntziachristos, Samaras , Xanthopoulos, Heinz, & Bugsel, 2008).

Fuel and Lubricant Quality

Vehicle emission control programs require treating vehicle, fuel and lubricants as a system. Fuel quality issues for emission performance cover sulfur and octane additives for gasoline and sulfur for diesel fuel. Lubricant quality issues that affect emissions performance include the use of low smoke oil, also referred to as 2T oil, for two-stroke motorcycles.

Reducing fuel sulfur levels improves the emissions performance of gasoline aftertreatment technologies. In the US, reduction of sulfur in gasoline from 320 ppm to 30 ppm improved the performance of catalytic converters, achieving NOx, HC and CO emission reductions by 9 percent, 18 percent and 16 percent respectively (Rutherford, et al., 1995).

Octane additives for gasoline change the behavior of fuel during combustion. Metal-base fuel additives containing lead have already been banned globally but others containing manganese and ferrocene are still a source for public health concern (ICCT, 2009). Methylcyclopentadienyl manganese tricarbonyl (MMT), a manganese-based compound and ferrocene, an iron-containing compound have been marketed as lead replacements for octane enhancement. The use of MMT and ferrocene results in the emission of manganese and iron oxide particles in vehicle exhaust (ICCT, 2004). Chronic exposure to manganese has been associated with neurological impacts similar to Parkinson's disease. Exposure to ferrocene combustion products has shown cellular damages in animal studies (Walsh, 2007).

Lubricant oil quality is of extreme importance for emission control in two- and four-stroke motorcycles and three-wheelers. In two-stroke vehicles the lubricant oil is dissolved and combusted altogether with the fuel, directly affecting vehicle emissions. Lubricating oil used in four-stroke motorcycles, even though it is not burnt during combustion, has an impact on fuel economy. Motorcycle oil has to lubricate piston, gears and wet clutch. Thus, using the right lubricant can significantly impact fuel economy. Lubricant standardization for four-stroke motorcycle engines is not as prominent as for two-stroke engines as its emission impact is lower.

Alternative Fuels

In addition to promoting the adoption of emission control technologies via strict standards, most successful comprehensive programs encourage the development and use of alternative fuels and advanced propulsion technologies. Alternative fuels include compressed natural gas (CNG) and liquefied natural gas (LPG), while advanced propulsion refers to electric vehicles.

Alternative fuels for mobile applications are pursued for different reasons. Alternative fuels encourage the development of local sources of energy, they can be employed for pollutant reduction programs and they can help in reducing life-cycle greenhouse gas emissions. In real life, the benefits can vary widely. Fuel availability, infrastructure investments, local practices, cost, taxes and other factors play a role in determining the environmental and social benefits of alternative fuels. Benefits must be weighted against costs derived from incremental vehicle, retrofit or maintenance costs, and the incremental cost of the alternative fuel.

CNG is an alternative fuel that offers significant emission benefits in terms of PM reductions, but also poses well-known challenges. Given that CNG requires a high-pressure storage tank (200 bar), CNG is restricted to three-wheeler applications. Fairly wide differences are reported for the emissions performance of CNG three-wheelers relative to an equivalent gasoline motorcycle.

The quality of CNG retrofits may play a role in the reported differences, but significant variation is reported even for original equipment installations. In Delhi, where 100 percent of three-wheelers are now powered by CNG in response to air quality-driven clean-fuel requirements, two-stroke CNG three-wheelers are reported to reduce NMHC and NOx emissions by about 80 percent and CO emissions by about 60 percent while four-stroke CNG three-wheelers reduce NMHC by about 75 percent and CO by about 60 percent and increase NOx by around 30 percent (Biswas, 2001). In contrast, estimates for more than 1,000 two-stroke three-wheelers converted to CNG fueling in Dhaka imply that NMHC, CO, and NOx have all declined by 80 to 90 percent (Walsh, Impact of Fuel Conversion on Emissions From 2-3 Wheelers, 2001).

LPG use for three-wheelers is conceptually similar to that of CNG. However, LPG can be stored as a liquid at lower pressures (4-5 bar), reducing the size and cost of fuel tanks. Available emissions data for LPG motorcycles show that with respect to two-stroke gasoline engines, idle emissions are reduced significantly for HC (~30 percent), CO (~35 percent), and NOx (~75 percent) (Li, 2002). Under load, Li et al. (2002) found that emissions estimates are much more variable. His study found HC and CO to decline between 0 and 70 percent and 75 to 99 percent respectively depending on specific speed and load conditions, while emissions of NOx increased by 200 to 1000 percent or more, although the authors felt that the NOx performance of LPG could be substantially improved in an optimized application (Li, 2002). Conversely, others have reported CO and NOx emissions similar to those of gasoline motorcycles, with total HC increasing by 15 to 30 percent. Other more recent data from India indicates that four-stroke LPG motorcycles reduce NMHC by about 50 percent and CO by about 60 percent, while increasing NOx by about 25 percent (Meszler, 2007).

Electric Motorcycles

Many consider zero tailpipe emission technology as the ultimate solution to transportation related pollution problems. Electric motorcycles, or e-bikes, have been available for many years but only recently have enjoyed commercial success, primarily in China (ICCT, 2009). In China there are an estimated 30 to 50 million e-bikes (GTZ, 2009), while in India the market is growing and there are ten manufacturers offering 25 models (Iyer, 2011).

There are two types of electric motorcycles- bicycle style and scooter style. Bicycle style have a maximum speed of 25 km/h while scooter style can reach 50 km/h. Both types have operational ranges of 40 to 70 km on a single charge, depending on model. Because size is loosely regulated in China, these vehicles are allowed the same privileges and have the same regulations as traditional bicycles, including shared way of right on bicycle lanes in some regions (GTZ, 2009).

Electric motorcycles offer significant reductions in pollutants and GHG emissions but also present some challenges. First, the net environmental impact of e-bike use is mixed as they tend to substitute bicycles and public transit, and the environmental impact of the electricity consumed depends on its source. Second, there is an environmental impact component associated with the manufacturing of e-bikes, specifically the lead required in their batteries.

Although e-bikes do not emit any pollutant directly from the tailpipe, there are emissions associated with electricity produced to charge them, especially when it comes from coal power plants. Thus, depending on the power source, whether it is a hydroelectric, nuclear or coal powered plant, emission factors can be associated with e-bikes use. Table 2 shows an example of emission rates for typical electric scooters by region and a comparison with respect to conventional four-stroke motorcycles. It is clear that e-bikes are extremely low pollutant emitting vehicles, even when the grid share included. However, the CO_2 emission reductions are not as significant.

Table 2. Emission Rates of Typical Electric Scooters and Four-Stroke Motorcycles (ADB, 2009)

Network	CO, g/km	NOx, g/km	PM10, g/km	PM2.5, g/km	SO_2, g/km	VOC, g/km	CO_2, g/km
Guangdong Grid	0.007	0.025	0.007	0.004	0.043	0.003	19
North Network	0.018	0.072	0.018	0.011	0.153	0.007	25
Typical 4-stroke Motorcycle	12.5	0.15	0.1	-	-	2.25	55

The biggest issue with electric motorcycles is lead emissions. Lead contamination from battery production and disposal can have a significant health impact. Lead emissions per passenger kilometer are several orders of magnitude higher for electric bikes than for buses (Cherry, 2006). Unregulated or under-regulated production and recycling by the lead and battery industries results in approximately 30 to 70 percent of lead into the environment (ICCT, 2009). According to GTZ, for every electric bike on the road between 664 and 774 grams of lead per year end up in the environment (GTZ, 2009).

Additional problems arise in countries like India, where regulation exempts e-bikes powered by engines of less than 250W and with a maximum speed of 25 km/h from meeting the norms established for the rest of the two-wheeler fleet. Because of that, vehicles and operators do not have to comply with safety standards and driving these vehicles does not require a driving license (Iyer, 2011).

Safety Measures for Two-Wheelers

Safety of two-wheelers is a great concern and measures must be employed to reduce alarming fatality rates. Measures for improving motorcycle safety can be categorized as exposure reduction measures, crash avoidance measures and crash protection measures (EC, 2011).

Exposure reduction is implemented through limitations on engine capacity and power. In the UK, motorcycle engine capacity and maximum power is restricted for novice motorcyclists at 125cc and 9 kW. Japan imposes limits on engine size and performance of motorcycles used domestically, but has no limits on exports.

Crash avoidance measures involve vehicle design features such as advanced breaking technology and daytime running lights. Improvements in braking technologies are required to avoid accidents derived from aggressive braking instability. Strong braking used in today's motorcycles is required for driving performance, but in case of emergency braking, it can cause the front wheel to lock. Locking of the front wheel can cause the driver to loose control of the motorcycle. Anti-lock braking systems (ABS) can prevent wheels from locking, improving their maneuverability during emergencies.

ABS systems for motorcycles were commercially introduced in 1989 on the BMW K100. In 2009 the lightest and smaller version of this system was launched in Europe as part of a Combined Brake System with ABS. According to information presented by Bosch, the ABS system weight, a limiting factor for small motorcycles, went from 4.5 kg in 1994 to less than 1 kg per unit by 2010. Advances in ABS and integrated electronic braking systems include ABS with rear-wheel lift mitigation. The ratio of installation on new motorcycles MY2010 with engines smaller than 250cc is less than 3 percent and around 36 percent for larger motorcycles in Europe (Teoh E. , 2011).

Recently, the Insurance Institute for Highway Safety and the Highway Loss Data Institute in the United States compared data of crash rates for motorcycles equipped with optional ABS against the same model without ABS. Results show that the ABS equipped motorcycles where involved in 37 percent less fatal crashes than vehicles without the system (Teoh E. R., 2011). In crashes of all severities, the frequency for collision claims was 22 percent lower for ABS quipped motorcycles (HLDI, 2009).

The use of daytime running light (DRL) also reduces accidents. The objective of daytime running lights is to improve vehicle visibility at all times in order to reduce the risk of crashes. Many European countries have mandated their use and some new motorcycles have standards mandating an automatic headlamp. In Europe, motorcyclists who use daytime running light have a 10 percent lower crash rate than non-users (EC, 2011). The use of DRL has reduced the number of injured motorcyclists by 16 percent (Bijleveld, 1997). The societal cost-benefit ratio of DRL is about 1:7 (Elvik & Vaa, 2004).

Crash protection refers to helmet use. The main purpose of helmets is to reduce deceleration of head and absorbing the energy of a collision. Research data strongly supports the fact that helmet use reduces the severity of head injury and reduces the rate of fatalities in motorcycle accidents. According to the *Motorcycle Accidents In-Depth Study*, helmets are effective at preventing or reducing the severity of head injury to motorcyclists who crashed by 69 percent (MAIDS, 2009).

The effectiveness of a helmet use regulation is linked to its quality. Special technical requirements for helmet quality are in place in the EU, India (IS 4151), Japan (JSI T8133:2000), UK (BSI 6658) and Vietnam (TCVN 5756:2001). In general, those specifications require helmets to be tested for impact, retention system (straps), and shell durability.

Current Two- and Three-Wheeler Policy Framework

This section covers the current regulatory framework that has promoted the adoption of emission control and fuel economy technologies for two- and three-wheelers sold in Asian countries. The discussion includes existing regulatory programs for countries where these vehicles significantly contribute to air pollution. Regulatory programs studied include tailpipe emissions standards, compliance and enforcement, in-use requirements, fuel economy standards, fuel and lubricant quality and safety and noise.

Current Two- and Three-Wheeler Emission Standards in Asian Countries

Given the large share of two- and three-wheelers in Asian countries, governments have taken steps to reduce pollutant emission rates through the adoption of emission standards. Typically the standards prescribe a limit for CO, HC and NOx. In some programs HC and NOx emissions are regulated into a single HC+NOx standard as a strategy to address ozone or smog formation. In a few regions, PM emissions from diesel three-wheelers are additionally regulated.

Current standards for motorcycles and three-wheelers in selected Asian countries are presented in Figure 3 for motorcycles and in Figure 4 for three-wheelers. In general, smaller motorcycles are regulated with more stringent standards, while heavier ones, especially three-wheelers, have more relaxed limits. Lack of or lax emission standards allow use of technologies that might not align with air-quality improvement efforts.

It is evident that a number of Asian countries have made significant progress, with some countries already taking steps towards world harmonization. Compliance with emission standards is determined by a driving cycle. In most Asian countries, the emission limits are currently based on the European system assessed on the ECE R47 drive cycle for mopeds and the ECE R40 for all other motorcycles. The UNECE, through the World forum for harmonization of vehicle regulation (also referred to as WP29), developed the World Motorcycle Test cycle (WMTC). This test cycle, developed in 2005, is designed to represent a global average driving pattern. Amendments to the test cycle, intended to better represent local driving patterns, were submitted by India and adopted in 2007. Currently only India, and China in the near future, includes provisions for compliance under the WMTC.

Durability and Deterioration Factors

Regulatory programs in China, India Japan, Taiwan Province of China and Thailand include durability requirements ranging from 6,000 to 30,000 km depending on motorcycle size. With average annual kilometers traveled estimated at 8,000 to 10,000 km for two-wheelers and 40,000 km for three-wheelers, these motorcycle durability requirements guarantee emission compliance for less than three years (Meszler, 2007).

Deterioration factors represent the expected deterioration of emission performance over the course of the

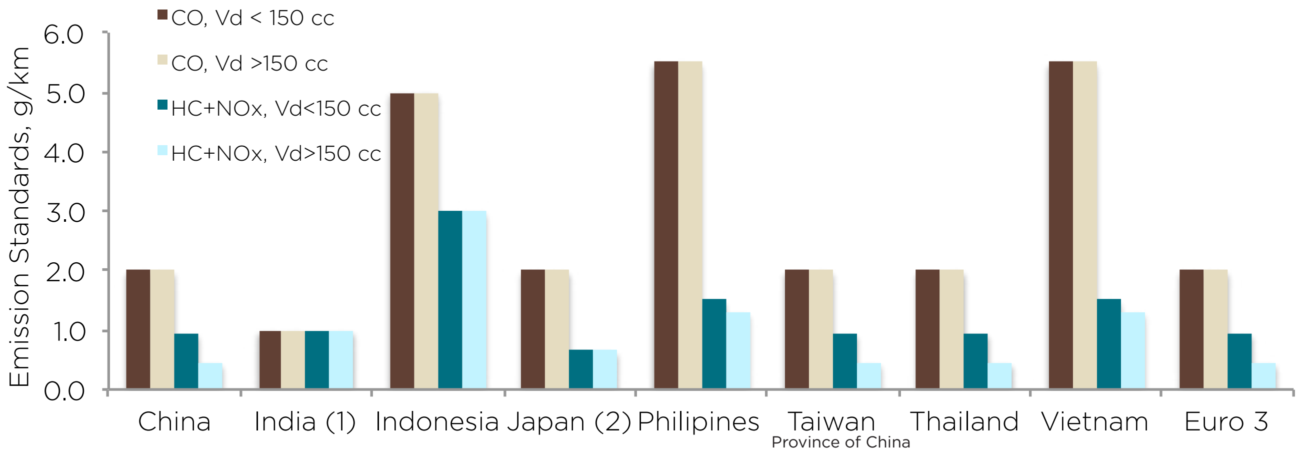

Figure 3. Latest Emission Standards for two different motorcycle categories for Selected Asian Countries. Note: (1) Test cycle corresponds to Indian Drive Cycle. (2) Japan does not include cold start for motorcycle <125 cc.

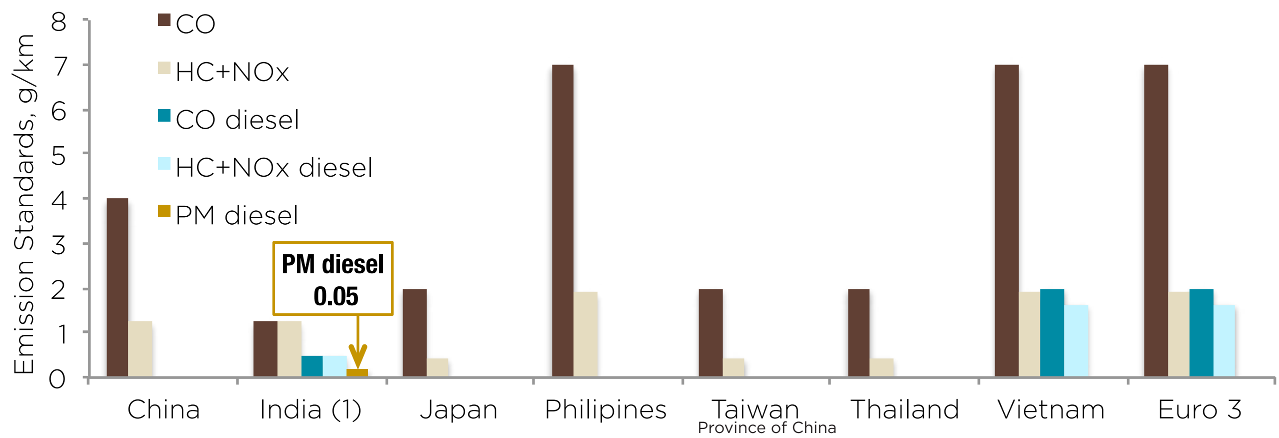

Figure 4. Latest Three-Wheeler Emission Standards for Selected Asian Countries.
Note: (1) Test cycle corresponds to Indian Drive Cycle.

vehicle lifetime and have the same purpose as durability regulations. Current Indian emission standards include deterioration factors of 1.2 for two-wheelers and 1.1-1.2 for three-wheelers. Compliance is granted either below deterioration factors or by demonstrating compliance from a motorcycle with 30,000 accumulated kilometers.

Cold Start Emission Testing

Vehicle emissions during the first seconds after start-up depend on engine and aftertreatment system temperature. Fuel vaporizes faster and combusts to completion better in hot engines, while catalytic converters require certain minimum temperature for maximum pollutant treatment effectiveness. Thus, during cold starts when the engine and the catalytic converter are below typical operational temperatures, pollutant emissions are higher.

Test procedures in China, Japan, Taiwan Province of China, Thailand, the EU and the US require cold start testing. Indian current regulations call for cold start testing, but the driving cycle includes 40 seconds of idling which allows for warming up before emission measures take place.

Evaporative Emissions

In addition to tailpipe emission standards, some regulatory programs include limits on evaporative emissions. The typical evaporative limit for motorcycle is 2 grams of HC emitted during the sealed housing for evaporative determination (SHED) test. During the SHED test the vehicle is placed in a sealed and temperature controlled chamber and HC evaporative emissions are measured while the chamber's temperature is varied to reflect variation in ambient temperatures over the course of a day.

Currently only China, Taiwan Province of China, Thailand and the United States have adopted evaporative emission standards for motorcycles (ICCT, 2007). In India, a proposal to introduce standards for evaporative emissions along the lines of those prevalent in Taiwan Province of China has been under the active consideration by the government for many years. The introduction of the evaporative emission control for two-wheelers in India will likely coincide with the introduction of the next stage of emission standards in the year 2015 (Iyer, 2011).

Compliance and Enforcement Programs

Compliance and enforcement programs are designed to ensure vehicle models meet new vehicle emission standards and adhere to in-use standards. The programs can be divided into 4 categories: type-approval, conformity of production and selective enforcement, audit process and vehicle recall programs (ICCT, 2007).

Type approval is intended to demonstrate that a vehicle meets the standard. Tests are conducted by the manufacturer at their own testing facilities or contracted with independent certified facilities. The process is usually overseen by a technical government agency, usually within the environmental ministry or administration. For type approval a vehicle representative of an engine family is tested. In the US, motorcycles above 50cc must be tested at different stages along the vehicle lifetime. Data from the tests is sent to the oversight agency. Periodic correlation tests are performed between manufacturers' test facilities, independent labs and oversight agencies to identify systematic errors and ensure reliability of results. Factory inspections by the oversight agency are also part of this mechanism.

Conformity of production and selective enforcement are designed to ensure that the approved vehicle meets requirements shortly after being introduced to the public. Manufacturers should document production and quality practices. The oversight agency judges the documented practices and decides if further production upgrades are needed.

Selective enforcement audits (SEA) are issued by the oversight agency for new engines or new vehicles. New engines or vehicles can be procured form the production line or the dealership. If vehicle fails the test, its sales can be restricted until proof of conformity with standards is presented.

Vehicle recall is issued by the oversight agency in cases where in-use vehicles, within durability requirements, are tested for emissions. The test provides information about real world emission performance. Data from inspection and maintenance (I/M) programs or warranty claims can trigger this compliance program. If tests prove systematic failure, manufacturers have to contact vehicle owners and assume the cost of repairs. Vehicle recall is not exclusive to emission control technology.

A successful Compliance and Enforcement program is currently running in Taiwan Province of China. The Taiwanese Environmental Protection Agency (TEPA) oversees new vehicle certification and conformity of production through a new vehicle Selective Enforcement Audit (SEA) carried out early in the vehicle's life. Subsequently the vehicle is subject to be tested under its warranty period, in parallel to annual tests that are part of the I&M program. Regulators in Taiwan Province of China measure program effectiveness by tracking the average emissions of the vehicles tested along various phases of the program. Over the years, the agency has seen a decrease in non-compliant vehicle models and in overall failure rates (ICCT, 2009). Taiwan Province of China institutes a motorcycle recall when average emissions from ten motorcycles in a single family do not meet the standard.

In-Use Requirements

In-use control measures are designed to control emissions from vehicles on the road. In use-control measures include in-use emissions standards, inspection and maintenance programs (I&M), retrofits and replacements, and vehicle restrictions-bans.

In-use emission standards are as important as new vehicle emission standards as they provide assurance that the vehicles are performing throughout their lifetime. These standards usually comprise CO and HC measurement over an idle or free acceleration test. Most of the top ten largest motorcycle markets in Asia have adopted in-use standards. Philippines only tests HC under idle tests and Malaysia, Pakistan and Sri Lanka have not adopted the measure. Measurements are performed under I&M programs.

I&M programs for motorcycles are designed to verify that emission control systems are in running order. Under I&M programs, vehicle's emission and safety are required to be inspected at regular intervals, usually annually or biannually. Vehicles that fail the inspection should be repaired by the owner and tested again. An I&M testing facility can be centralized or decentralized. Centralized testing is usually government operated, which offers easy oversight and low cost, while limiting the access to vehicle owners and increasing waiting time. Decentralized testing is privatized, facilitating the access to numerous vehicle owners, but increasing challenges to oversight and corruption prevention. Transparency is key to public acceptance for all I&M programs (ICCT, 2009).

Retrofits and replacements are carried out by governments or independent organizations with the support of financial institutions. This type of measures usually targets the heaviest polluting vehicles. Retrofits should be performed with certified kits or replacement engines. For example, in response to the ruling by the Supreme Court of India, all three-wheelers were retrofitted with a CNG kit.

Fuel Economy

Due to their low weight, motorcycles tend to have better fuel economy (FE) than passenger vehicles. Currently in Asia, only Taiwan Province of China and mainland China have fuel economy standards, while some additional countries are beginning to consider standards. Taiwan Province of China began their motorcycle fuel economy program in 1987 and mainland China adopted standards in 2009. Table 3 shows the current FE standards for select engine sizes for mainland China and Taiwan Province of China, In India, manufacturers started to voluntarily report fuel economy for motorcycles in Spring of 2009.

Fuel economy testing and certification is similar to the testing process for conventional pollutants. Typically manufacturers are required to test a representative vehicle during the type approval process. An oversight agency might conduct independent testing to verify fuel economy data provided by manufacturers. Although there are no compliance and enforcement programs associated with fuel economy, I&M programs can help keep vehicles in proper running order to achieve adequate fuel economy over their lifetime. It should be noted that comparing fuel economy among countries is difficult given that testing methodologies are different.

Table 3. Fuel Consumption Standards in China and Taiwan Province of China (effective 2009). Note: Two-wheeler standards in Taiwan Province of China and Mainland China are not directly comparable as test procedures are not the same.

Engine Size (cc)	China 2-Wheeler, L/100 km	China 3-Wheeler, L/100 km	Taiwan 2-Wheeler, L/100km
≤50 (mopeds)	2	2.3	2.3
>50-100	2.3	3.3	2.7
≥100-125	2.5	3.8	2.8
≥125-150	2.5	3.8	2.8
≥150-250	2.9	4.3	4
≥250-400	3.4	5.1	4
≥400-650	5.2	7.8	5.5
≥650-1000	6.3	9	6.3
≥1000-1250	7.2	9	6.9
≥1250	8	9	6.9

Fuels and Lubricants Quality

Some Asian countries are offering low sulfur diesel and discussing the introduction of ultra-low sulfur diesel while other Asian countries with large motorcycle populations do not have a supply of low or ultra low sulfur diesel (Figure 5).

Some octane additives in gasoline result in emissions that have negative effects on human health. Methylcyclopentadienyl manganese tricarbonyl (MMT) is subject to strict limits or is banned in some countries due to its negative health impacts (ICCT, 2009). Europe will introduce a 2mg/l MMT limit on gasoline by 2014. Beijing has adopted a maximum of 6mg/l MMT (ICCT, 2009).

In many countries, low smoke oil (2T oil) premixed with gasoline is required to be dispensed at service stations. Some Asian countries, such as Bangladesh, India and Pakistan, have two-stroke lubricant quality and/or dispensing requirements. Bangladesh requires 2T oils meeting JASO FB or API TC and India mandates JASO FC for the entire country while sale of pre-mixed fuel-oil is mandated only for selected cities. Pakistan has implemented bans on recycled oil sales and allows oil sales only at dispensing facilities. Standards for four-stroke engines used in motorcycles are not defined.

Safety

Although most countries in Asia have adopted measures to reduce fatalities by implementing mandatory helmet use, experiences from other countries and regions can be applied to further improve two- and three-wheeler safety in Asia. Regions and countries such as Europe and the US have been actively engaged in improving safety for all transportation, including motorcycles. In Europe, the European Road Safety Charter (ERSC) was launched in 2003 with an aim to halve the number of fatalities related to transportation activities. A series of measures were implemented to target motorcycle safety. Measures for improving motorcycle safety can be categorized as exposure reduction measures, crash avoidance measures and crash protection measures (EC, 2011).

Exposure reduction, by limiting engine capacity and power limitations for certain drivers can be applied to novice motorcyclists, as is being done in the UK. Power and speed limitations can also be applied at the higher power range.

Crash avoidance measures such as mandating advanced breaking systems are not implemented in any market but are being discussed as part of the European proposal for emissions and safety in two- and three-wheelers. The proposal includes provisions that mandate the use advanced braking systems, combined brake systems or ABS or an integrated system (EC, 2010).

Crash avoidance measures including daylight running headlamps are included in the current European proposal. This proposal requires motorcycles, at the discretion of the vehicle manufacturer, to have either lighting or light-signaling devices or dedicated daytime running lights (DRL) that turn on automatically (EC, 2010).

Crash protection measures requiring helmet use have been adopted globally. EU legislation on helmet use

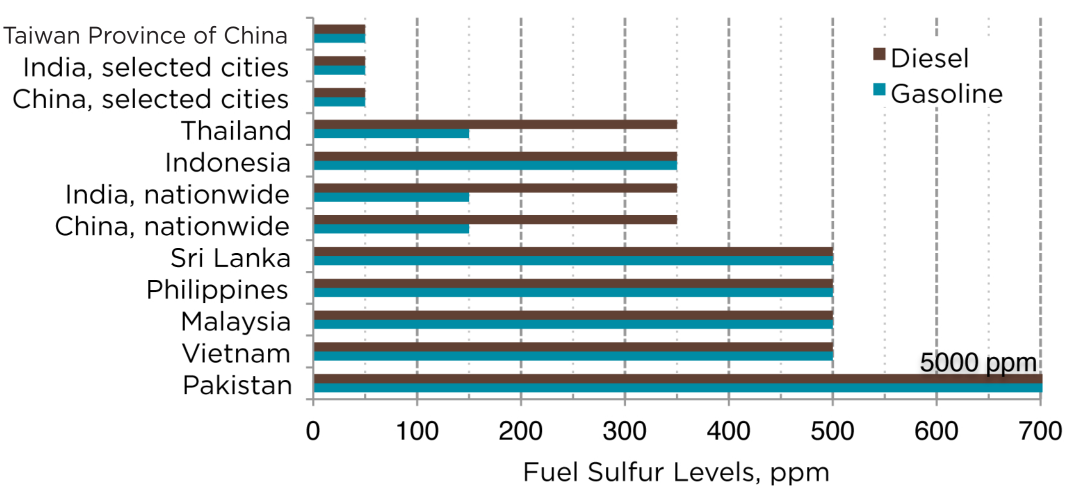

Figure 5. Current Fuel Sulfur Limits for Selected Asian Countries/Regions.

was proposed and suspended during the past decade, given that specific norms were already available in some member states. Presently in Europe, helmet use is carried out as a voluntary agreement with vehicle manufacturers. In Asia, most Asian countries mandate helmet use and are actively engaged in promoting its use (Red Cross and Red Crescent Society, 2010).

Noise

Noise from motorcycle sources is considered a significant local environmental problem in Europe. The main focus of reducing unacceptable noise pollution in the EU is through the use of mandatory technical standards. In Europe, directive 97/24/EC set limits on permitted sound levels from motorcycles, their exhaust systems and silencers, together with requirements for measurement and testing (REC-UBA, 2008).

Although original manufacturer equipment is noise-regulated, excessive noise is caused by the use of illegal (non type-approved) exhaust systems. A uniform type-approval testing procedure does not apply to every exhaust system. Type-approved non-original exhaust systems may violate legal noise levels, due to less stringent type-approval testing conditions. Simplification and harmonization of the legal framework setting equally stringent measures for every exhaust system should contribute to reducing the problem of illegal noise levels (ACEM, 2010).

India has enacted regulations on noise from all motor vehicle exhaust systems, following ECE Regulation No. 41. For two- and three-wheelers, the maximum exhaust noise levels range from 75 dB to 80 dB depending on engine size. In China, the standard for a 125cc engine is 77 dB. Thailand has a 95 dB limit measured at 0.5 meters from the motorcycle and at specific engine speed settings.

Policy Recommendations

Successful management of two- and three-wheelers requires improved regulatory programs and focus on both current vehicles and the next generation of two- and three-wheelers. Improved emissions monitoring is required for current two and three-wheelers. Cleaner and more efficient vehicles are key for the next generation of two- and three-wheelers.

The first policy priority is to establish more rigorous emission standards and certification for current and next generation technologies through manufacturer oversight and verification. Additionally, labeling and incentives can be employed to shift consumer preferences to cleaner models. The next crucial step is controlling in-use emissions, which requires inspection and maintenance programs. The final step is technology innovation, applying all available technologies for emission control, fuel economy, safety and noise.

Emission Standards

In Asia, Taiwan Province of China was the first to adopt emission standards and has remained a leader, also adopting fuel economy standards. Thailand and China have adopted enhanced versions of the European program with added durability requirements. Indonesia, Philippines and Vietnam are following similar steps. Vietnam has set a timetable for Euro 3 levels for 2017. India has developed its own unique set of norms and test cycles, including provision for alternative testing under the World Motorcycle Test Cycle (WMTC).

Regulations based on Euro 3 or higher levels promote the use of technologies to meet emission requirements. In line with the European strategy on air quality, the European Union has strengthened emission standards for hydrocarbons, carbon monoxide, nitrogen oxides and particulate matter. Three steps for emission limits for motorcycles are proposed through Euro 4, Euro 5 and Euro 6, with timelines of 2014, 2017 and 2020 respectively (EC, 2010).

One significant characteristic of the European proposal for two- and three-wheelers is that the Euro 6 emission levels for motorcycles will have the same nominal values as the Euro 5 emission levels for passenger cars. For motorcycles with a maximum design speed of 130 km/h, the proposed Euro 4 limits for HC, CO and NOx establish a 25 percent reduction for each pollutant from current Euro 3 limits under the optional WMTC cycle. By 2020, HC limits for motorcycles would fall 87 percent from current levels and CO and NOx limits would decrease 62 percent (EC, 2010).

Given that Asian motorcycle manufacturers are exporting products worldwide, harmonizing regulatory standards offers great benefits, including reduced compliance costs and the opportunity to leapfrog to the most stringent emissions standards. Harmonization of test procedures can further facilitate the dissemination of regulatory enhancements. The World Motorcycle Test Cycle (WMTC) for motorcycles was developed by the United Nations Economic Commission for Europe (UNECE) and designed to represent a global average of driving patterns. India has participated in the test programme to develop correlations that led to the finalization of proposals for WMTC limits to be transposed by the member countries into their own regulations. With a view to transpose the relevant parts of WMTC into its own legislative requirements, India has issued a draft notification in December 2010, with possible implementation by 2015.

With most major motorcycle manufacturing countries meeting stringent standards, other nations, especially motorcycle importers, should consider leapfrogging to the most stringent standards. A larger market would further reduce the cost of technology development and production, benefiting all parties. Given that Asia is the home to the largest two- and three-wheeler manufacturers, these measures can have a positive ripple effect in many developing markets globally.

Durability

Emission standards should be designed and enhanced with an oversight program that helps ensure emission limits will be met throughout a vehicle's lifetime. Durability requirements, such as those already adopted by some Asian countries are good examples in that direction and can be enhanced to cover longer useful-life periods.

Adopted emission regulations in most Asian countries already include certain durability requirements, ranging from 8,000 km to 30,000 km. The latest European proposal requires that manufacturers ensure that type approved vehicles meet the environmental requirements over the vehicle's useful life. Durability tests require mopeds to be tested at 12,000 km for Euro 5 regulations, motorcycles with V_{max}<130 km/h are required to be tested at 30,000 km, and motorcycles with V_{max}>130 km/h are required to be tested at 50,000 km.

It is recommended that local Asian requirements be revised to adopt longer durability requirements such as those suggested in the Euro 5 proposal.

Compliance and Enforcement

Compliance and enforcement programs are often the weak link in many programs, with understaffed and underfunded agencies. Compliance and enforcement programs should cover the certification process before mass production, conformity of production shortly after it is introduced to the market, manufacturer based warranties, selective enforcement audits shortly after production, and recall investigations during warranty periods.

In-Use Requirements

Inspection and maintenance programs should be improved. Technical improvements involve adopting more stringent in-use standards according to changes in certification standards and better testing procedures. India has been involved in developing a transient in-use test mode, which relies on the same instruments but is a great improvement over the idle test. For this level of testing the inspection can be done every year or two years, instead of the conventional biannual test (Iyer, 2011).

I&M programs have reported administrative issues regarding lack of oversight of the test centers, lack of professionalism and low public credibility. These issues must be addressed and I&M programs should be enhanced with better training for technicians and managers as well as public educational campaigns that the importance of these programs for air-quality.

OBD

OBD is a new topic for two- and three-wheeler regulatory programs around the globe. The benefits experienced in passenger car OBD programs have motivated its possible implementation for two- and three-wheelers in Europe.

The European regulation proposal requires OBD technologies at the level of minor malfunction monitoring (e.g. circuit integrity) (OBD stage 1) for all two- and three-wheelers, but no catalyst efficiency and misfire monitoring or provision for access to repair and maintenance information, as in passenger cars. OBD-1 is expected to start on January 2017 for mopeds, motorcycle and three-wheelers. OBD stage 2 will be considered for two- and three-wheelers upon completion of an environmental study planned for 2016, which will evaluate the impact of the proposed OBD measures. OBD-2 will cover complete failures and deterioration of systems. The specific threshold limits for HC, CO and NOx are specified in the proposed regulation for ODB-1 and OBD-2.

In Asia the application of OBD on two-wheelers still using carburetors and catalytic converters without electronic air-fuel ratio control is not useful. It is suggested OBD be introduced for two- and three-wheelers in parallel with the introduction of Euro 4 equivalent standards. These standards would likely require the use of electronic control of air-fuel ratio and a catalytic converter supported by an oxygen sensor.

As an example, HMSI, a major Indian motorcycle manufacturer, has introduced a malfunction indicator on a commercial model powered by a 125cc four-stroke engine that uses port fuel injection (Iyer, 2011).

Although OBD systems entail additional costs for new components and sensors, they also help detect engine malfunctions, reducing vehicle fuel consumption. It is therefore recommended that motorcycles be fitted with on-board sensing capabilities, ensuring that the emission control system will last through the normal life of the vehicle.

Fuel Economy

Steps by Taiwan Province of China, China and India point in the right direction for reducing fuel consumption and CO_2 emissions. However, further technology research and policy development is required across all other Asian countries. Motorcycle technology could be implemented in the next generation of motorcycles provided that standards are set, the public is informed, and costs are reasonable and will pay back the incremental purchase cost. Moreover, stringent emission standards and fuel economy can be used as levers for introducing technologies that improve both.

As with emission standards, harmonization for fuel economy test procedures and standards based on the WMTC and UNECE test procedures would facilitate global trade and reduce the cost of certification. A country that follows this logic is China, which is developing new fuel economy standards that include the use of the WTMC for motorcycles.

Complementary taxation policies can be implemented to motivate the public to adopt new engine technologies for fuel efficiency, such as a feebate-rebate structure similar to the one used currently for passenger cars in France where fuel economy is highly monitored (ICCT, 2011).

Policy recommendations for Electric Motorcycles

From an air quality perspective, the policy recommendation for managing electric motorcycles focuses on lead emissions. Electric motorcycles are very low emitters, but lead emissions are of growing concern and have to be regulated along the battery lifecycle, including production, recycling and final disposal. Stricter standards are needed to guide domestic lead production and recycling and to limit air and water contamination. A second option is to promote the adoption of alternative energy batteries, such as Li-ion or NiMH batteries which have fewer environmental externalities (GTZ, 2009).

Safety programs

Many people associate safety regulations for motorcycles with only the use of helmets and proper driving habits. However, additional technologies can also be applied in the new generation of motorcycles to reduce the high fatalities rates. For these technologies to be implemented standards that mandate their use are required.

In Europe the current proposal for emission regulations includes provisions for safety. The proposal includes mandatory fitting of advanced brake systems. This refers to optional combined break system and/or ABS for smaller motorcycles, and ABS for larger ones. Vehicles will also have to improve vehicle visibility by adopting automatic daytime running lights (EC, 2010).

In addition vehicle maneuverability is also revised. The recommendation includes measures that improve safe cornering on hard surfaces. This specifically targets three-wheelers in that it the vehicle has to be designed in such way that each of the wheels can rotate at different speeds at all times (EC, 2010).

Conclusions

Despite progress, emission certification standards for two- and three-wheelers pale in comparison to the stringency of standards for passenger vehicles and light commercial vehicles. In general, larger and heavier two- and three-wheelers have less stringent regulations. Lack of regulatory pressure has led to continuous use of older, less clean and less efficient technologies, which in some cases have led to direct bans on some vehicles, with shocking impacts for their owners and users.

Other regulatory requirements, such as evaporative emissions, compliance and enforcement mechanisms, and in-use standards have been applied in some countries and regions, but there are still many countries lacking appropriate programs. Fuel efficiency standards should be adopted and extended to all categories of two- and three-vehicles. Fuel economy standards help mitigate the effects of the larger, faster and less fuel efficient models on the overall fleet fuel economy. Public awareness of fuel economy standards and financial incentives on less expensive models can help drive a successful program. Harmonization of test procedures and regulatory requirements is recommended, as a larger market allows for significant cost reduction to develop and produce technologies and stimulates competition and advances in technology.

The adoption of technologies that help prevent engine and emission control deterioration such as OBD should be promoted across all two- and three-wheeler categories. Technologies for improving safe driving should also be mandated for active prevention of accidents.

Works Cited

ACEM. (2010). The Motorcycle Industry in Europe. Association des Constructeurs Européens de Motocycles. ACEM.

ADB. (2009). Electric bikes in the People's Republic of China: impact on the environment and prospects for growth. Asian Development Bank, Mandaluyong City, Philippines.

Ambler, M., & Zocchi, A. (2001). Development of the Aprilia DITECH 50 engine. SAE Technical Papers (2001-01-1781).

Archer, M., & Bell, G. (2001). Advanced Electronic Fuel Injection Systems – An Emissions Solution for Both 2 – and 4- Stroke Small Vehicle Engines. SAE Technical Papers (2001-01-0010).

Bijleveld, F. D. (1997). Effectiveness of daytime motorcycle headlights in the European Union. Foundation for Road Safety Research.

Biswas, D. (2001, September 5-7). CNG Conversion Programme for Auto Rikshaws in Delhi. presented at the Regional Workshop on Reduction of Emissions from 2-3 Wheelers . Hanoi, Vietnam.

Bovonsombat, P. (1998). Field Test Study of Two-Stroke Catalytic Converter in Thailand. SAE Technical Paper (982711).

CAI-Asia. (2011). Managing two and three wheelers in Asia. Clean Air Initiative for Asian Cities.

Cherry, C. (2006). Implications of Electric Bycicle use in China: Analysis of Costs and Benefits. UC Berkeley Center for For Future Urban Transport - Volvo Summer Workshop. Berkeley, CA.

Colombo, P. (2010). Closed Loop Controlled Electronic Carburation System. SAE Technical Paper (2010-32-0115).

Coultas, D. (2001). The Development and Application of 2-Stroke Catalysts for 2-Wheelers in Europe and Asia,. SAE Technical Paper (2001-01-1821).

Cursetji, R. (2008, Nov 12-14). Catalytic Converter Design For Two Wheelers. Presented at Better Air Quality Conference . Bangkok.

EC. (2011). European Comission Soad Safety. Retrieved October 25, 2011, from European Commission's Directorate-General for Energy and Transport: http://ec.europa.eu/transport/road_safety/specialist/knowledge/vehicle/safety_design_needs/motorcycles.htm

EC. (2010, April 10). Motorcycle safety and emission performance: European Commission proposes substantial improvements. Retrieved November 15, 2011, from IP/10/1270: http://europa.eu/rapid/pressReleasesAction.do?reference=IP/10/1270&format=HTML&aged=0&language=EN&guiLanguage=en

EC. (2010, October 4). Regulation (EU) No …/2010 of the European Parliament and of the Council on the approval and market surveillance of two- or three-wheel vehicles and quadricycles. COM 2010-542 . Brussels.

Elvik, R., & Vaa, T. (2004). Handbook of road safety measures. Amsterdam: Elsevier.

Gambino, M., & Iannaccone, S. (2001). Two Stroke Direct Injection Spark Ignition Engine for Two Wheelers. SAE Technical Papers (2001-01-1842).

Geivanidis, S., Ntziachristos, L., Samaras , Z., Xanthopoulos, A., Heinz, S., & Bugsel, B. (2008). Study on possible new measures concerning motorcycle emissions. Arisotle University Thessaloniki, Thessaloniki.

Govindarajan, S. (2005). Fuel Management Systems for Petrol Engines - State of the Art in Electronic Fuel Injection. Symposium on International Automotive Technology. Pune: ARAI.

GTZ. (2009). Two and Three Wheelers. Module 4c. Sustainable Transport: A Sourcebook for Policy Makers in Developing Cities . Deutsche GesellSchaft fur Technishche Zusammenarbeit (GTZ) GmbH, Report prepared by N. V. Iyer, J. Shah and C. Cherrry. Deutsche GesellSchaft fur Technishche Zusammenarbeit (GTZ) GmbH.

HEI. (2010). Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects. HEI Panel on the Health Effects of Traffic-Related Air Pollution. Special Report 17, Health Effects Institute.

HLDI. (2009). Motorcycle Antilock Braking System (ABS). Highway Loss Data Institute. Arlington, VA: Highway Loss Data Institute.

Honda. (2003, October 3). Honda Develops World's First Electronically Controlled Fuel Injection System for a 4-Stroke 50cc Scooter. Retrieved July 14, 2011, from http://world.honda.com/news/2003/2031003.html

ICCT. (2009). Managing Motorcyles: Oportunities to Reduce Pollution and Fuel Use from Two- and Three-Wheeled Vehicles. International Council on Clean Transportation. Washington: International Council on Clean Transportation.

ICCT. (2004). StatusReport Concerning the Use of MMT in Gasoline. International Council on Clean Transportation, san Francisco.

Iijima, S., Kubota, R., & Kikuchi, K. (2009). Development of Technologies for Improving Fuel Economy of Small Motorcycle Engines. SAE TEchnical Paper (2009-32-0083).

Iyer, N. V. (2011). A Technical Assessment of Emission and Fuel Consumption Reduction Potential from Two and Three Wheelers in India. International Council on Clean Transportation - Working Report, Washington.

Kojima, M. (2002). Measurement of Mass Emissions from In-Use Two-Stroke Engine Three-Wheelers in South Asia. SAE Technical Paper (2002-01-0862).

Leighton, S., & Ahern, S. (2003). Fuel Economy Advantages on Indian 2-Stroke and 4-Stroke Motorcycles Fitted with Direct Fuel Injection. SAE Technical Paper (2003-26-0019).

Li, L. (2002). Combustion and Emissions Characteristics of a Small Spark-Ignited LPG Engine. SAE Technical Paper (2002-01-1738).

Lung, S. C., Mao, I., & Liu, L. S. (2007). Resident's Particle Exposure in Six Different Communities in Taiwan. Science of the Total Environment , 377 (1), 81-93.

MAIDS. (2009). In-depth investigations of accidents involving powered two wheelers. European Association of Motorcycle Manufacturers and the European Commission.

MEP-China. (2010). China Vehicle Emission Control Annual Report. Vehicle Emission Control Center. Beijin: Ministry of Environmental Protection of the People's Republic of China.

Meszler, D. (2007). Air Emission Issues Related to Two and Three Wheeler Motorcyles. Maryland: MES.

Ntziachristos, L., Geivanidis, S., Samaras, Z., & Xanthopoulos, A. (2009). Study on possible new measures concerning motorcycle emissions - Final Report – Revised Version, Report No: 08.RE.0019.V4. Thessaloniki.

Quin, S. W. (2001). Motorcycle Fleet Field Test Study of Two-Stroke Catalytic Converters in China. SAE Technical Papers (2001-01-1819).

REC-UBA. (2008). Section 9 - Noise Legislation. In REC, Handbook on the Implementation of EC Environmental Legislation. Regional Environmental Center and Umweltbundesamt GmbH.

Red Cross and Red Crescent Society. (2010). Global Road Safety Partnership: Annual Report 2010. Red Cross and Red Crescent Society.

Roychowdhury, A., Chattopadhyaya, V., Shad, C., & Chandola, P. (2006). The Leapfrog Factor Clearing the Air in Asean Cities. Center for Science and Environment (CSE), New Delhi.

Rutherford, J. A., Koehl, W. J., Benson, J. D., Burns, V. R., Hochhauser, A. M., Knepper, J. C., et al. (1995). Effects of Gasoline Properties on Emissions of Current an- T50, T90 and Sulfur Effectsd Future Vehicles. SAE Paper (952510).

Saksena, S., Presad, R. K., & Shankar, R. (2007). Daily Exposure to Air Pollutants in Indoor, Outdoor and In-Vehicle Micro-Environments: A Pilot Study in Delhi. Indoor and Built Environment (16), 39-46.

Teoh, E. (2011, August 19-21). Motorcycle Safety: The Case for ABS. Des Moines, Iowa, US: SMSA Annual Conference.

Teoh, E. R. (2011). Effectiveness of antilock braking systems in reducing motorcycle fatal crash rates. Traffic Injury Prevention , 12 (2), 169-173.

Walsh, M. (2007). Alternative Octane Bossters and the Impact on Vehicle Emissions and Public Health. Walsh Car Lines.

Walsh, M. (2001, September 5). Impact of Fuel Conversion on Emissions From 2-3 Wheelers. presented at the Regional Workshop on Reduction of Emissions from 2-3 Wheelers . Hanoi, Vietnam.

WHO. (2009). Global status report on road safety: time for action. World Health Organization, Geneva.

WHO. (2005). Health Effects of Transport Related Air Pollution. World Health Organization, Copenhagen.

Xie, H., Hu, C., Zhou, N., Hao, M., Tan, T., & Tan, R. (2006). A Micro-Controller Based Control Unit for Motorcycle Engines to Meet Emission and OBD Requirements. SAE Technical Papers .