Two- and three-wheeled vehicles and quadricycles

HIGHLIGHTS

TECHNOLOGY STATUS – Uptake of two-wheelers and three-wheelers is highest in Asian countries, where on average they account for almost three-quarters of the passenger vehicle fleet. Two-wheelers are particularly important as a transport mode for lower income groups, but are increasingly bought by wealthier urban workers who wish to avoid congestion and parking restrictions. The market is expected to grow due to their low running costs, rapid urbanization, lack of public transportation and the rising population. The Chinese two-wheeler market is the largest in the world, standing in 2010 at over 100 million, two-wheelers (running stock, mainly petrol engine) and another 100 million electric bicycles ("e-bikes"). The second-largest two-wheeler market in India was estimated at 56 million units (mainly petrol) in 2010. In OECD countries uptake is much lower; Europe is the largest market outside of Asia, with around 36 million units in circulation. The market for two-wheelers is split between high quality vehicles used in OECD countries and lower quality cheaper vehicles in developing countries. However, worldwide the most popular market segment is for small urban commuter vehicles with petrol engines <125cc. In China, this segment accounts for around 70-80% of two-wheelers purchases. A number of hybrid, LNG, CNG and fuel cell two-wheelers have also been developed, but they have no significant market penetration. Three-wheelers are less common worldwide than two-wheelers, but may provide an important transport service to people without access to a private vehicle or public transport. India has the largest market in the world, with annual sales of around 0.5 million. Quadricycles exist in niche markets, and most car manufacturers are expected to launch electric-powered "sub A" models in Europe by 2013 (the A segment includes the smallest passenger cars).

PERFORMANCE AND COSTS – Most two- and three-wheelers use internal combustion engine. Fuel efficiency improvement technologies used in passenger cars could theoretically also apply to two- and three-wheelers and quadricycles using internal combustion engines. However, uptake is likely to be limited due to space and cost constraints. Significant benefits can be achieved by improving fuel injection, particularly for the two-stroke engines common on smaller two-wheelers and on three-wheelers. Air-assisted direct fuel injection systems for two-stroke engines can reduce fuel consumption by 30-60% at a cost of $40 for motorcycles and up to $300 for three-wheelers. Four-stroke engines are 35-50% more fuel efficient than similarly sized two-stroke engines, but are larger, heavier and more complex. Electronic port fuel injection using sensors can reduce fuel consumption on four-stroke engines by 20% compared to mechanical carburetors (used on older models) and 5-10% compared to newer engines at a cost of $85-$170. Swirl control valves can reduce fuel consumption by 7% at a cost of $32. In the largest world market (China), the purchase cost for two-wheelers with engines <125cc is typically less than $380. In India, the entry level two-wheelers cost around $360, but the most, popular size segment (i.e. 60% of the market) is motorcycles with engine size 75-125cc, with a cost of $700-1,050. In Europe, the largest market segment (60%) is again the smaller engine sizes <125cc, but costs are much greater ($1,310-3,930). Energy consumption is around 0.41-0.47MJ/km (1.3-1.5 litres/100km), but can be much higher for older or more powerful vehicles, and the majority run on petrol. Electric bicycles ("e-bikes") are gaining popularity in several markets, although 95% are currently sold in China (20 million units per year). These cheap models use lead-acid batteries and cost $200-320. The electricity requirement from "plug to wheel" is around 0.05-0.06MJ/km. The main three-wheelers market (i.e. India) consists largely of three-seated passenger vehicles ("auto rickshaws"). On-road prices are around $1,270 and fuel consumption varies greatly from 0.8-1.75MJ/km depending on the age of the vehicle. Uptake of CNG and LPG versions with lower fuel consumption (around 0.86MJ/km) and retrofitting cost of is $400-450 has been driven by attempts to reduce air pollution in cities. Electric three-wheelers are used in niche markets, but have not gained significant market share. Electric quadricycles with low energy consumption (0.18-0.45MJ/km) and cost below $21,000 could emerge in the sub-A segment.

POTENTIAL AND BARRIERS – Uptake of motorized two- and three-wheelers is expected to increase in emerging economies. This growth could eventually give way to uptake of cars as countries become richer; however, increasing urbanization and high levels of congestion could counterbalance this effect. Other policies can inhibit the uptake of these vehicles – for example, some cities have banned two- and three-wheelers in order to reduce air pollution. The market for e-bikes is expected to grow rapidly, particularly in China. However, they cannot currently compete directly with gasoline two-wheelers (except in specific niche uses) due to their limited range, low speeds and long recharging times. Uptake of electric quadricycles is currently low, but is expected to increase (especially in Europe) due to exemption from congestion charges, improvements in battery technology, tighter CO_2 emission standards for passenger cars and the exemption from needing to obtain a license for these vehicles.

Please send comments to Gena.Gibson@ricardo-aea.com, Nikolas.Hill@ricardo-aea.com, Craig.Dun@ricardo-aea.com (Authors), and to Giorgio.Simbolotti@enea.it and Giancarlo Tosato (gct@etsap.org), Project Coordinators

TECHNOLOGY STATUS

This brief discusses motorized two-wheeled vehicles ("two-wheelers"), three-wheeled vehicles ("three-wheelers") and quadricycles. At a global level, two- and three-wheelers accounted for 3% of total transport energy use in 2007 – around the same proportion as for passenger rail – but this varies greatly depending on the region [1]. Uptake is highest in Asia, where these vehicles are a major mode of transport and are expected to remain so for at least the next three decades [21]. In Asian countries, two- and three-wheelers account for almost three quarters of the total passenger vehicle fleet on average (although this proportion can be as high as 95% in some regions [9]). The IEA estimates that in 2010, two-wheelers emitted 13% of road transport CO_2 in Asia [27]. Therefore, the share is high enough that in such countries it could be very important to improve fuel economy in these vehicles [27].

The market for two-wheelers is supported by many factors, including their low running costs, better access to finance, a rising population in general and a growing working population due to women entering the workforce. Low-density development around cities means that motorized transport is increasingly necessary, as there are often no viable public transport links. These vehicles provide transport to people who may not be able to afford a car, but traffic congestion and limited parking spaces in urban areas drive demand even from users who can afford cars.

■ **Two-wheelers** include motorcycles, scooters and mopeds. **Motorcycles** are the largest and heaviest category of two-wheeler, with the most powerful engines. Note that in some literature, the term "motorcycle" is used to encompass all three types of two-wheeler described here. **Scooters** tend to have smaller wheels compared to other types of two-wheelers. They have a distinctive design with the engine and fuel tank mounted under the driver seat, and a foot-platform between the driver seat and the handle bars. **Mopeds** are small, light vehicles that are usually started by pedaling (the name derives from motorcycle + pedal).

Two-wheeler registrations in Asia, and increasingly in urban areas in Africa and Latin America, are significant and growing [10]. The fleet statistics are usually divided between "motorized" two-wheelers that have conventional internal combustion engines, and electrified two-wheelers that run on electricity.

The Chinese motorized two-wheeler market is the largest in the world. Sales totaled over 26 million in 2010 – more than double the number sold in India, which is the second-largest market [17]. In addition, electric bicycles ("e-bikes") are gaining huge popularity in China. Annual sales of e-bikes in China have reached volumes of over 20 million [4], and in 2010 the total e-bike stock in China was estimated to be of a similar size to the stock of motorized two-wheelers, at over 100 million units [1]. The uptake of e-bikes is much lower in other countries.

In India, two-wheelers are one of the main modes for urban passenger travel, and account for three-quarters of domestic vehicle sales [15]. Over one million units are sold each month - more than five times that of passenger car sales [15]. Motorcycles have dominated the growth of the two-wheeler market in India, rising from 30% to 80% of the fleet over the past decade [15]. The stock of two-wheelers in 2010 was estimated to be over 56 million units [14].

In OECD countries, consumers tend to prefer cars; only a small number of countries such as Japan and Italy have significant shares of two-wheelers [1]. In 2010 the number of newly registered two-wheelers in Europe dropped to just over 1.5 million units - a reduction of 25% from 2008 – most likely due to the recession [7]. The number of two-wheelers in circulation in Europe is around 36 million [14].

■ **Three-wheelers** usually refer to **tricycles,** which are variously known as auto rickshaws, baby taxis, tuk-tuks or tempos [10]. This category may also include motorcycles with side cars, although these have negligible market share.

Three-wheelers are less common worldwide than two-wheelers. India has the largest three-wheeler market in the world; sales in 2010-2011 were expected to be around half a million units – approximately the same amount as all commercial road vehicles taken together (light commercial vehicles, trucks, buses etc) [15]. Other markets are in Africa, Central America and South Asia – mainly Bangladesh and Sri Lanka [15].

In the **passenger carrier segment,** three-wheelers commonly operate as taxis, where they often provide an important transport service to people without access to a private vehicle or public transport [6]. Around 80% of the Indian three-wheeler market in 2009-2010 was made of **three-seated** passenger carriers ("auto-rickshaws") [15]. Typically they have a fabric hood, open sides and are steered by a handle bar like one in a scooter. They have small engines and can hold speeds of up to 50km/h [6]. In recent years, **six-seated** rickshaws ("Tempos") have gained popularity in India, although they still made up less than 1% of the three-wheeler market in 2009-2010 [15]. Three-wheelers are also used as **goods carriers** for intra-city carriage of small payloads. Most of these vehicles have a payload capacity of 0.5 – 1 tonne, and they accounted for 17% of the Indian three-wheeler market in 2009-2010 [15].

■ **Quadricycles** are four-wheeled vehicles that are much lighter and have smaller engines than passenger cars. **Mini-cars** tend to be built by specialized firms. The European fleet of mini-cars is around 340,000 vehicles and global sales in 2007 were 35,000 vehicles – mainly in France, Italy and Spain [8]. Vehicle mass is typically less than 550kg [10].

A newly emerging market known as **"sub A"** is emerging in Europe, which occupies the space between heavy mini-cars and passenger cars. The term "sub-A" refers to the A category cars, which are the smallest passenger car segment. All the European OEMs and 7 out of the top 10 global OEMs are expected to launch sub-A models in Europe by 2013, and most of these will be electric vehicles [24]. Drivers of this market include

Please send comments to Gena.Gibson@ricardo-aea.com, Nikolas.Hill@ricardo-aea.com, Craig.Dun@ricardo-aea.com (Authors), and to Giorgio.Simbolotti@enea.it and Giancarlo Tosato (gct@etsap.org), Project Coordinators

exemption from congestion charges, improvements in battery technology, tighter CO_2 emission standards for passenger cars and the exemption from needing to obtain a license for these vehicles [24].

PERFORMANCE AND COST

Most two- and three-wheelers currently operate on internal combustion engines. There are two types of internal combustion engine discussed here: two-stroke and four-stroke. The engine size is measured in cubic centimetres (cc).

In **two-stroke engines**, the fuel-air mix enters the cylinder through one port, and the exhaust gases exit through a separate port. When both ports are opened simultaneously, the exhaust gas is expelled and the cylinder is filled with fresh fuel-air mixture. However, "scavenging losses" occur because part of the unburned fuel-air mixture escapes along with the exhaust. These losses can amount to 15-40% of the unburned fuel-air mixture [10]. **Air-assisted direct fuel injection systems** for two-stroke engines allow the engine to run on lean air-fuel mixtures, which reduces fuel consumption by 30-60% over carbureted engines depending on engine size and duty cycle [9]. Direct injection is currently available for small motorcycles in Europe, and is being developed for some markets in Asia, as well as being retrofittable to three-wheelers. The cost is around $40 for motorcycles [9] and $300 for retrofit on three-wheelers [10]. In an effort to control air pollution, two-stroke engines have been phased out of two-wheelers in many countries including India, Japan and China, but are still available on smaller vehicle types (mopeds, small scooters and some motorcycles) and three-wheelers [9].

In **four-stroke engines**, the fuel-air mixture enters the cylinder through valves instead of ports. Since the two-stroke engine completes twice as many power strokes as a four-stroke engine operating at the same speed, the four-stroke engine needs to be larger and heavier to reach the same power rating. A four-stroke engine also needs a valve train and a camshaft to operate the valves. This makes four-stroke engines more complex and heavier per unit of power output than two-stroke engines, but they can be 35-50% more fuel efficient than similarly sized two-stroke engines [10]. Typically, four-stroke engines use inexpensive mechanical carburetors. **Electronic port fuel injection** uses sensors to measure engine operational conditions and deliver the optimal amount of fuel, which can reduce fuel consumption by 20% compared to a mechanical carburetor on an older model [9], but could reduce to improvements of 5-10% compared to newer engines [15]. The cost is estimated at $85-$170 depending on engine size [9]. **Swirl-control valves** on intake ports create turbulence in the air-fuel mix, which improves combustion and reduces unburned fuel in the exhaust. Improvements in fuel economy of 7% could be expected compared to a conventional intake engine [3]. The cost for motorcycles is estimated to be around £20 ($32) [3]. **Gasoline direct injection** has been developed mainly for larger passenger car engines and is not yet widely available for two- and three-wheelers. Testing on motorcycles suggests that fuel efficiency improvements of 13-20% could be achieved [15]. Tests of **dual spark plug technology** on commercial motorcycles show improvements in fuel consumption of 13% compared to equivalent vehicles with single spark [9]. However, the technology is difficult to introduce due to the small amount of space available on two- and three-wheeler engines.

Many engine technologies that have been used to improve fuel efficiency in passenger cars could theoretically also apply to two- and three-wheelers and quadricycles (see ETSAP briefs T01 and T02 for a detailed discussion of available engine technologies). However, due to space constraints, only a few can be practically applied to smaller engines [15]. In addition, technologies usually cannot penetrate the two-wheeler market until costs have been significantly reduced through learning effects and economies of scale in the automotive industry [27]. **Light-weighting** through use of materials such as high strength steel could soon enter the market for two-wheelers [27]. Additional costs of $280 are estimated, with a corresponding fuel consumption reduction of around 2% [3]. **Engine friction reduction** technologies on passenger cars have been continuously improving, and these efforts need not be restricted by the size of the engine. However, the extent of these efforts on commercial models will be limited by cost. It is estimated that friction reduction could deliver a fuel efficiency improvement of 4%, and cost approximately $102 [3]. Advanced tyres are available for cars that have **reduced rolling resistance** without compromising wet grip (which is important for safety). Estimates for the motorcycle market suggest that low rolling resistance tyres could improve fuel efficiency by 1.5% at an additional cost of $24 [3]. **Variable valve timing** is common on automobiles, but due to the challenge of installing complex mechanisms involving hydraulic and electronic systems, it is not often used on small engines. Recent research has developed a fully mechanical, simple, compact variable valve timing system suitable for small two-wheeler application, although this system is not commercially available at present [15]. The fuel efficiency gain obtained in tests was 5-7% [15]. For larger two-wheelers, such as those available in Europe, variable ignition timing is expected to have an efficiency improvement potential of around 8.5% at an additional capital cost of around $300 [3].

■ Two-wheelers

China is by far the largest two-wheeler market in the world. The Chinese Government discourages use of motorized two-wheelers in cities in order to control air pollution, and sometimes also discourages electric two-wheelers in order to reduce congestion. As a result, demand for scooters and motorcycles has been pushed to the semi-urban and rural areas where purchasing power is lower. Thus, the bulk of demand in China is for low quality and cheap vehicles. Small 50cc two-wheelers account for 30-40% of the market, and cost 2,000-2,500 Yuan ($225-270) [16]. Two-wheelers with 100-125cc engines account for 40% of the market, costing 3,000-3,500 Yuan ($330-380) [16]. Larger models account for 20-30% of the market and are priced at 4,000-5,000 Yuan ($440-550) for a 250cc vehicle [16].

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Information of fuel consumption is scarce, but based on the regulatory limits, two-wheelers with engines <50cc must use less than 0.66MJ/km (2 litres/100km), increasing to a limit of 0.83MJ/km (2.5 litres/100km) and 0.96MJ/km (2.9 litres/100km) respectively for engines 100-150cc and 150-250cc [15].

India is the second-largest market for two-wheelers. The price of two-wheelers varies greatly between segments and manufacturers often provide model variants with optional extra features. The most popular segment is motorcycles with engine sizes from 75cc to 125cc. In 2009-2010 they made up 58% of the two-wheeler market in India and cost around RS39,000-58,000 ($700-1,050) [15]. Energy consumption of 75-125cc motorcycles is around 0.41-0.47MJ/km (1.3-1.5 litres/100km), based on analysis of petrol motorcycle models [15]. Entry-level mopeds cost RS20,000-25,000 ($360-450) and made up around 6% of the Indian two-wheeler market in 2009-2010 [15]. Thus, two-wheelers provide an individual mode of transport to people who may not yet be able to afford a car, which usually cost upwards of $6,000 [6]. More powerful motorcycles with engine sizes upwards of 125cc to 250cc can cost RS53,000-110,0000 ($960 to $1,990), and made up around 20% of the market in 2009-2010 [15]. Typical energy consumption of petrol models is 0.55-0.65MJ/km (1.7-2.2litres/100km) [15]. The fuel efficiency of two-wheelers decreases with increasing engine size. Some car manufacturers are aiming to capture the upper end of the motorcycle market by offering low-priced cars, such as the Tata Nano, which sells for around $2,500 [10].

In **Europe** the largest market segment (60%) is made up of urban commuter vehicles with engines below 125cc and costs of €1,000-3,000 ($1,310-3,930) [32]. Larger motorcycles with engines above 500cc make up 25% of the market and cost upwards of €5,000 ($6550) [32]. Since 2007, all new powered two-wheelers with engines >50cc must comply with Euro 3 emission standards for tailpipe air pollutants. These require the implementation of technical solutions such as fuel injection and fuel mix regulators, which has led to improvements in the fuel efficiency of newer models. The energy consumption of a Euro 3 moped can be as low as 0.49MJ/km (1.48 litres/100km) compared to 0.81MJ/km (2.45 litres/100km) for a conventional moped [31]. Fuel consumption for larger motorcycles ranges from 0.76MJ/km (2.30 litres/100km) up to 2.06MJ/km (6.22 litres/100km) depending on the engine size, as shown in Table 5 [31].

A number of **hybrid two-wheeler** models are commercially available. They are usually configured to use the electric motor at lower speeds and the engine for higher speeds and to recharge the batteries [11]. Some models may operate in dual mode most of the time. The additional cost could be as much as 50% more for a hybrid compared to a conventional version [11].

Several **alternative** fuels are available for two-wheelers. Both Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG) models are available, although it is rather difficult to introduce these fuels for two-wheelers because of the limited space available for the fuel tanks and pressure regulators. The high cost of installing the gas handling system on small low-cost two-wheelers is an important barrier to wider uptake [15]. **Bioethanol compatibility** is not expected to cause problems with newer models in blends of up to 10% [29]. **Fuel cell** technology is currently being researched for motorcycle applications but uptake is low. A proton-exchange membrane (PEM) fuel cell prototype has been developed recently; the vehicle can travel up to 160km on a single tank and is expected to sell for around $6,000 [15].

Electric two-wheelers are divided into two markets: high quality and expensive vehicles for developed economies, and lower quality cheaper vehicles in emerging economies.

Over 95% of the world's electric bicycles ("**e-bikes**") are in China [12]. **Bicycle-style e-bikes** supplement human pedaling with electric power from an on-board battery. Chinese models usually have a maximum speed of around 25km/h [9] with 36-volt batteries and 180-300W motors [10]. **Scooter-style e-bikes** are powered almost entirely by electricity, although they usually have pedals as well. They have a maximum speed of up to 50km/h [9], larger 48-volt batteries and 350-500W motors [10]. Both types are recharged by plugging into standard wall outlets and have a range of 40-70km on a single charge (6-8 hours) [9]. The electricity requirement from "plug to wheel" is around 1.5-1.8kWh/100km on a generic urban driving cycle (0.05-0.06 MJ/km) [12]. Currently, lead-acid batteries are the main technology. They typically last 1-2 years or up to 10,000km before they need to be replaced [12]. Most e-bike producers in China do not have an incentive to develop models with higher performance given the strong domestic demand for small models [22]. Due to the design of the Chinese e-bikes, with their limited power, low speeds (less than 40km/h) and light weight, they have not become widely popular outside of China.

In India, **battery electric two-wheelers** have entered the market in recent years. Most models are powered by brushless 250W DC motors and use 48V lead acid batteries, so that they are small enough not to be considered motor vehicles under the Motor Vehicle Act [15]. As such, they do not have to comply with safety standards, and drivers do not need a license. These electric two-wheelers range in price from RS25,000-35,000 ($450-635) [15]. A few models use electric motors with higher power ratings of 500-1800W, at prices of RS35,000-40,000 ($635-725) [15]. Annual sales are currently modest, at around 100,000 units, but are expected to grow [15].

Europe is the largest market for e-bikes outside of China, with sales expected to reach 1.5 million units in 2018 [30]. These are usually **"pedelec" style (pedal assist) e-bikes** with Li-ion batteries, although NiMH batteries are also used [12]. The rider pedals constantly, but is assisted by a small electric motor (150-250W) when extra power is needed during acceleration or uphill climbs [12]. Energy consumption is 0.01MJ/km on average [35]. In the US, sales of e-bikes are much lower

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at around 100,000 annually, and are not expected to exceed 345,000 units in 2018 [30]. The cost of e-bikes using Li-ion batteries instead of lead-acid is much higher due to the expense of the Li-ion battery technology. Prices range from $800-1,500 for standard models, and $1,900-2,400 for premium models [30]. High-end **electric motorcycles** have much larger batteries that offer a range of 70-185km on a single charge, and can cost $11,500-14,000 [34].

Tailpipe CO_2 emissions from lightweight two-wheelers with smaller engines tend to be relatively low on a per-vehicle basis compared to passenger cars, but more powerful models have higher fuel consumption that can be equal to or greater than small cars (particularly for high performance motorbikes). Fuel efficiency shows a progressively decreasing trend with increasing engine displacement. Consumers in developed economies tend to purchase higher-powered vehicles; therefore the average emissions intensity in OECD countries ($64gCO_2$-eq/pkm) is higher compared to non-OECD countries ($43gCO_2$-eq/pkm) [1]. The overall impact on CO_2 emissions achieved by switching to electric two-wheelers is rather uncertain, as this depends on the emissions that are produced at the electricity generation plant. In addition, it is not clear whether these e-bikes have replaced pedal bicycles.

■ Three-wheelers

The largest market for three-wheelers is in **India.** Until recently, **passenger vehicles** operated almost exclusively on petrol but uptake of diesel versions has recently increased [15]. Two-stroke engines maintain a significant share of the overall three-wheeler fleet. On-road prices for a two-stroke gasoline engine three-wheeler are typically around RS70,000 ($1,270) [15]. Information on fuel efficiency is scarce, but some reports show that on-road fuel efficiency for older three-wheelers (2-stroke carburetor, 145cc, petrol) is around 1.2-1.75 MJ/km (3.63-5.29 litres/100km), improving to 0.75MJ/km (2.27 litres/100km) for state-of-the-art models (2-stroke direct injection, 145cc, petrol) [15].

Most **goods vehicles** use diesel fuel and have engines of around 400cc [15]. Diesel engines are inherently more fuel efficient compared to petrol engines. A typical diesel-powered engine (indirect injection, 415cc) has fuel economy of 38km/l (0.94MJ/km[1]) [15]. **High Speed Direct Injection** engines are 10-15% more efficient than Indirect Injection systems [15]. Advanced diesel technologies such as common rail injection, multiple valves and turbocharging are theoretically possible but may be too costly to apply on small engines.

Three-wheelers can successfully be converted to run on **alternative fuels,** including Compressed Natural Gas **(CNG)** and Liquefied Petroleum Gas **(LPG)**. LPG is conceptually similar to CNG, but since the fuel is stored as a liquid the size and cost of the fuel tanks is smaller. Use of CNG in three-wheelers started as a result of directives from the Supreme Court of India to curb the high level of pollution faced by the city of Delhi. The Court directed that "clean fuels" be used in petrol three-wheelers, and CNG was a natural choice given the availability of vehicle filling stations.

Technology pathways for two-wheelers [27]

	<200cc (urban)	>200cc
Medium-term	Four-stroke, biofuel compatibility, human-electric hybrids	Direct injection, VVT, biofuel compatibility
Long-term	Full electrification, human-electric hybrids	Engine downsizing with low boost turbocharger, ICE-electric hybrids

The implementation of the programme started in the year 2000, and CNG three-wheelers are available as new models or retrofit [15]. The current situation is that all auto-rickshaws in Delhi are powered by CNG. Fuel efficiency of 4-stroke petrol three-wheelers is estimated to be around 0.95MJ/km (2.87 litres/100km), improving to 0.87MJ/km (3.52 litres/100km) for LPG and 0.83MJ/km (2.27 litres/100km) for CNG [15]. The typical on-road price (inclusive of taxes) for a 4-stroke natural gas engine three-wheeler is over RS100,000 ($1,810) [15]. Retrofits of CNG and LPG cost around $450 and $400 respectively [10].

Electric three-wheelers have not gained significant market uptake, but are known to operate in certain niche areas. One example is the use of electric three-wheelers to transport visitors to the Taj Mahal, where conventionally-fuelled vehicles are banned to avoid damaging the site [10].

■ Quadricycles

Mini-cars have maximum speeds of less than 45km/h, maximum continuous power of less than 15kW and typically weigh less than 550kg [24]. A diesel mini-car will typically consume less than 4l/100km (1.5MJ/km) [25].

The newly emerging **sub-A segment** can reach speeds of up to 200km/h and carry up to 4 people including the driver [24]. Almost all sub-A cars are expected to be electric vehicles, with driving ranges of around 100-160km [24]. Around 40% of sub-A cars are expected to cost less that €16,000 ($21,000), but prices can range from €4,000-25,000 ($5,250-32,250) [24]. Energy consumption for electric sub-A cars can be as low as 0.18-0.45MJ/km [24].

POTENTIAL AND BARRIERS

In developing countries, ownership of two- and three-wheelers is expected to grow rapidly in coming years. Rising household incomes and falling vehicle costs have stimulated large numbers of people to purchase these vehicles, as well as moving up-market to more powerful models [21]. Some literature suggests that the growth in two- and three-wheeler ownership could eventually give way to uptake of cars as countries become richer [1];

[1] Assuming energy content of diesel is 35.9MJ/litre – this can vary depending on region and supplier

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however, increasing urbanization and high levels of congestion in cities could counterbalance this effect [21].

In urban areas, measures such as such as reductions in road space, removal of flyovers, parking restrictions and full pricing of externalities are becoming increasingly common [21]. Light vehicles such as two- and three-wheelers are usually less affected by these policies; however, they may be the subject of specific policies to curb air pollution. In a number of Asian and southern European cities, motorized two-wheelers are banned from city centres to reduce air pollution – especially emissions of particular matter. Some Asian cities have banned two- and/or three-wheelers in an attempt to control congestion, but evidence shows these policies are unlikely to be successful. Indeed, congestion can sometimes increase as a result, and that these policies disproportionately affect lower income groups [21].

Electric two-wheelers have the potential to improve local air quality, noise and CO_2 emissions. However, they cannot currently compete directly with gasoline two-wheelers (except in specific niche uses) due to their limited range, low speeds and long recharging times. Annual sales of electric two-wheelers (primarily e-bikes) are projected to reach 65.5 million units in the Asia Pacific region by 2018, with over 90% of these vehicles sold in China [4]. Drivers of this growth include a greater household income, the low running costs of electric vehicles and increasing urbanization [4]. The uptake of e-bikes in China has also been stimulated by price incentives [4]. In addition, many Chinese cities have prohibited gasoline-powered two-wheelers to reduce noise and air pollution.

Several cities are starting to offer incentives for the purchase of electric two-wheelers in order to reduce pollution and noise, including cities in France and the US [11]. The Ministry of New and Renewable Energy in India provided incentives of up to 20% on ex-factory prices of electric two-wheelers from 2010.

Most markets in Asian regions are highly price sensitive, so more expensive abatement options (such as hybrid engines) may have limited uptake [10]. In Europe, a target of $70gCO_2/km$ in 2020 has been suggested for powered two-wheelers in the European Commission's 2011 White Paper on Transport [28].

The market for three-wheeled rickshaws in India is greatly affected by policy, which determines the total number allowable in cities [6]. They may be phased out in some areas due to perceived competition with public transport and concerns over air pollution, although there is not always sufficient data to support this view [6].

Regulation of fuel economy is an emerging issue, driven by growing concerns over climate change and energy security. Currently, only China and Taiwan have fuel economy standards for two- and three-wheelers [9]. There standards become more demanding as engine size decreases.

There is some evidence that introducing fuel economy labels could encourage uptake of more efficient vehicles, particularly for people who buy two-wheelers for commuting to work [7]. People who ride these vehicles for pleasure or sport are less likely to be influenced [7]. In 2010 the European Commission published a proposal to introduce mandatory reporting of CO_2 emission measures and fuel consumption according to a global test cycle. This would allow energy efficiency labels to be introduced, similar to the mandatory labels already in place for passenger cars.

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References and Further Information

1. IEA, 2010. Energy Technology Perspectives. International Energy Agency.
2. IEA, 2010. Transport Energy Efficiency. International Energy Agency. http://www.iea.org/papers/2010/transport_energy_efficiency.pdf
3. AEA, 2012. Review of the efficiency and cost assumptions for road transport vehicles to 2050. Committee on Climate Change. http://hmccc.s3.amazonaws.com/ED57444%20-%20CCC%20RoadV%20Cost-Eff%20to%202050%20FINAL%2025Apr12.pdf
4. Pike Research, 2012. Electric Two-Wheel Vehicles in Asia Pacific. http://www.pikeresearch.com/research/electric-two-wheel-vehicles-in-asia-pacific
5. Munjal, N. 2012. Implementing Li-ion Batteries in Two-Wheelers. E-Bikes Forum. http://files.evbatteryforum.com/ebikes/1HERO%20ELECTRIC_Naveen%20Munjal_Implementing%20Li-ion%20Batteries%20In%202%20Wheelers%20And%20Achieving%20An%20Optimum%20Price%20Level.pdf
6. ITDP, 2009. Two- and Three-Wheelers in India. Innovative Transport Solutions. http://www.itdp.org/documents/2_and_3_wheelers_in_India.pdf
7. AEA, 2012. Report on the implementation of Directive 1999/94/EC relating to the availability of consumer information on fuel economy and CO_2 emissions in respect of the marketing of new passenger cars. http://ec.europa.eu/clima/policies/transport/vehicles/labelling/docs/final_report_2012_en.pdf
8. European Commission, 2010. Accompanying Document to the Proposal for a Regulation on the Approval and Market Surveillance of Two- and Three-Wheel Vehicles and Quadricycles. SEC(2010)1151.
9. ICCT, 2011. Sustainable Management of Two- and Three-Wheelers in Asia. International Council on Clean Transportation.
10. ICCT, 2009. Managing Motorcycles. International Council on Clean Transportation.
11. IEA, 2009. Transport, Energy and CO_2. International Energy Agency.
12. ADB, 2009. Electric Bikes in the PRC. Asia Development Bank.
13. European Parliament, 2012. Approval and market surveillance of L-category vehicles.
14. EMTRA, 2012.Statistics. European Tyre & Rubber Manufacturer's Association http://www.etrma.org/uploads/Modules/Documentsmanager/20120612-etrma-statistics-2011.pdf
15. ICCT, 2012. A Technical Assessment of Emissions and Fuel Consumption Reduction Potential from Two and Three Wheelers in India. International Council on Clean Transportation. http://www.theicct.org/sites/default/files/publications/Iyer_two-three-wheelers_India_August2012.pdf
16. WTO Consulting & Research, 2010. China and the two-wheeler industry in India. http://www.slideshare.net/Hondafanatics/china-and-the-two-wheeler-industry-in-india
17. Economist Intelligence Unit, 2011. China motorbikes: Stay or Go?. http://viewswire.eiu.com/index.asp?layout=ib3Article&article_id=387809823&pubtypeid=1112462496&country_id=1800000180&=page_title&fs=true
18. UNEP, 2009. Managing two- and three-wheelers in Asia. United Nations Environment Programme. http://www.unep.org/transport/pcfv/pdf/23-Wheelers-in-Asia-Book.pdf
19. WRI, 2010. Sustainable urban transport in India. World Resources Institute. http://pdf.wri.org/sustainable_urban_transport_india.pdf
20. GTZ (2009) two- and three-wheelers. http://www.imtt.pt/sites/IMTT/Portugues/Planeamento/GestaoMobilidade/DocumentosReferencia/Documents/Sustainable%20Transport%20Sourcebook/Module_4c.pdf
21. ITSP, 2009. Best practices on regulation and design for motorized and non-motorized two and three-wheelers in urban traffic. http://cleanairinitiative.org/portal/system/files/23_Wheeler_Best_Practices_DraftFinal_22Oct09.pdf
22. ASD, 2009. Electric two-wheelers in India and Viet Nam. Asia Development Bank. http://cleanairinitiative.org/portal/system/files/E-bikes_in_India_and_Vietnam_FINAL.pdf
23. European Commission, 2012. Case study: scooter. http://www.ika.rwth-aachen.de/r2h/index.php?title=Case_Study:_Scooter&oldid=7385
24. Frost & Sullivan, 2010. Strategic analysis of the European Microcars Market. http://france-mobilite-electrique.org/IMG/pdf/M55D-Microcars-Key_findings-media.pdf
25. The European Quadricycle League. http://www.equal-mobility.com – accessed 20-September 2012
26. Cherry et al, 2007. The transition to electric bikes in China.
27. IEA, 2012. Technology Roadmap: Fuel Economy of Road Vehicles. International Energy Agency. http://www.iea.org/publications/fueleconomy_2012_final_web.pdf
28. European Commission, 2011. White Paper on Transport. http://ec.europa.eu/transport/strategies/doc/2011_white_paper/white-paper-illustrated-brochure_en.pdf
29. ACEM, 2012. List of ACEM member company petrol vehicles compatible with E10 petrol http://www.acem.eu/index.php/policy-access/environment/e10
30. Pike Research. Electric Bicycles. http://www.pikeresearch.com/research/electric-bicycles
31. EEA. Emission Inventory Guidebook. European Environment Agency. http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1.a.3.b-road-transport-gb2009-update.pdf/at_download/file
32. ACEM, 2010. Comments from the European Motorcycle Industry http://ec.europa.eu/information_society/activities/esafety/doc/ecall/pos_papers_impact_assessm/acem.pdf
33. European Parliament, 2012. Approval and market surveillance of two- or three-vehicles and quadricycles – Impact assessment of IMCO compromise amendments. http://www.fema-online.eu/uploads/documents/vehicle%20aspects/20120221_IMCO_Impact_Assessment.pdf
34. Based on MU, ZF6 and ZF9 models from the Zero motorcycle range. http://www.zeromotorcycles.com
35. Pro-EE. Guidelines for sustainable public procurement – pedelecs. http://www.pro-ee.eu/fileadmin/pro_ee/inhalte/dokumente/Pedelecs_Guidelines.pdf

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Table 1 – Vehicle characteristics (according to the European classification system) [8]

Category	Vehicle Name	Example	Vehicle characteristics
L1e	Moped		**Two wheels** and maximum designed vehicle speed of not more than **45** km/h **and** characterised by: • cylinder capacity does not exceed **50 cc** in the case of the internal combustion type, or • maximum continuous rated **power** is no more than **4 kW** in the case of an **electric motor**;
L2e	Three-wheel Moped		**Three wheels** and maximum designed vehicle speed of not more than **45** km/h **and** characterised by: • cylinder capacity does not exceed **50 cc** if of the **spark (positive) ignition** type, or • maximum net **power** output does not exceed **4 kW** in the case of **other internal combustion engines**, or • maximum continuous rated **power** does not exceed **4 kW** in the case of an **electric motor**;
L3e	Motorcycle		**Two-wheels**, without a sidecar fitted with an engine having a cylinder capacity of **more than 50 cc**[3] of the internal combustion type and/or having a maximum designed vehicle speed of **more than 45 km/h**,
L4e	Motorcycle & Sidecar		**Two-wheels**, **with a sidecar** fitted with an engine having a cylinder capacity of **more than 50 cc** if of the internal combustion type and/or having a maximum designed vehicle speed of **more than 45 km/h**,
L5e	Tricycles		**Three** symmetrically arranged **wheels** fitted with an engine having a cylinder capacity of **more than 50 cc** if of the internal combustion type and/or a maximum design speed of **more than 45 km/h.**
L6e	Light Quadricycles		**Four wheels**, unladen mass is not more than **350 kg** not including the mass of the batteries in case of electric vehicles, whose maximum design vehicle speed is **not more than 45 km/h**, and • whose engine cylinder capacity does **not exceed 50 cc** for spark (positive) ignition engines, or • whose maximum net **power** output does **not exceed 4 kW** in the case of **other internal combustion engines**, or • whose maximum continuous rated power does **not exceed 4 kW** in the case of an **electric motor**. These vehicles shall fulfil the **technical requirements applicable to three-wheel mopeds of category L2e** unless specified differently in any of the separate directives;
L7e	Heavy Quadricycles (minicar)		**Four wheels**, other than those referred to in category L6e whose unladen mass is **not more than 400 kg** (**550 kg** for vehicles intended for **carrying goods**), not including the mass of batteries in the case of electric vehicles, and whose maximum net engine **power** does **not exceed 15 kW**. These vehicles shall be considered to be motor tricycles and shall fulfil the technical requirements applicable to motor tricycles of category L5e unless specified differently in any of the separate Directives.

Table 2 – Evolution of motorized two-wheeler stock in major world regions (in thousands) [14]

	2000	2005	2010	2015	2020	2025
ASEAN	40,131	68,404	90,747	115,310	140,899	164,016
China	37,720	67,729	102,322	140,447	179,616	215,958
Europe	37,713	33,875	36,274	35,642	34,987	34,974
India	27,125	38,416	56,116	70,493	89,652	109,227
Japan	13,974	13,175	12,718	12,398	12,109	11,960
N. America	4,467	6,590	7,,664	7,916	7,,741	8,158
Rest of World	28,266	37,278	41,169	48,212	55,164	62,247
S. America	7,435	13,961	15,641	21,771	29,207	35,411
Total	196,831	279,428	362,651	452,189	549,375	641,951

Notes: Does not include electric two-wheelers. The precise number of motorized two-wheelers is unknown, due to unreliable registration statistics in many countries

Table 3 – Motorized two-wheeler stock as a % of passenger vehicles [14]

	2000	2005	2010	2015	2020	2025
ASEAN	67%	71%	72%	71%	71%	71%
China	71%	68%	56%	44%	38%	36%
Europe	12%	10%	10%	9%	8%	7%
India	73%	72%	70%	63%	58%	55%
N. America	2%	2%	3%	3%	2%	2%
S. America	17%	24%	23%	23%	24%	24%
Average	**21%**	**25%**	**26%**	**27%**	**27%**	**27%**

Notes: passenger vehicles includes cars, light duty vehicles, motorcycles and mopeds

Table 4 – Characteristics of typical motorized two-wheelers in emerging countries [15]

Technical Performance	**Moped**	**Scooter**	**Low-end motorcycle**	**Mid-range motorcycle**	**High-end motorcycle**
Base country	India/China	India/China	India/China	India/China	India
Energy Input	Petrol	Petrol	Petrol	Petrol	Petrol
Engine size (cc)	50	75-125	75-125	125-250	>250
Energy Consumption (MJ/km)	<0.66 (China) 0.54-0.71 (India)	<0.83 (China) 0.54-0.71 (India)	<0.83 (China) 0.41-0.47 (India)	<0.96 (China) 0.55-0.65 (India)	0.60-0.91 (India)
Energy Consumption (litres/100km)	<2.0 (China) 1.7-2.2 (India)	<2.5 (China) 1.7-2.2 (India)	<2.5 (China) 1.3-1.5 (India)	<2.9 (China) 1.7-2.0 (India)	1. 9-2.8 (India)
Technical Lifetime, yrs	10	10	10	10	10
Environmental Impact					
Tailpipe CO_2-e emissions, g/km	<46 (China) 36 – 48 (India)	<58 (China) 36 – 48 (India)	<58 (China) 28 – 32 (India)	<67 (China) 37 – 44 (India)	40 – 61 (India)
Costs					
Capital Cost, $/unit	225-270 (China) 360 – 450 (India)	330-380 (China) 740 – 905 (India)	705 - 1,050 (India)	960 - 2,000 (India)	2,170 - 2,735 (India)
O&M cost, $km	n/a	n/a	n/a	n/a	n/a

Notes: Exchange rate from RS to $ of 0.0181 and £ to $ of 1.59; Assumed energy content of petrol to be 33.1MJ/litre (this can vary depending on region, supplier and season); assumed emission factor for petrol of 2.322kgCO_2-e/litre. The lower number for energy consumption is based on the average manufacturer's declared values from source [15], whereas the higher value is based on the average reported on-road values. Declared fuel consumption is based on official driving test cycles and may not be directly comparable between different countries. Specific figures for O&M costs were not available, but are usually referred to as being very low in the literature.

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Table 5 – Characteristics of typical motorized two-wheelers in developed countries [31], [32], [33]

Technical Performance	Moped	Scooter	Low powered Motorcycle	High powered Motorcycle
Base country	Europe	Europe	Europe	Europe
Energy Input	Petrol	Petrol	Petrol	Petrol
Engine size (cc)	~50	~125	<250	>250
Energy Consumption (MJ/km)	0.49-0.81	0.76-1.48	1.43-1.61	1.61-2.06
Energy Consumption (litres/100km)	1.48-2.45	2.3-4.47	4.32-4.86	4.86-6.22
Technical Lifetime, yrs	10	10	10	10
Environmental Impact				
Tailpipe CO_2-e emissions, g/km	35-79	54-104	104-114	114-145
Costs				
Capital Cost, $/unit	1,310	3,930	6,500	Starting at around 11,780
O&M cost, $km	n/a	n/a	n/a	n/a

Notes: Assumed density of petrol to be 0.73kg/litre; assumed emission factor for petrol. Exchange rate of 1.31 from € to $. The range of energy consumption given for each vehicle type depends on the Euro standards for air pollutant emissions. Since 2007, all two-wheelers of >50cc must meet Euro 3 standards, which have the lowest energy consumption. Older Euro standards still exist in the fleet. Very high powered motorcycles of >950cc exist in the fleet, but these represent a small proportion of overall vehicles and are not considered here, as price and fuel consumption become very high for these vehicle types.

Table 6 – Characteristics of typical Indian three-wheelers [15], [20], [24]

Technical Performance	2-stroke rickshaw			4-stroke rickshaw		
Energy Input	Petrol	LPG	CNG	Petrol	LPG	CNG
Base country	India	India	India	India	India	India
Energy Consumption (MJ/km)	0.75 (state of the art) 1.2-1.75 (pre-1996)	1.00	1.19	0.95	0.87	0.83
Energy Consumption (litres/100km)	2.27 (state of the art) 3.63-5.29 (pre-1996)	4.04	3.26	2.87	3.52	2.27
Technical Lifetime, yrs	10	10	10	10	10	10
Environmental Impact						
Tailpipe CO_2-e emissions, g/km	53 (state of the art) 81-117 (pre-1996)	64	68	58	55	48
Costs						
Capital Cost, $/unit	1,270	1,720	1,800	1,355	1,720	1,955
O&M cost, $km	n/a	n/a	n/a	n/a	n/a	n/a

Assumed exchange rate of 0.0181 from RS to US$. Assumed incremental cost of the 4-stroke petrol three-wheeler over the two-stroke version is ~$85 in line with [20]. Density of petrol assumed to be 0.73 kg/l; energy content of petrol 44.74MJ/kg; density of LPG assumed to be 0.539kg/l; energy content of LPG assumed to be 45.91MJ/kg; density content of CNG assumed to be 0.77kg/l: energy content of CNG assumed to be 47.6MJ/kg. Estimates for LPG and CNG models are based on limited data and should be interpreted with care. Figures for O&M costs were not available, but are usually described as “low”, e.g. see [15].

Table 7 – Characteristics of electric two-wheelers [3], [10], [12], [26], [34], [35]

Technical Performance	Bicycle-style e-bike (lead acid)	Scooter-style e-bike (lead acid)	Pedelec e-bike (Li-ion)	Electric motorcycle (Li-ion)
Base country	China	China	Western markets	Europe
Energy Input	Electricity	Electricity	Electricity	Electricity
Battery type	Lead-acid	Lead-acid	Li-ion	Li-ion
Battery pack capacity (kWh)	0.4-0.6	0.8-1.0	0.2-0.6	3.0 – 9.0
Energy Consumption (MJ/km)	0.05	0.06	0.01	0.14 – 0.28
Environmental Impact				
CO_2-e emissions from electricity production, g/km	12 (China grid mix)	13 (China grid mix)	5 (EU grid mix)	15 - 30 (EU grid mix)
Costs				
Capital Cost, $/unit	200 - 250	250 - 320	800-1,500 (standard) 1,900-2,400 (premium)	7,700-14,000
O&M cost, $km	Negligible	Negligible	Negligible	Negligible

Notes: For e-bikes, CO_2 emissions depend on the electricity generation mix r. Conversion factor used from RMB to $ is 0.12, and inflation factor (year 2006 to 2012) is 1.14. Electric motorcycle is based on the MU, ZF6 and ZF9 models from the Zero motorcycle range [34]. EU grid emission factor is assumed to be 0.38kgCO_2/kWh and China grid emission factor is assumed to be 0.84kgCO_2/kWh on average grid mix of electricity consumed from Defra conversion factors, including losses in transmission and distribution.

Table 8 – Technology efficiency improvement measures for two-wheelers [3]

Efficiency Improvement Technology	Efficiency Improvement	Capital cost ($)	Learning Rate
Air assisted direct injection for 2-stroke engines	30.0%	35	0.95
Electronic port fuel injection for 4-stroke engines	20.0%	113	0.95
Swirl control valve	7.0%	32	0.95
Variable ignition timing	8.5%	301	0.95
Engine friction reduction	4.0%	102	0.95
Optimising transmission systems	0.5%	32	0.95
Start-stop hybridisation	5.0%	462	0.95
Aerodynamics improvement	0.9%	70	1.00
Low rolling resistance tyres	1.5%	24	0.95
Light weighting	2.0%	280	0.95
Thermo-electric waste heat recovery	2.0%	637	0.95

Notes: Exchange rate £ to $ of 1.59. These figures were developed for the UK motorcycle market. The uptake of these technologies in highly price-sensitive markets (e.g. developing countries) may be limited by cost.

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