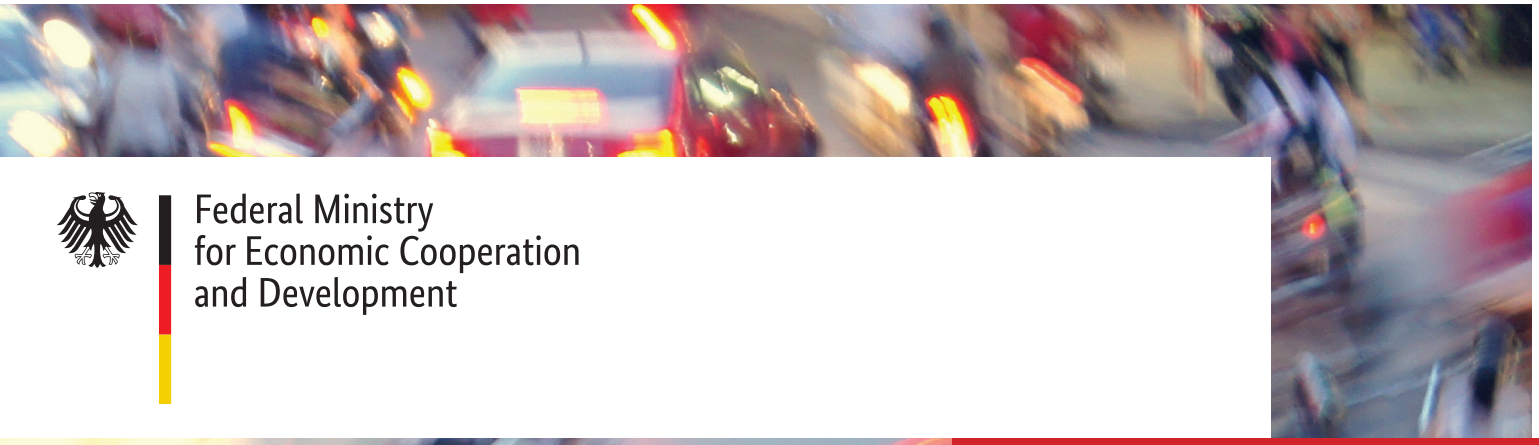

Federal Ministry
for Economic Cooperation
and Development

Two-and-Three-Wheelers

A Policy Guide to Sustainable Mobility Solutions for Motorcycles

Module 4c
Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities

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Module 4c

Two-and-Three-Wheelers

A Policy Guide to Sustainable Mobility Solutions for Motorcycles

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I. Introduction

Should we prioritize two-and-three-wheelers to improve the sustainability of urban transport systems?

Two-and-three-wheelers pose some of the most serious unresolved questions within the context of sustainable urban mobility. Currently, two-and-three-wheelers constitute close to 30% of total motorised vehicles worldwide. In middle and low-income cities such as Saigon, Colombo, and Dar es Salaam, their share is much higher, varying between 50% and 90% depending on socio-economic characteristics. However, the recognition of two-and-three-wheelers in transport policymaking has seen a slow start. Over the past decades, policymakers have struggled to understand the role of motorised two-and-three-wheelers in urban areas[1]. This led to a crisis of policy, regulation, and implementation.

This module aims to provide policymakers and advisers in middle and low-income cities with the most updated information on the challenges, issues, policies, and regulations related to two-and-three-wheelers. We start with a discussion of the present situation of two-and-three-wheelers in middle and low-income cities. Despite policymakers' best efforts, challenges posed by two-and-three-wheelers have only magnified. The rapid influx of motorised two-and-three-wheelers was as spontaneous as it was unplanned. Considering high durability of such vehicles, policies today will affect the next twenty years. Building a case for early intervention, we first aim to sketch out the role of two-and-three-wheelers in urban mobility more generally. Next, we turn to externalities caused by two-and-three-wheelers and identify recent changes in the respective policy agenda. We then summarize the most important policy conclusions and highlight key priorities. Our conclusion is that with increasing income, modernization of urban transport does not require the complete elimination of two-and-three wheelers. Rather, these vehicles need to be appropriately integrated within different means of transport. As two-wheelers in particular hold a strong potential to be used via digital mobility service, they could become key facilitators of long-lasting structural and systematic changes in shared mobility services, electrification, and autonomous driving.

Figure 1 *Metropolitan City of Rome, Italy* @mauro_bighin

II. Two-and-Three-wheelers' role in Urban Transport Systems

"Two-and-three-wheelers provide access and mobility to disadvantaged groups"

Close to half of the global motorised two-and-three-wheeler fleet operates in urban areas . Two-wheelers include mopeds, and motorcycles. They are predominantly used for personal transportation, though in Bangkok, Hanoi and Jakarta in Asia, Rio de Janeiro, Bogota and Caracas in Latin America and Nairobi, Dar es Salaam and Yaoundé in Africa - motorcycles are also used in paratransit modes. Two-wheelers also rapidly gained importance as urban freight delivery vehicles.

Three-wheelers include small taxis usually carrying up to three passengers. These include Auto-Rickshaws in India, Baby Taxis in Bangladesh, Tuk-Tuks in Cambodia, Guatemala, South Africa, Sri Lanka, and Thailand, Tricycles in the Philippines, Bajaji in Tanzania, Bajay in Indonesia, and Mototaxis in El Salvador. Larger vehicles, such as Tempos in Bangladesh, Nepal, and India carry as many as ten passengers.

Box 1: Basic Definition of Two-and-Three-wheelers in the Sourcebook

Source: *Regulation and Design of Motorized and Non-Motorized Two-and-Three-Wheelers in Urban Traffic*

1. A bicycle is any two-wheeled vehicle, propelled only by manual pedaling. In this publication, we consider electrically assisted bicycles, or electric two-wheelers, not as bicycles but as ultra-light motorcycles (see category I motorcycle below).
2. A cycle rickshaw is any three-or-four-wheeled passenger- or load-carrying vehicle propelled only by manual pedaling.
3. A motorcycle is any two-wheeled vehicle propelled by any type of power other than pedaling (including but not restricted to internal combustion engines and electric motors). Motorcycles are divided into the following sub-categories:
   a. **Category I motorcycle *(or ultra-light moped):*** has a maximum speed of 20 km/h, maximum weight of 40 kg, and meets the most stringent air quality and noise standards.
   b. **Category II motorcycle *(or moped):*** has an engine displacement of no more than 50 cc, a maximum speed of 45 km/h, and a maximum weight of 65 kg.
   c. **Category III motorcycle:** has an engine displacement of no more than 125 cc, a maximum speed greater than 45km/h, and a maximum weight greater than 65 kg.
   d. **Category IV motorcycle:** has an engine displacement of more than 125 cc.
4. A motor three-wheeler rickshaw is any three-wheeled vehicle propelled by a motor, generally used for commercial transport of passengers. Motor rickshaws are subdivided into three categories:
   a. **Category I motor rickshaw:** has a maximum speed of 20 km/h, a weight standard to be defined, and meets the most stringent air quality and noise standards (to be defined).
   b. **Category II motor rickshaw:** has a maximum speed of more than 20 km/h but less than 45 km/h and a standard weight yet to be defined.
   c. **Category III motor rickshaw:** has a maximum speed of more than 45 km/h and a maximum weight that has yet to be defined.

In this module, we generally refer to two-and-three-wheelers as of type 3 and 4 and make explicit reference to 1 and 2 types where required.

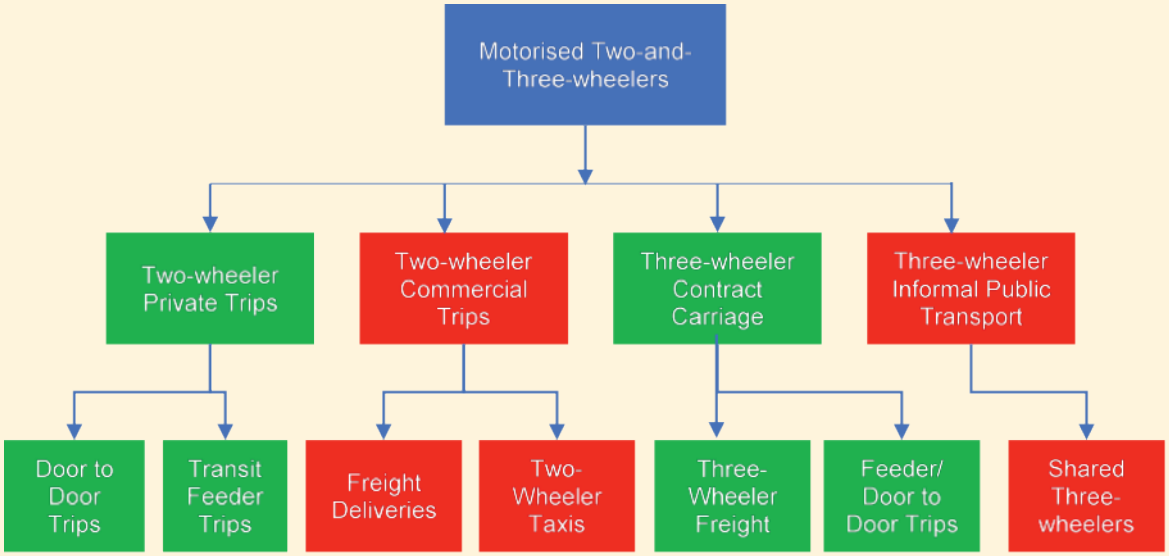
Two-and-Three-wheeler mobility depends on affordability, manoeuvrability, and door-to-door accessibility. In middle and low-income cities, two-and-three-wheelers offer significantly cheaper and faster travel compared to public transport *(Table 1)*. Two-wheeler transport modes, in particular, provide a high level of route and scheduling flexibility at relatively low operating costs. They also guarantee increased ease of access and manoeuvrability in congested traffic. Recent surveys in Latin America corroborate this point as they indicate that two-wheeler ownership is linked to enhanced employment opportunities[2]. However, two-and-three-wheelers pose challenges of their own to the implementation of fully sustainable mobility concepts.

Due to the quick manoeuvrability of two-and-three-wheelers, they incentivise riskier driving behaviour and thereby create a significantly higher risk of accidents. Furthermore, two-and-three-wheelers are appearing in ever-greater numbers, which creates a rivalry between them and other modes of public transport. In many large cities, public transport by busses is not possible anymore, because streets have become too crowded by two-and-three-wheelers. Drivers of two-and-three-wheelers are also more vulnerable to sun and rain. Nevertheless, due to the perceived unattractiveness of public transport services, people increasingly use two-and-three-wheelers despite noticeable disadvantages such as exposure to sun and rain.

	Route Flexibility	Schedule Flexibility	Ease of Access	Capacity	Speed	User Cost/km
Metro	1	1	1	3	3	2
Bus	1	2	1	3	2	1
Taxi	2	2	2	1	2	2
Car	3	3	1	1	2	3
Three Wheeler	2	2	2	2	2	2
Two Wheeler	3	3	3	1	2	1

Table 1 *Characteristics of Urban Transport Modes*

Box 2: Motorised Two-and-Three-Wheeler Trip Typology



We propose the following typology to analyze the role of two-and-three wheelers in urban areas.

Private two-wheelers *(green box)* are typically used for door-to-door trips. They also serve in ingress and egress modes of public transit. City officials regulate these trips, imposing restrictions on ownership, usage, and technologies. Two-wheeler commercial trips *(red box)*, e.g. as freight delivery and taxi trips, are rarely regulated and mostly considered illegal by city officials. Only a few cities, Bangkok included, developed regulations to direct the flow of commercial two-wheelers.

We consider three-wheeler modes of transport in two broad categories: contract carriages *(green box)* and informal, shared trips *(red box)*. Contract carriage services are flexible, demand-based taxi services. Cities regulate the ownership, use, and technologies associated for three-wheelers used in these services. The second type of three-wheeler trips constitute shared personal transport rides that compete with public transport outlets. These trips are characterized by fixed-route taxi services with intermediate stops for boarding and alighting; regulatory frameworks and enforcement are largely absent. This type is most often found in larger cities.

Two-and-three-wheeler mobility has numerous distinguishing characteristics. There is also great variation across cities. This type of mobility is considered both a main mode of transport and an intermediate phase before commuters switch to passenger cars and public transport.

The length of two-wheeler trips lies in between the length of walking/cycling/bike sharing and public transport/motorised four-wheeler modes of transport. However, the number of two-wheeler trips taken in cities depends on several factors such as public transport accessibility and the quality of pedestrian as well as cycling infrastructure. A survey undertaken in Pune[3] shows that two-thirds of riders of two-wheelers relied on public transportation prior to switching to two-wheelers. The same study found 80% of respondents to be interested in purchasing a passenger car in the future. In cities with poor public transport, walking and cycling facilities as well as two-and-three-wheelers play a significant role in transport systems as they cater to the mobility needs of low and middle-income people. The following examples illustrate this point:

a) In Phnom Penh (Cambodia)[4], two-wheelers and para-transit services such as Motodop (motorcycle taxi) and Motorumok Modern (tuk-tuk) account for the vast majority of person transits in the absence of reliable public transport services (city buses are operated only across three major routes). Here, 48% - 80% of all trips taken between 1 and 20 km are made by two-wheelers. *(Figure 2)*.

b) While public transport infrastructure was virtually absent in 1990's Hawassa (Ethiopia)[5], significant investments during the 2000's dramatically improved the road infrastructure of the city. Meanwhile, the city's population increased from 150.000 to 250.000. Here, improved road infrastructure had been one of the main drivers for growing numbers of two-stroke three-wheelers. Between 2005 and 2013, the number of three-

wheelers increased from 57 to more than 2400. Three-wheelers constituted most of the public transport trips as minibuses were not able to compete with three-wheelers in terms of speed, time, and cost efficiency. Typical for Ethiopian cities, three-wheelers perform the unofficial role of public transport as their fleet is rapidly expanding. This development is illustrated by the fact that Ethiopian imports of three wheelers increased from 6.920 in 2012 to more than 75.000 in 2016[6].

c) Two-and-three-wheeler taxis constitute the main mode of urban public transport in Nigeria as well. While official public transport buses account only for 13% of trips, informal public transport services provided by two-and-three-wheelers make up a share of 51%[7]. Survey research shows that people are attracted to two-and-three-wheeler taxis because of their short waiting times (>50% of respondents), reliability (18%), comfort (11%), and affordability (6%)[8]. A further 8% of respondents stated that there was no other alternative mode of transport available[9].

d) A survey involving 4,500 pedestrians[10] throughout Asia revealed that if pedestrian environments fail to be improved, 81% of respondents will shift to other modes if they can afford them. 25% among the respondents stated their intent to switch to cars while 13% preferred two-wheelers. This aspect is worrying as many households in middle and low-income cities have reached a threshold income at which two-wheelers become affordable.

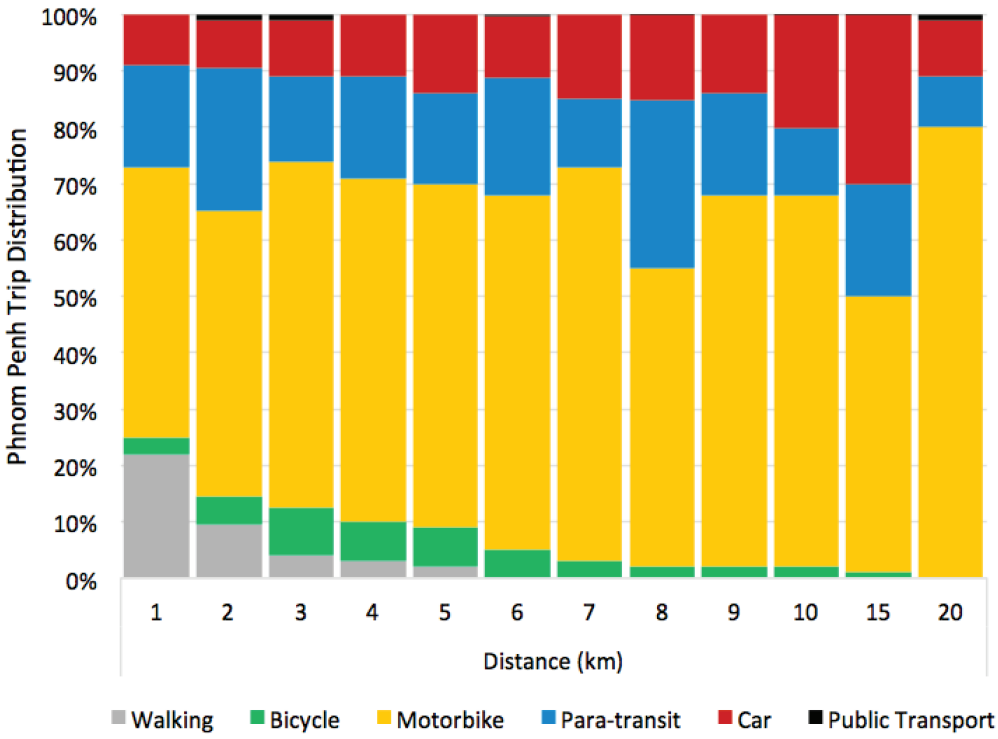


Figure 2 *Phnom Penh Trip Distribution* (Source: JICA, 2014)

In cities with a high density of public transport facilities, two-and-three-wheelers still play a significant role as they cater to the first and last connecting mile connectivity in such areas. They also satisfy the mobility needs of people in areas of poor public transport accessibility. The following examples provide more evidence for these phenomena:

a) Bangalore has one of the highest public transport densities in India, however, the share of two-and-three-wheelers has remained consistently high for the last two decades. Here, 44% of households own two-wheelers. Two-and-three-wheelers are used predominantly (70%) for trips ranging between one and ten kilometres. For trip lengths exceeding 10 kilometres, buses are the main mode of travel[11].

b) In Nashik (India), surveys[12] revealed that two-wheeler ownership and use is prevalent in zones with poor public transport accessibility. In middle-income neighbourhoods, the average two-wheeler household ownership varies from 56% (good public transport access) to 78% (poor public transport access). In terms of its share among different trip modes, two-wheeler trips make up for 6% to 19% of total trips depending on public transport accessibility.

c) In Hanoi (Viet Nam), 94% of households have access to two-wheelers. Here, two-wheelers are mainly used for shorter trips, i.e. 87% of two-wheeler trips lie within a distance of 10km[13] with an average trip length of 5km. Buses predominantly cover longer distances with an average trip length of 12 km *(Figure 3)*.

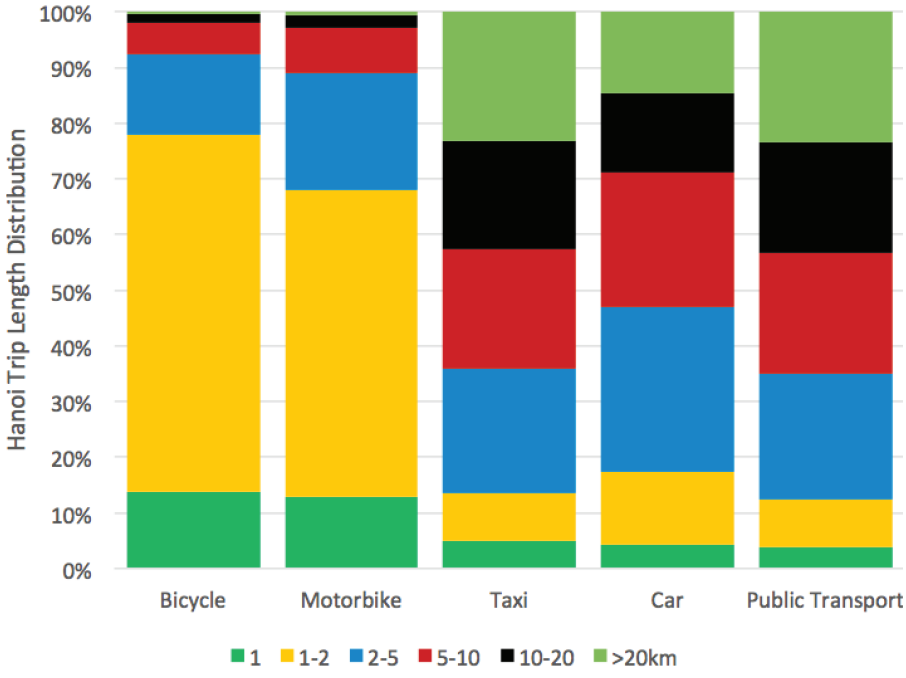


Figure 3 *Hanoi Trip Length Distribution* (Source: JICA, 2015)

Figure 4 *Three-wheelers provide first and last mile connectivity*

The role of two-and-three-wheelers in urban freight distribution has become increasingly widespread. This poses a challenge for cities, as such freight movements are emission intensive *(Figure 5)*. Urban freight differs substantially concerning the size of shipment and the size and type of the vehicle used for deliveries. Growing traffic congestion contributes to the growth of motorcycle delivery services with two-and-three-wheelers. Their share of total freight deliveries will therefore continually rise over the coming years

For example,

- In Curitiba, nearly 10% of registered motorcycles are used for urban freight distribution[14].
- In Chennai, establishment surveys revealed that two-and-three wheelers carry out 44% of freight trips[15].
- In Bangkok, total vehicle kilometres travelled by delivery motorcycles sum to almost 4.6 million per day[16]. Here, the average trip length is about 6.3km for which two-wheelers are most efficient with regard to time and costs spend for delivery
- In an average European city, half of all motorised freight trips could potentially be shifted to non-motorised two-and-three-wheelers[17].

Average Global Freight Mode Emission Factors		(gCO2/t-km)		
		min	max	average
Two Wheeler	Gasoline/Urban (5 to 100 kg with average of 10 kg)	600	8000	4300
	Electric (5 to 100 kg with average of 10 kg) with 700 tCO2/Kwh	400	1400	900
Three Wheeler/Mini LCV	Gasoline	150	1200	675
	Diesel	130	1000	565
	Electric	90	900	495
LCV (Light Commercial Vehicle)	Diesel	70	300	185
	Electric	50	250	150
New Medium Duty Trucks	2010 Stock Average	270	490	380
	Diesel	240	370	305
	Diesel Hybrid	180	270	225
	CNG	200	300	250
	Electric	50	170	110
New Heavy Duty Long-Haul Trucks	2010 Stock Average	76	180	128
	Diesel	70	130	100
	CNG	60	110	85
	Electric	15	45	30
Rail (freight train)	Diesel, light goods	26	33	30
	Diesel, heavy goods	18	25	22
	Electric, 200g CO2/kWhel	6	12	9
Aviation (commercial, long haul)	2010 Stock Average	550	740	645
	Dedicated Aircraft	500	820	660
	Belly-hold	520	700	610

Figure 5 *Average Carbon Emission Factor for Freight Modes* (Source: IPCC and author's analysis)

Due to growing e-commerce, traffic congestion, restrictions for urban freight distribution, and limited on street parking at destinations, two-and-three-wheelers are gaining popularity in urban freight distribution for small and medium enterprises. The Mayor of London's 2017 draft transport strategy[18] promotes a so-called *"Healthy Streets Approach"*, suggesting that two-wheelers should play a significant role in low-impact freight and servicing trips. Ultra-low emission motorcycles play a key role here, as they replace trips otherwise carried out by lorries or vans.

In terms of the traffic management in urban areas, two-and-three-wheelers typically operate within a speed range from 20 to 30km/h *(Figure 6)* indicating a high potential for vehicles[19] (category I and II) operating with smaller engines and at slower speeds. World Bank surveys in Bangkok, Hanoi and Jakarta have estimated the average occupancy of two-wheelers at 1.3 persons per trip, which compares closely to the average occupancy for car trips (at 1.8 persons per trip). Considering that an average two-wheeler occupies only about 25% of the round space of a car, motorcycles are the most efficient users of road space among private vehicles. Increased usage of two-wheelers thus leads to reduced parking space requirements while curbing the demand for additional roads. In the short run, high levels of motorcycle usage may therefore not appear as an immanent problem, especially in smaller cities. However, in the intermediate and long run, a sheer 'motorcycle dependency' (i.e. exponential increase in two-wheeler ownership and use) can lead to intolerable congestion, high accident fatalities, high levels of fuel consumption, and increased air pollution.

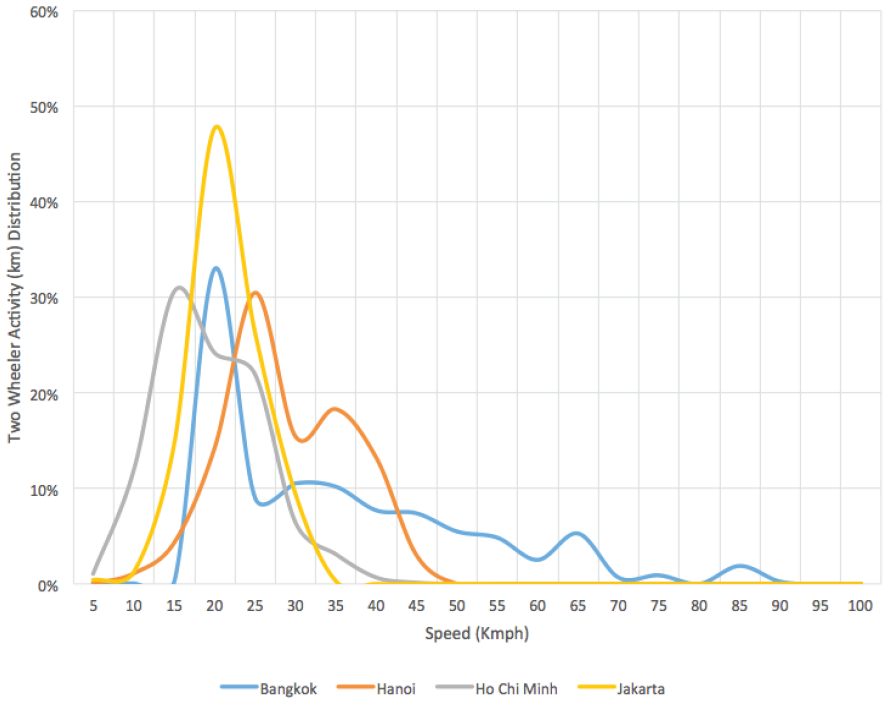


Figure 6 *Two-Wheeler Activity Distribution* (Source: World Bank, 2010)

Figure 7 *Two-and-three-wheelers provide access and mobility to the disadvantaged groups* (Vietnam)

In many cities, two-and-three-wheelers are becoming the victims of their own success as their movement becomes increasingly restricted to specific trip objectives caused by high externalities. In many of Colombia's[20] large cities (e.g. Cali, Cartagena, Cúcuta, Ibagué, Medellín, Neiva, Riohacha, and Pasto) for example, motorcycle taxis have been temporarily and/or partially prohibited. In some cases, the occupancy of such taxis is restricted to only one passenger due to personal safety concerns (burglars sometimes use motorbikes in pairs). Stating road safety reasons, Malaysia[21] has banned the use of motorcycle taxi hailing services. In Manila[22], motorcycles are prohibited from service as public vehicles and passenger transport.

A global analysis by the Institute for Transport and Development Policy (ITDP) in 2014[23] indicated that if middle and low-income cities were to significantly improve public transport quality and infrastructure while maintaining safe and comfortable pedestrian and cycling facilities, they would have the potential to substantially reduce motorised two-wheeler passenger activity and thereby reduce externalities, such as traffic congestion and high levels of emissions *(Figure 8)*.

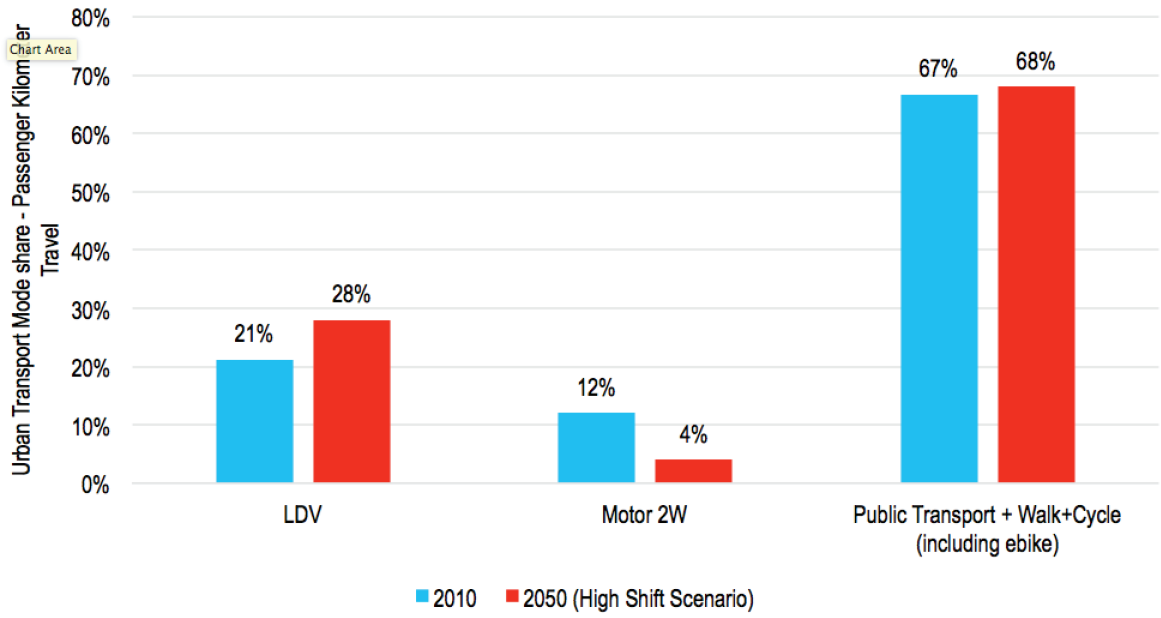


Figure 8 *Urban Transport Mode share - Passenger Kilometre Travel* Source : ITDP, UC Davis (2014)

III. Future Growth of Two-and-Three-Wheelers

Will Motorcycle ownership shrink as we become rich?

Global estimates of serviceable two-and-three-wheelers in 2010 range anywhere between 400[24] and 700[25] million vehicles. This number is hard to estimate due to unreliable registration statistics and varying definitions used for such vehicles across different countries. Experts, however, are reasonably confident that:

a) In 2015, motorised two-and-three-wheeler sales in China and India exceeded 40 million[26] (excluding electric two-wheelers). Asia now accounts for 95% of the global motorised and electric two-wheeler production[27]

b) Middle and low-income countries in Asia hold the world's highest density of two-and -three-wheelers, both in absolute terms and as a fraction of the overall serviceable fleet. In many cities of Asia, two-and-three-wheelers constitute most of the motorised vehicle fleet. For example, in Kathmandu and Hanoi, two-and-three-wheelers make up approximately 75% and 94% of the total fleet. Furthermore, cities like Vientiane and Kathmandu accommodate more than 50% of their respective countries' two- and three-wheeler fleet.

Over the past two decades, two-and-three-wheeler fleets have expanded at an annual average rate above 7% in many middle and low-income countries including Bangladesh, India, Indonesia, the Philippines, Myanmar, the Maldives, Nepal, and Sri Lanka. Thus, the current stock of two-and-three-wheelers is expected to double every five years in many of those countries.

The economic crisis of 2008 triggered a renewed interest in motorised two-wheelers among high-income cities. In Barcelona, for instance, the number of motorised two-wheelers has increased by 36% during the past eight years. Currently, motorised two-wheelers constitute about 26.5% of all motorised trips there[28].

Given that the density of two-and-three-wheelers is already high in many middle and low-income cities, ownership levels might become saturated or even reduce as income levels rise. However, experience from India indicates that two-and-three-wheelers may continue to play an important role in urban transport. The National Transport Development Policy Committee (NTDPC) established by the Indian Government recognized the role of two-and-three-wheelers within urban transport systems. It has recommended desirable modal shares for different city sizes based on trip length distributions among urban areas in India. Among all trips, two-and-three-wheelers hold shares ranging between 11% and 37% depending on the city size *(Figure 9)*.

Factors influencing Motorcycle Ownership	Impact	Description
Growing Congestion	+++	Motorcycles are highly effective in congested environments
High Fuel Economy Standards	+++	High motorcycle fuel efficiency reduces travel costs
Growing Income	+++	Ownership of motorcycles grows twice as fast as income at middle-income levels (from USD 3,000 to USD 10,000) per capita
Low Ownership Costs	+++	Ownership increases due to low ownership cost
Available Parking	+++	Can be easily parked anywhere in an urban environment
Short Trip Length	+++	Motorcycles are considered most effective for up to '10km' trips.
Gender and Population	+++	Younger males are more likely to use motorcycles than females and older people
Road Infrastructure Improvement	++	Improvement in road infrastructure positively influences ownership
Household Size (high)	++	Increase in household size leads to higher ownership rates
Low-cost Financing	++	Easy financing, sometimes with zero percent interest
Low Maintenance Costs	++	Motorcycles have low maintenance costs
Low Taxation	++	Motorcycles are taxed lower than other modes and they do not pay for their external costs
Permeability of traffic system	++	High manoeuvrability (positively) influences ownership
High Public Transport Fares	+	Higher public transport fares positively influence ownership
High Fuel Prices	+	High fuel costs positively influence ownership
High Density and Diversity of Land use	-	High density and diversity of land use reduce motorcycle ownership
Growing City Size	--	As city size increases transit becomes more effective for longer trips, leading to a reduction in motorcycle ownership
High Quality Bike Lanes	--	Cities with high quality bike lanes have lower motorcycle ownership rates
Weather	---	Exposure to sun and rain reduces motorcycle use
Susceptibility of traffic system to accidents	---	Higher probability of accidents
Congestion Charge	---	Road pricing and congestion charges reduce motorcycle usage
Vehicle Quota System	---	Prevents easy access to motorcycle ownership
Good Public Transport Accessibility & Quality	---	Improvements in transit services can reduce the number of motorcycles

Table 2 *Factors influencing Motorcycle Ownership* Source: Sudhir Gota

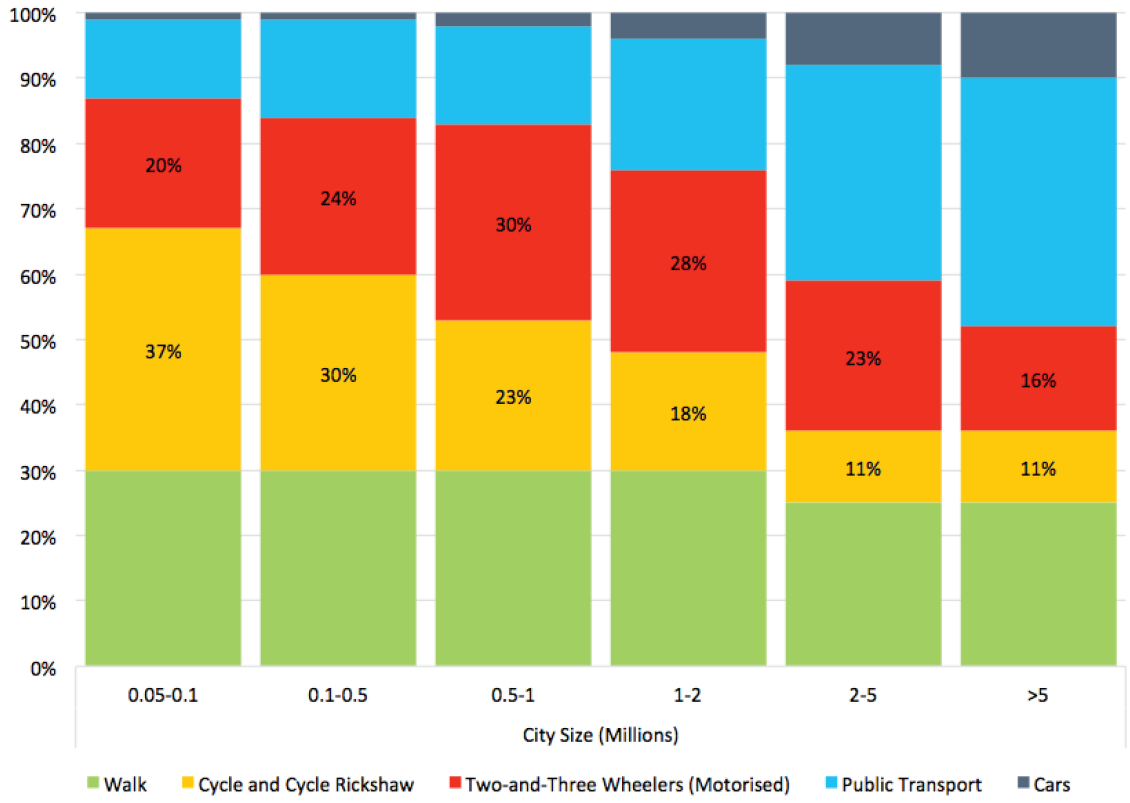


Figure 9 *India Desirable Trip Mode Share* Source: NTDPC, 2013

Box 3: Motorcycles in Latin America

Two-wheeler ownership and use in Latin American cities has grown significantly in recent years. Studies estimate the regions' total fleet size at about 30 million motorcycles.
Factors contributing to the rise in motorcycle use in Latin America include: i) increased per capita incomes, ii) low cost of motorcycles, iii) inferior service of other transport modes (fares, coverage, reliability, traffic congestion), iv) motorcycle transport as an important source of employment and reliable mobility, v) motorcycles as a means of achieving social status, vi) transport of family, vii) driver education as a factor affecting road safety, and finally vii) motorcycle culture.

The main drivers of growth in global two-and-three-wheeler usage include growing urbanization, rising per capita income, high traffic congestion, perceived failures of public transport systems, economic opportunities provided by two-and-three-wheeler-reliant jobs, and rapid expansions in road infrastructure. Current research[29] indicates that vehicle ownership does not grow linear compared to income increases on all income levels. Ownership grows relatively slowly when income increases at the lowest levels of per-capita income. Ownership grows about twice as fast as incomes at middle-income levels (from USD3,000 to USD10,000 per capita). At higher income levels, ownership and income grow linear, before reaching saturation at the highest levels of income. Given that it is much cheaper to buy a motorcycle than a car (1000 USD vs 10,000 USD), income growth affects motorcycle ownership stronger and faster than car ownership. Projections under a business-as-usual scenario indicate that by 2050, the global two-and-three-wheeler population will increase to a total between 1.3 Billion[30] and 1.7 Billion[31] vehicles (Category II, III and IV). The latest research confirms that as income levels rise, two-wheeler usage may not necessarily decrease[32] over the next 3 to 4 decades.

IV. Externalities of Two-and-Three-wheelers

"Two-and-Three-Wheeler users should be charged for the external costs of their trips"

High densities of motorised two-and-three-wheelers in urban areas pose serious strains on overall traffic congestion, energy consumption, carbon emissions, air and noise pollution, and road safety. During the last three decades, the relationship between benefits and externalities of two-and-three-wheelers has been analysed from a policy perspective in middle and low-income countries. Drivers of urban transport policy include congestion, air pollution, and road safety. During the last few years, stakeholders have started to prioritize the role of two-and-three-wheelers in climate change mitigation.

As a guide to policy makers, the European Commission[33] developed a comprehensive analysis of common approaches used to determine the external costs of different modes of transport based on urban roads of a typical EU member state. The analysis shows that two-wheeler trips generate higher externalities compared to passenger cars (2.5x) and bus travel (5x) *(Figure 10)*. However, this may not necessarily reflect the conditions in middle and low-income cities. Furthermore, as demonstrated by the definitions proposed in the previous section, a distinction must be made between different types of two-and-three-wheelers. The external costs among two-and-three-wheelers differ based on how heavy, noisy, pollution emitting, expensive, accident-prone, and fuel-inefficient the vehicles are. Moreover, a single specific mode can cause different externalities depending on the time of travel, route of travel, city typology, infrastructure quality and standards, vehicle occupancy, and vehicle characteristics (e.g. EURO standards for pollutant emissions), as well as fuel type and quality. For example, two-wheelers with engines between 50 and 100 cc have a very different energy consumption profile compared with 250 cc engine two-wheelers. Similarly, crash rates, crash severity, and two-wheeler congestion varies by the speed and proportion of the two-wheeler traffic mix.

Each of the assumptions in the EU study should be scrutinized in the context of Asian and Latin American traffic and economic environment. Back of the envelope calculations indicate current global external costs caused by urban two-and-three-wheelers to lie above 200 billion Euros[34]. In the light of the expected growth rates in the two-and-three-wheeler population by 2050, a continuation of existing policies will likely result in a 1.6 to 5-fold increase in externalities compared to the 2015 level (*Figure 12*). ***The substantial contribution of two-and-three-wheelers to transport externalities makes a compelling case for prioritizing policy action.***

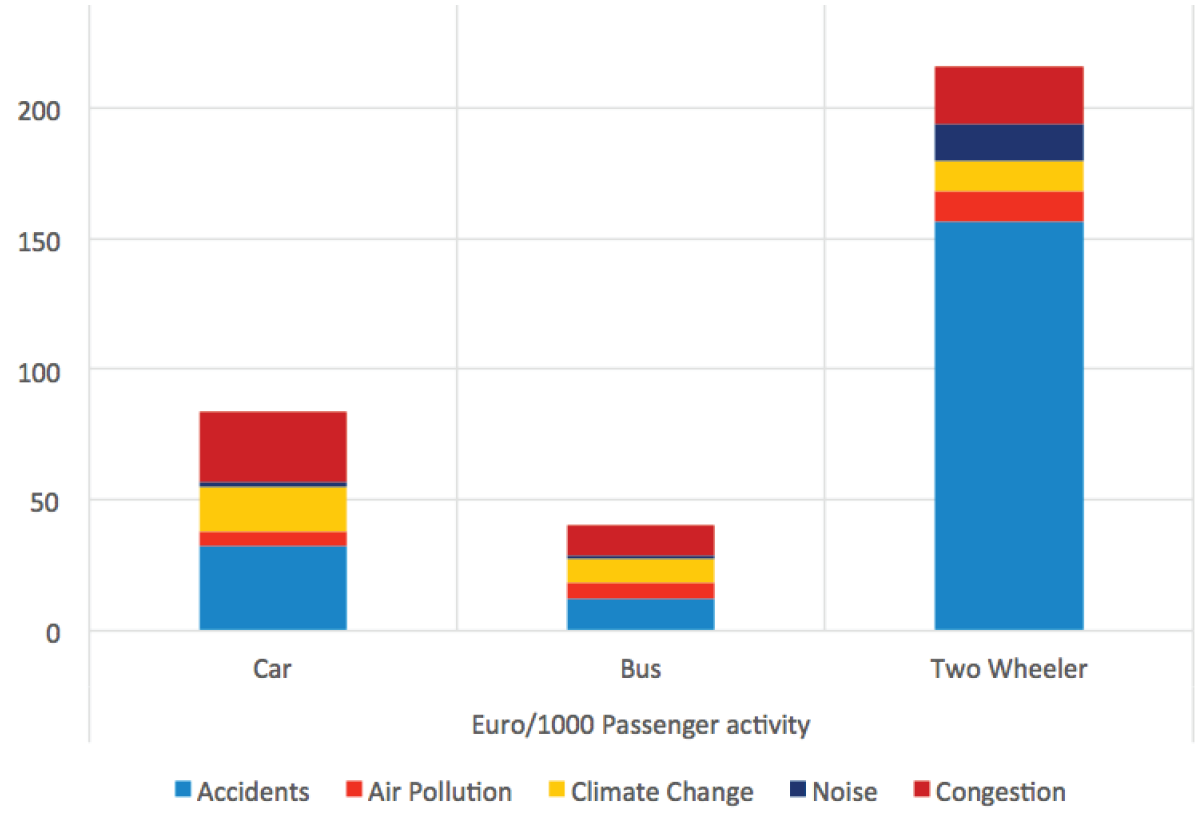


Figure 10 *External Costs in EU* Source: European Commission

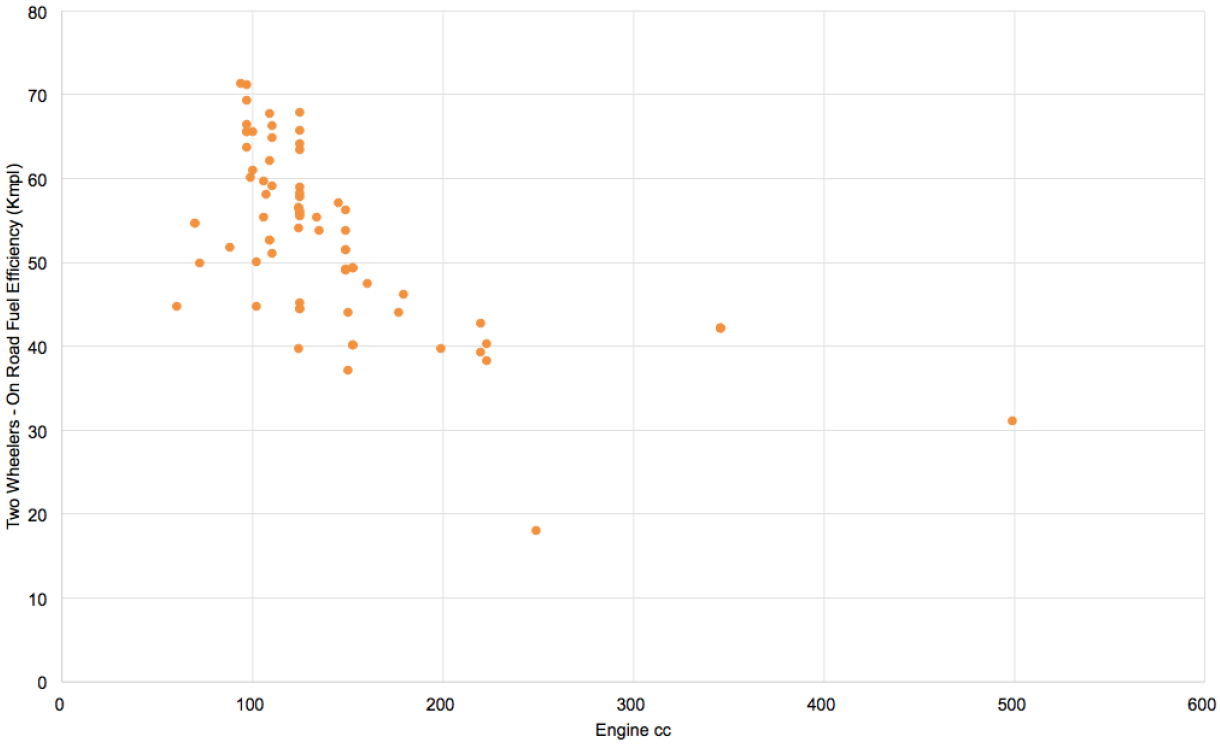


Figure 11 *India Two Wheelers - On-Road Fuel Efficiency (Kmpl)* Source: Author analysis based on data from the Society of Indian Automobile Manufacturers

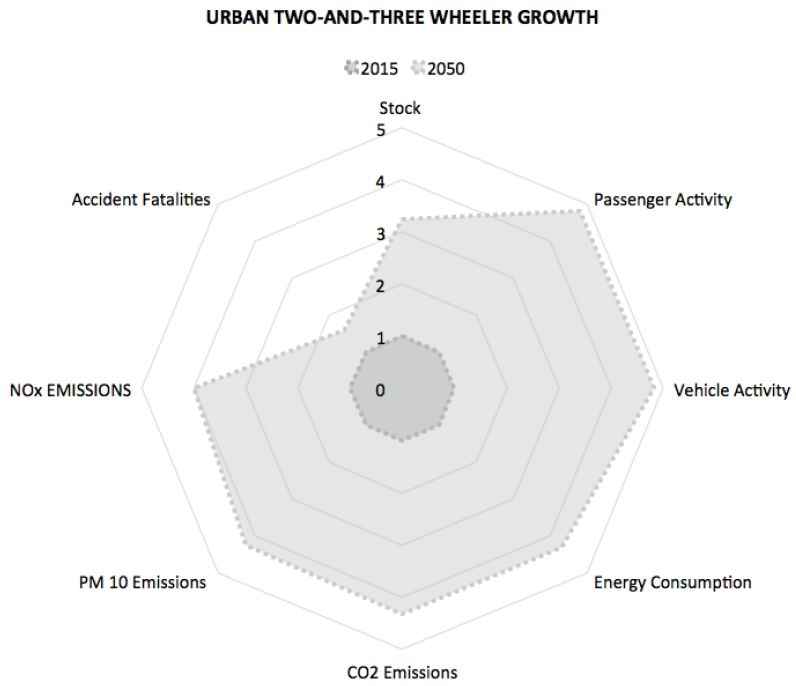


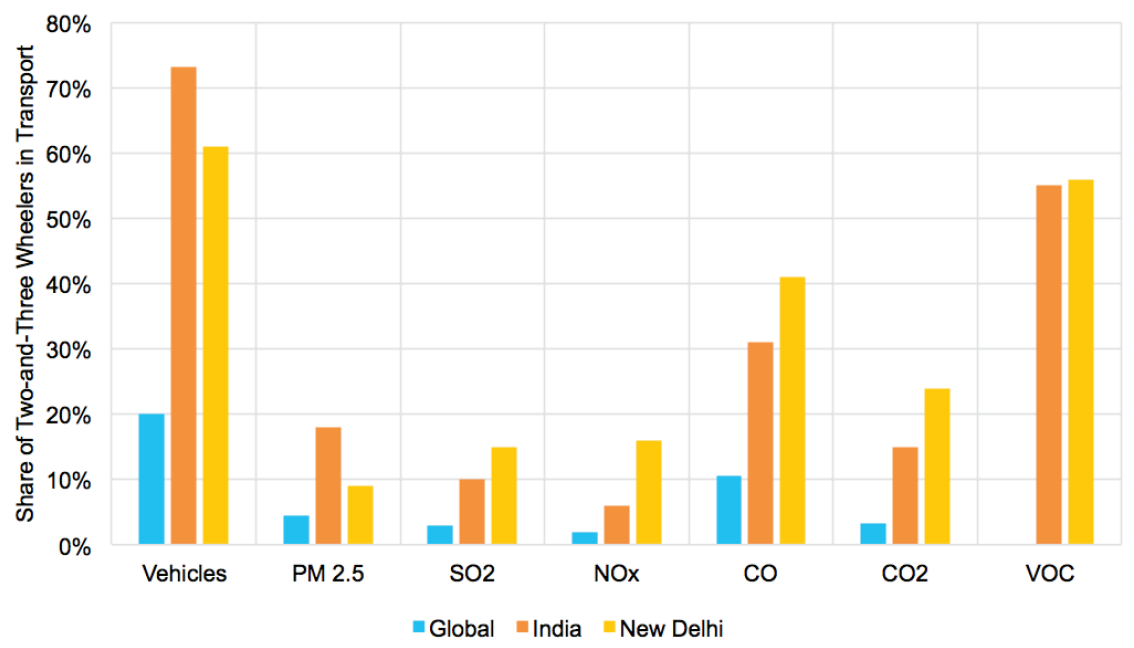
Figure 12 *Global Urban Two-and-Three-Wheeler Growth* Author analysis based on ICCT and WHO Data

Figure 13 *Two-wheelers are a significant contributor to air pollution*

Box 4: Air Pollution

The World Health Organisation (WHO) estimated that in 2012, outdoor air pollution caused about 3 million premature deaths worldwide due to exposure to small particulate matter (PM 10). This exposure resulted in higher rates of cardiovascular and respiratory disease as well as cancer. Both exposure and deaths (87% of the 3 million premature deaths) occurred predominantly in low- and middle-income countries where traffic is a major source of air pollution. Two-and-three-wheelers are growing contributors to rising levels of particulate emissions (PM), particularly in Asia, Africa, and Latin America. According to a comprehensive survey, 98% of cities in low- and middle-income countries with more than 100 000 inhabitants do not meet WHO air quality standards.

On a global scale, two-and-three-wheelers are only a minor contributor to total transport sector emissions. However, in middle and low-income countries, they contribute a significant share in total emissions. They also grow faster than other modes of transport *(figure below)*. In Duala, for example, two-wheelers are estimated to be responsible for 78% of poor urban air quality.
The past two decades have seen a significant transformation in the two-and-three-wheeler fleet due to air

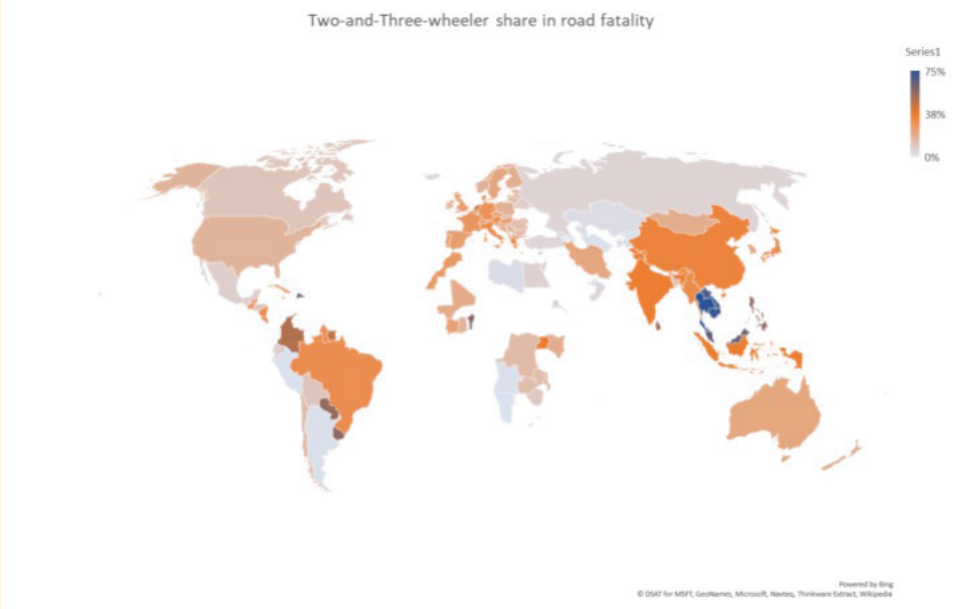


pollution regulations. Large proportions of two-wheelers are now powered by four-stroke gasoline or electric engines. In Delhi during the early 1990's, for example, most two-wheelers sold had a 2-stroke engine. Two-stroke engine vehicles, however, emit significantly higher amounts of unburned gasoline compared to the four-stroke variety. During this period, unburned lubricating oil was responsible for 80% to 95% of total 2-stroke PM emissions. Therefore, the high penetration of two-stroke vehicles became a major air pollution challenge in the mid-1990's. Governments began to promote 4-stroke engines by tightening two-wheeler emission standards. Consequently, the share of 2-stroke engines reduced from 80% in late 1990's to about 6% in 2004. Current 2-stroke vehicles typically have an engine size between 50–60 cc; their share among the two-wheeler fleet lies below 5%.
Taiwan provides another example for air pollution reduction measures: Here, tighter emission standards for two-stroke engines compared with four-stroke engines resulted in an effective ban of two-stroke engine two-wheelers.

Box 5: Road Accidents

On roads, the fatality risk for motorcyclists is 20 times higher than for car occupants. More than 350,000 people die each year from accidents involving two-and-three-wheelers. Most of these deaths occur in low- and middle-income countries where rapid economic growth has accompanied increased ownership of two-and-three-wheelers. Public health concerns aside, two-and-three-wheeler accident injuries are a development issue as well. Low- and middle-income countries lose close to 1.5% of GDP because of two-and-three-wheeler accidents while most fatalities occur among young people aged between 15 and 29 years. The problem is most severe in South-East Asia and the Western Pacific, which account for 34% of deaths among motorcyclists worldwide.

New data has revealed that while countries have achieved progress in improving overall road safety, two-and-three-wheeler fatalities are still increasing in several regions. In the Americas for example, the proportion of motorcycle deaths among all road traffic fatalities rose from 15% to 20% between 2010 and 2013. In Tanzania, the share of two-wheelers in the total vehicle fleet has increased from 46% to 54% during the past three years. Subsequently, the share of motorcycle deaths increased from 13% to 22% among all road traffic related deaths. In Taiwan and Thailand, motorcyclists comprise approximately 45% and 70% of road traffic fatalities respectively.



The 2030 Sustainable Development Goals and the Decade of Action for Road Safety 2011–2020 identifies road safety as a global priority. These reports contain evidenced examples for successful intervention strategies aimed at increasing the safety of two-and-three-wheeler traffic. A global application of these regulations and strategies would have great potential to save lives.

V. Policy Options

Should we prioritize two-and-three-wheelers to improve the sustainability of urban mobility?

One might argue that in a middle and low-income country context, two-and-three-wheelers provide a more sustainable transport solution than passenger cars. Following this logic, promoting two-and-three-wheelers would delay growth in car ownership, thereby increasing the efficiency and sustainability of the transport system. However, promoting two-and-three-wheelers may adversely impact pedestrian, cycling, and public transport trips. Among these modes, motorised two-and-three-wheelers have the strongest lock-in effect because they provide a direct and fast connection and can be parked closer to the origin and destination. Urban transport systems are complex with various interactions leading to unexpected outcomes.

Among middle- and low-income cities, there is widespread acknowledgement of the need to improve the sustainability of two-and-three-wheeler traffic. Looking to the future, cities need good knowledge of policies and measures on how to proceed. There a various urban examples of reorganizing, regulating and integrating two-and-three-wheeler as a mode of transport within existing transport systems to achieve accessible, affordable, environmentally friendly, and efficient transits. Seven main elements are important to transform the use of two-and-three-wheelers into a valuable addition to urban sustainable mobility concepts *(Figure 14)*. These elements include measures such as driving restrictions, regulations for air pollutants and CO2 emissions, infrastructure solutions, and technology-based retrofits. They further suggest improving sidewalks, cycling facilities, as well as public transit accessibility, and quality. In this module, we discuss six policy solutions for two-and-three-wheelers as public transport, walking, and cycling improvements are already discussed in detail in SUTP modules – *3a,3b,3c,3d and 3e*.

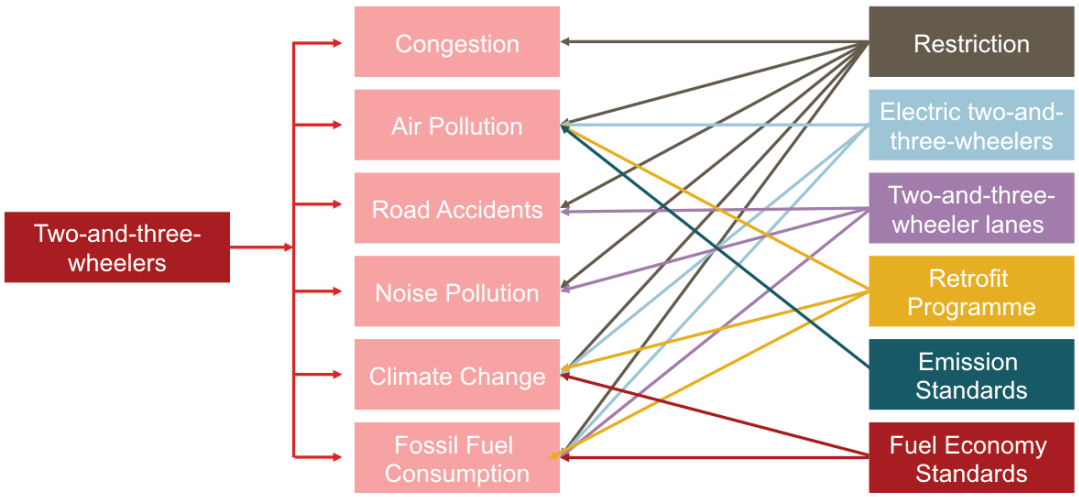


Figure 14 *Two-and-Three-Wheelers Externalities and Solutions*

Box 6: Two-and-Three-Wheeler Accident Reduction Strategies (WHO)

Key measures	Interventions	Safety Effectiveness	
		Proven	Promising
Safer roads and mobility	Exclusive motorcycle lanes	■	
	Protected turn lanes and widened shoulders/lanes		■
	Removal of roadside hazards		■
	Speed limiters and traffic calming		■
	Improving road surface conditions		■
Safer vehicles	Antilock brake systems (ABS)	■	
	Headlights at night		■
	Daytime running headlights		■
Safer road users	Setting and enforcing legislation - Mandatory helmets, helmet standards, strengthening penalties	■	
	Wearing reflective and protective clothing		■
	Mandatory registration of vehicles & licensing of two-and-three-wheeler operators	■	
	Training - Compulsory skill test for permit	■	
Minimizing exposure to high-risk scenarios	Expanding public transport	■	
	Improving walking and cycling facilities	■	
Modifying use behaviour	Setting and enforcing speed limits	■	
	Setting and enforcing alcohol impairment legislation	■	
	Social marketing	■	
Improving post-crash medical care and response times	Introduction of uniform treatment protocol	■	
	Quick response time	■	
	Offer early rehabilitation	■	

a. Restricting Two-and-Three-wheelers

Many cities have considered or already implemented bans on two-and-three-wheelers because of traffic congestion and road accidents. Motorcycles also pose a threat to public safety as they are involved in a considerable share of urban crime. The cities of Guangzhou, Shenzhen, and Dongguan for instance banned motorcycles as part of a crime prevention strategy[35]. The 2007 Guangzhou motorcycle restriction strategy serves as a template to understand the typical development path of motorcycles in China, and more recently, in urban areas throughout Asia. Research indicates that more than 168 Chinese cities have implemented such bans thus far. Numerous cities in Asia such as Jakarta, Kuala Lumpur, Yangon, and Hanoi have since followed this example.

Experience[36], however, suggests that banning specific types of vehicles should be justified only after carrying out a comprehensive socioeconomic impact analysis. It is important to acknowledge that the specific externality of a transport mode on a specific road depends on several factors, such as traffic operating conditions, existing laws, maximum speed, passenger occupancy, vehicle characteristics, human behaviour and city typology. These factors vary significantly among cities and there is no standard template available for banning two-and-three-wheelers. However, private cars carrying only one passenger are expected to cause the highest external costs within urban areas. Cars should thus be the starting point for restrictions as all alternative travel and transport modes available to former drivers would be more efficient than their previous travel mode. The mere banning of two-and-three-wheelers as a silver-bullet policy instrument could have serious rebound effects. Cities may need to determine specific set of circumstances where appropriate two-and-three-wheeler restriction will have a net aggregate positive impact.

For example,

1. Singapore operates a vehicle quota system[37] to limit the growth of all private vehicles, two-wheelers included. Between 2009 and 2012, the annual growth rate was capped to 3% per annum, between 2012 and 2013, to 1%, and between 2013 and 2015 to 0.5%, and to 0.25% between 2015 and 2018. From 2018 onwards, Singapore will implement a zero-growth target. This policy is applicable to all private passenger transport modes. As the quota system is also combined with several other regulations such as electronic road pricing, mass transit improvement, taxation, etc. this restriction is expected to result in a net-positive impact as all transport modes compensate their respective externality costs.

2. Starting in 2019, Taipei authorities will restrict the use of two-stroke scooters by amending city regulations in a bid to reduce air pollution and become a low carbon city. With an estimated 350 two-wheelers per 1.000 citizen, Taipei City aims for a zero-growth rate for motorcycles[38]. With a combination of policy instruments, it has already managed to reduce the density from 418 to 353 motorcycles per 1.000 citizen, corresponding to an average annual reduction of -2.2% between 2010 and 2016[39]. Its public transit ridership, in contrast, saw an annual increase of 1% over the same period. Taipei City has the best public transit services among 23 counties and cities throughout Taiwan* while maintaining the lowest rate of motorcycles per household. Moreover, there are plans to extend the city's motorcycle restriction policy to the entire region. Taiwan furthermore announced its goal to completely ban fossil-fuel powered motorcycles by 2035 due to increasing air pollution[40].

3. Hanoi[41] also recently developed a roadmap to restrict motorcycles. Estimates suggest that the number of motorcycles could increase from 1 million in the late 1990s to about 7.5 million by 2030. The roadmap proposes to first restrict motorcycles that fail to meet the city's emission regulations between 2018 and 2020. Between 2025 and 2029, the city plans to restrict motorcycle movement for certain hours and on certain days along major corridors. From 2030 onward, motorcycles will no longer be allowed to access any district of the city. These bans are planned alongside improvements to public transport capacity, aiming to cover 25% of total transport demand in Hanoi by 2020. For instance, the city plans to establish 15 to 20 new bus routes serviced by more than 500 additional buses.

4. In 2003, motorcycles were banned in certain zones (CBD) of Yangon (Myanmar) to reduce traffic accidents and criminal activities[42]. During the past 14 years, the share of motorcycles among the city's total fleet reduced significantly compared to that of other cities[43]. For instance, while the average in other cities remained close to 90%, trips in Yangon are now dominated by public transport (formal and informal) with 61% accounting for shared, 8% for car, 7% for motorcycle and 23% for bicycle trips. Here, the share of motorcycles among trips is significantly lower than in most Asian middle and low-income cities. In 2014, JICA surveys revealed a majority of citizens to be supporting the policy with 58% in favour and only 16% of respondents opposing the ban[44].From the macro perspective, Yangon's two-wheeler restriction can thus be considered a success. However, the latest statistics indicate that despite these restrictions, road accident fatalities have increased significantly due to raising ownership of cars. Research indicates that the motorcycle ban[45] only provides short-term benefits. In the long run, the ban could lead to a dramatic increase in car ownership and thus eliminate any positive impact of reduced motorcycle traffic. Household surveys already

reveal that car ownership levels are significantly higher in areas with a motorcycle ban.

5. One of the most common regulatory approaches is to ban all vehicles violating emission limits. This, however, can have profound adverse socioeconomic impacts on drivers, operators, and even the public (as experienced when drivers affected by the ban of two-stroke two-and-three-wheelers engaged in protestants in cities such as Manila, Jakarta, Peshawar, Kolkata, Colombo, Dhaka, Karachi, Taipei, Nairobi and Hawassa). Experience suggests that the use of economic incentives embedded within a regulatory approach leads to a more effective policy. In Bangalore, exist about 120.000 three-wheelers and about 10% of them run on two-stroke engines. As part of the ban of two-stroke vehicles, a 500 USD subsidy was offered to drivers to purchase new, four-stroke, LPG-driven three-wheelers. The economic incentive provided was substantially higher than the resale value of 15 years old three-wheelers (350 USD[46]) which explains the success of this policy.

Based on the above case studies, we recommend that banning a specific type of two-and-three-wheelers should be justified only after conducting a comprehensive socioeconomic impact analysis as it could have serious rebound effects.

Box 7: Ridesharing

Motorcycle taxis are considered the dominant mode of informal public transport. However, the emergence of affordable mobile communication technologies has increased the popularity of two-and-three-wheelers as a form of ridesharing, on-demand ride-sharing, and micro-transit services based on mobile apps. For example, GO-JEK, an Indonesian start up firm which caters to motorcycle on-demand ride services is now valued at more than 2.5 billion USD. Within 10 years, it increased its operations from 20 to more than 400,000 drivers across 50 cities. In India, UberMOTO, an online cab hailing service, has completed 2 million trips within one year. However, the use of motorcycles as app-based, on-demand ride services is increasingly restricted due to violations of existing public transport regulations (e.g. in Bangkok) and competition regulation (e.g. Vietnam), because traditional motorcycle taxi drivers face a competitive disadvantage vis-à-vis mobile, app-based services. Many app-based services have ceased operations due to regulatory restrictions (such as Zingo, Dot, TuWheelz, Headlyt, and Rideji).

The Indonesian government recently revised their taxi regulation to accommodate fast-growing, online ride hailing services that had disrupted established transportation businesses. The non-route public transportation regulation is both responsible for setting minimum and maximum rates for ride-hailing services. India recently revised its taxi regulations to accommodate motorcycle use as on-demand ride services. The motorcycle taxis are now acknowledged as a low-cost last mile connectivity solution for the passengers. The cities and state governments can legally allow two-wheeler taxi permits like those for city taxis to facilitate greater utilisation of idle assets. The online cab hailing service Uber's bike taxi service UberMOTO has already completed 2 million trips in a single year in India.

b. Electric Two-and-Three-wheelers

Ideally, the introduction of new technologies to two-and-three-wheelers should neither be accompanied by the promotion of nor a ban of specific technologies. This can only be achieved by middle and low-income countries with technology forcing fuel-neutral standards for fuel efficiency and emissions with due consideration of external costs. For the past two decades, policymakers have tried to set regulatory standards for two-and-three-wheelers without committing to specific winning technologies. In the long run, this has ensured a future lock-in of technological developments into specific paths, discouraging investments in alternative, potentially more efficient technologies. However, after a decade of experiments and research, electric two-wheelers are now largely considered winners among various two-and-three-wheeler technologies. The International Energy Agency has estimated that two-and-three-wheeler fleets need to be completely electrified by 2040 to 2050[47] to curb global warming at a maximum of 2-degrees Celsius *(Figure 15)*. The results of a cost-benefit analysis among various technologies indicate that electric two-and-three-wheelers[48] can provide a maximum in social benefits among all other available technologies[49].

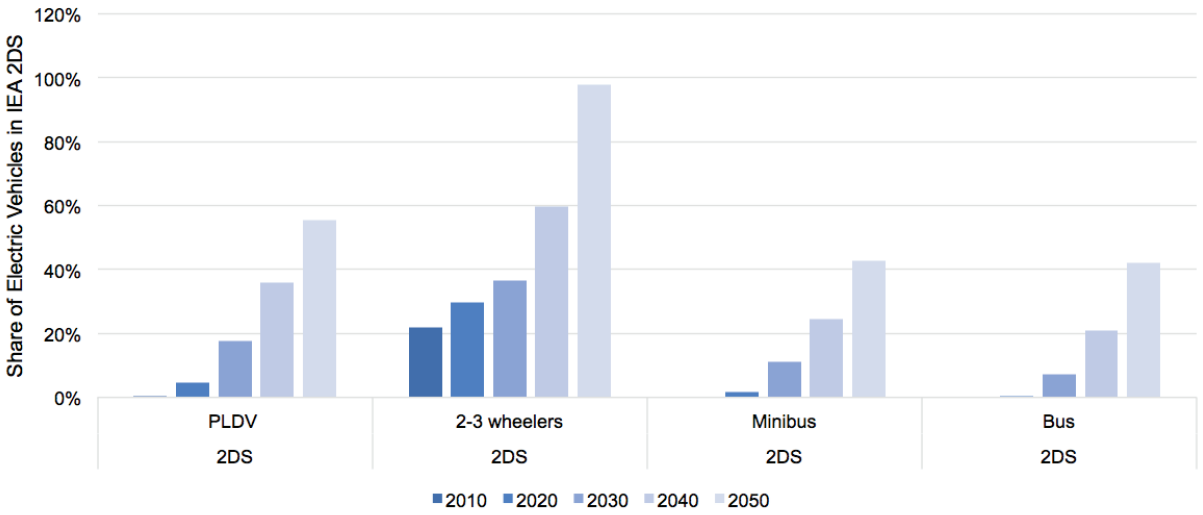


Figure 15 *Share of Electric Vehicles in 2-Degree Scenario* Source IEA -ETP, 2017

In 2015, global sales for electric two-wheelers reached almost 38 million, with China accounting for more than 90% of the market share[50]. In 2016, China's total serviceable electric bike fleet totalled approximately 250 million[51]. Market projections indicate that global electric bike sales could reach 40 million in 2025, and about 50 million in 2035[52].

Box 8: Substitution Matters

For cities to compete in the global economy, emerging transportation systems require a mix of competitive modes and technologies to support sustainable transportation systems that meet diverse travel needs. Electric two- and three-wheelers could be part of that solution as they meet door-to-door and short trip travel needs that are not well-suited for fixed route transit systems. They are the appropriate technology for such trips. They can also complement cars and other modes for ex-urban travel, as well as longer trips more generally.

In the study cited here, one in four electric two-wheeler riders in Kunming responded that they would use a car-based transport mode if they didn't have an electric two-wheeler. This is significant as nearly half of the electric two-wheeler users stated that they have a car at home. Moreover, 15-20% of electric two-wheeler owners plan to buy a first or second car within one year. Most electric two-wheeler rider fatalities are caused by cars. With adequate dedicated and protected two-wheeler infrastructure, speed management, and complementary mode development, electric two-wheelers can be safely integrated into the wider transportation system, while providing excellent environmental performance and high personal mobility standards. However, policy must support a portfolio of sustainable modes to assure that electric two-wheelers complement, rather than compete with, transit and other mobility objectives.

The transformation of China's two-wheeler fleet was part of by the government's efforts to restrict motorcycle ownership, which is rising significantly due to rapid urbanization and economic growth. But switching to electric two-wheelers is not as simple a decision as it appears to be at first glance. A diverse range of electric two-wheelers is currently offered on the Chinese market and these products vary greatly in terms of their environmental performance, speed, and design. There is also an issue of conflict of goals: while electric two-wheelers can help reduce urban noise pollution, they are even more accident prone than motorised two-wheelers.

In Taiwan, the cumulative number of electric motorcycles has increased by more than 4 times within 4 years[53]. Following the success of Taipei's "YouBike bike-sharing program", the electric scooter sharing program "WeMo Scooters" was launched in 2015. By 2017, the system had expanded to a total of 1.000 electric two-wheelers; it is further expected to reach 3.000 electric motorcycles by the end of 2018. The company currently charges about US 0.8$ per minute for the first 10 minutes, and then about US 0.08$ for every minute after that[54]. As the scooters are equipped with a battery swapping technology (switching discharged battery packs for charged ones), charging times are reduced while increasing the trip catchment area. The mobile App for electric motorcycle sharing services integrates vehicle locating, unlocking, battery charging, payment, and other functions.

Environmental performance evaluations of electric two-wheelers indicate that they would be more efficient at reducing carbon emissions and air pollutants provided that they attract riders reliant on motorised transport modes. In other words, the benefits of electric two-wheelers depend on the type of trips they replace (mode shift). Similar to bus-based public transits, electric two-wheelers offer considerable environmental improvements compared to passenger cars. However, since power generation emissions occur more commonly at low-density population locations, health benefits are often of larger magnitude. If pedestrians and cyclists shift to electric two-wheelers, there is a net negative impact on the environment.

Research on shifts in transport mode behaviour shows a diverse range of shifts pointing to other relevant factors on usage of two-and-three-wheelers. For example,

- In Kunming, a 6-year long study on the use of electric two-wheelers found that such devices act as intermediate transport mode[55], occluding in between the transition from bicycle to bus and from bus to car. The study found that electric bikes attracted 55% to 65% of prospective bus riders, between 15% and 24% car and taxi riders, and between 7% and 19% of regular bicycle riders.
- In Jinan[56], electric two-wheelers replace bus rides (49%), previously owned bicycles or electric two-wheelers (36%), walking (7%), car trips (7%). In 1% of the cases, they enable trips that would otherwise not have been made.
- In Shijiazhuang[57], just one-third of electric two-wheeler riders were former bus riders while more than 60% of respondents had shifted from previous bicycle use.

Figure 16 *Shared electric two-wheelers*
Source: *wemoscooter.com.tw*

One of the most critical parameters to be analysed when considering the environmental impact of electric two-wheelers is toxic lead pollution during the production, recycling, and disposal of lead-acid batteries. However, this problem could be mitigated by Lithium-ion batteries (which are common in EU, Japan, and the US), effective battery production, and recycling practices.

In the light of the above discussion, we recommend

- To set ambitious electric two-wheeler penetration targets and include a subsidy scheme for greater penetration of electric two-wheelers (to prevent market failures)
- To internalize external costs ensuring pricewise competitiveness between electric two-wheelers and internal-combustion engine two-wheelers.
- Electric two-wheelers to be regulated to maximise safety. This can be ensured by regulations demanding speed governors to be set to locally agreed safe speeds
- The implementation of stringent battery production and recycling standards
- The regulation of conventional two-wheeler parking while granting free parking slots for electric two-wheelers
- providing greater access/circulation of electric two-wheelers that use pedal assistance instead of throttle power
- increasing the share of renewables in the electricity mix and substituting lithium-ion batteries for lead-acid batteries
- The promotion of electric scooter sharing schemes and integrating them with existing public transport schemes.

c. Two-and-Three-Wheeler Lanes

Dedicated lanes are built with the aim of segregating two-and-three-wheelers from mixed traffic, thereby reducing the risk of accidents while improving the capacity and level of service. Such lanes are often introduced along with space for two-stage left turn waiting zones, motorcycle waiting zones, and lane markings. Research has shown that a dedicated motorcycle lane on the roadway halves the risk of motorcyclist crashes; a segregated lane without a barrier reduces the same risk down to one-tenth of that of dedicated motorcycle lanes[58]. Dedicated two-wheeler lanes should ideally be located between mixed traffic curbs and car lanes to avoid right turn conflicts as well as clashes with stopped vehicles, pedestrians, and cyclists in the curb lane.

Cities and countries that experimented with dedicated lanes for two-and-three-wheelers have thus far made varied results. Dedicated lanes are very common in Thailand, Malaysia and Taiwan. For example:

- The Road Layout Design (RLD) blueprint for Iskandar (Malaysia) proposes motorcycle lanes between 1.3m and 2.6m[59] depending on single or bi-directional flow.
- Taiwan experimented with motorcycle waiting/stop zones on roads with speed limits below 60 kmph. Motorcyclists are allowed to stop in this area when the traffic lights are red and may pass when the lights are green. Motorcycle waiting zones are generally designed with a minimum width of 0.8 and length of 2.3 meters in turns. Additionally, Taiwan established a two-stage left turn rule. Motorcycles are not allowed to make direct left turns. They instead use dedicated double left turns at major intersections. Left-turning motorbikes need to travel straight across an intersection to a painted motorcycle box and wait for the next traffic signal to turn green. Additionally, two-wheelers have a specific waiting zone in front of cars due to their faster acceleration speeds when fully stopped.
- Some Indian cities (e.g. Bangalore and Mumbai) tried establishing separate lanes for three-wheelers. In 2002, Bangalore began enforcing lane divisions for motorised three-wheelers in arterial roads to ensure that these would no longer obstruct other modes of transport. This lane separation was realized with physical barricades. Ultimately, these experiments were not successful as three-wheelers opposed the dedicated lanes due to a lack in overtaking width.

Figure 17 *Three-wheelers in Mumbai, India*

Figure 18 *Motorcycle Parking in Taiwan*

Based on our literature evaluation, we recommend

- Establishing an efficient lane width with a range between 1.7m and 3.8m
- Avoiding separate lane demarcations for roads where motorcycles and three-wheelers constitute over 50% of the vehicle modal split
- segregated motorcycle lanes to be established on roads frequented by more than 1.000 motorcycles per hour and if motorcycles represent between 10% and 50% of traffic on such roads
- Avoiding segregated three-wheeler lanes as they do not provide any benefits
- Roads with an intended operational speed of 40 kmph or less to be redesigned for safe integration of traffic at slow speeds rather than segregating traffic into separate lanes
- for traffic congested roads (where average speeds are lower than 15 kmph) that meet the following additional conditions:
  - bicycle volumes below 1000 bicycles per hour
  - dedicated two or three-wheeler lanes are absent

to create some form of barriers to prevent motorcycles from encroaching into the bicycle lanes

d. Retrofit Programs

Generally, available technological solutions to reduce tailpipe emissions can be categorised into two broad categories: enforcing standards for new vehicles entering the fleet, and retrofitting/scrapping of existing vehicles. In many countries, old two-and-three-wheelers emit a disproportionate share of transport emissions. For example, in Singapore motorcycles registered before July 1, 2003, contributed to about 40 per cent of carbon monoxide emissions from motorcycles while making up only 21 per cent of Singapore's motorcycle population[60]. Because of this problem, many countries have implemented age-based or emission-based regulations to keep old and pollution intensive vehicles off the road. However, countries find it difficult to impose such regulations due to stakeholder resistance. Over the last decade, there have been numerous experiments involving retrofitting polluting vehicles, leading to limited success. Consider for example, New Delhi's retrofitting program. In 1998, the Supreme Court of India ordered the replacement of all pre-1990 three-wheelers and taxis with new, clean fuel propelled vehicles by March 31, 2000. It further included financial incentives to replace post-1990 three-wheelers and taxis with cleaner vehicles. Due to this judicial intervention, all taxis and auto-rickshaws in Delhi had been retrofitted to run on compressed natural gas (CNG) by 2003.

Comparison with a two-stroke tricycle	Retrofit			
	Direct Injection 2-stroke	Repowering 4-stroke	LPG Direct Injection 2-stroke	LPG Repowering 4-stroke
Energy Consumption (km/l)	55%	28%	17%	13%
HC (g/km)	-90%	-92%	-97%	-100%
CO (g/km)	-88%	10%	-70%	-68%
CO2 (g/km)	38%	32%	22%	28%
NOx (g/km)	98%	221%	190%	684%
PM (g/km)	-97%	-96%	-99%	-99%
SOx (g/km)	-35%	-22%	-100%	-100%
Methane (g/km)	7%	-6%	-76%	-96%
N2O (g/km)	34%	31%	22%	25%

Table 3 *Impact of Different Retrofit Options in the Philippines Philippines (compared with two-stroke tricycles)* (Source: Manny Biona)

Technologies available to retrofit old two-stroke three-wheelers include direct in-cylinder fuel injection, liquefied petroleum gas (LPG) direct injection, four stroke re-powering technology, and LPG four stroke re-Powering technology. However, such technologies have limited impact. For example:

1. A detailed evaluation carried out in the Philippines[61] indicated that the adoption of four-stroke and direct injection two-stroke systems provides significant environmental benefits relative to carburetted two-stroke units. These benefits can further be enhanced by conversion of these technologies to LPG fuel. However, the environmental considerations are not by themselves enough to ensure sustained adoption of these technologies. But since the operational savings of all retrofit technologies are sufficiently high enough their acquisition at approximately 3% per month lending rates is justified. These options provide payback periods shorter than 2 years. LPG direct injection retrofitting has proven to bring the highest financial benefits.
2. In Delhi, the air pollution benefits of replacing 50.000 four-stroke gasoline three-wheelers with CNG are equivalent to replacing 5.000 2-stroke three-wheelers with CNG four-stroke vehicles[62].

It is now well established that retrofitting pollution-intense two-stroke three-wheelers with financial incentives only exerts a limited, short-term impact. The best strategy is to ensure the implementation of age-based and/or emission-based regulations to prevent old, pollution intensive vehicles from operating.

e. Vehicle Emission Standards

Two-and-three-wheeler emissions are now regulated in many countries, but there is a very high diversity in the stringency and typology among current regulations between countries. In general, smaller two-wheelers are subject to more stringent standards, while heavier ones, especially three-wheelers, enjoy more relaxed standards. During the past two decades, the development of progressive standards has led to the near complete replacement of two-stroke with four-stroke engines. Most two-wheelers sold now feature four-stroke engines with a recent trend towards fuel-injected, four-stroke varieties. However, two-strokes equipped with catalytic converters are still being sold. These consist of smaller vehicles such as mopeds and scooters. Progressive emission standards force automobile and oil industries to seek the lowest-cost solution to comply with standards, thus enabling technology innovation and fleet transformation. A step-by-step implementation enables long-term transformation with economies of scale.

Currently, there are standards imposing limits for CO, HC, and NOx emissions. In some countries, a single HC+NOx standard regulates both HC and NOx emissions to combat ozone layer depletion[63]. Composite standards allow manufacturers to flexibly increase NOx emissions while adhering to other standards. They also incentivize improved evaporative emission control and generate higher co-benefits in fuel efficiency. However, except for PM standards for compression-ignition motorcycles in India and Europe, there are no motorcycle PM standards, even though two-stroke PM emissions can be very high[64]. In a few regions, PM emissions caused by three-wheelers are additionally regulated.

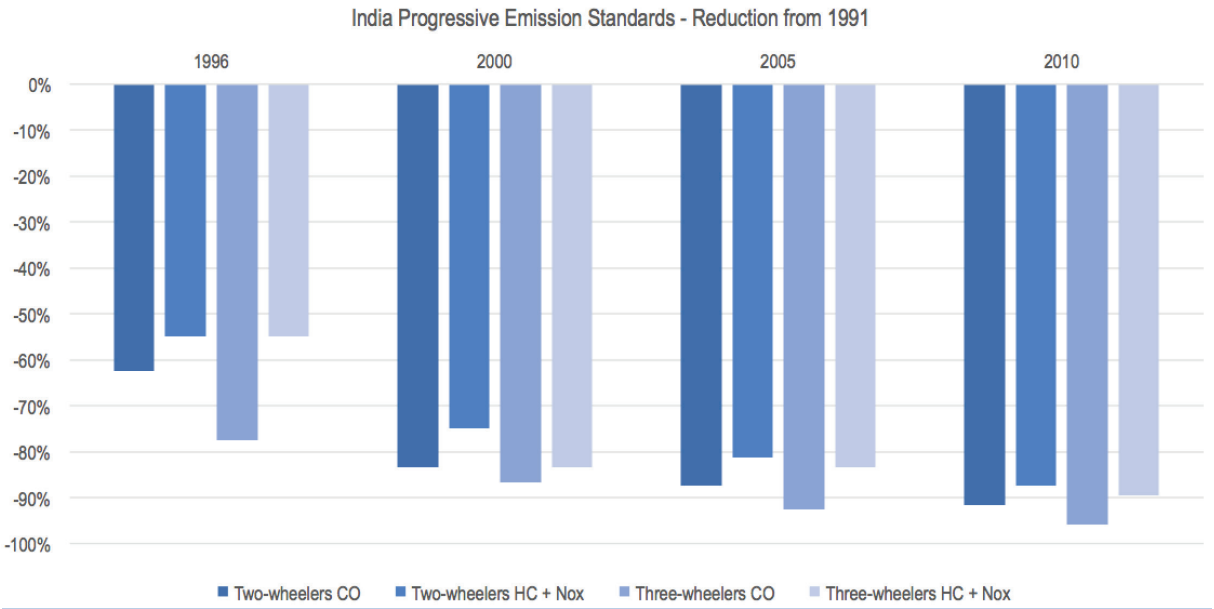


Figure 19 *India Two-and-Three-Wheeler Emission Standards* Source: Central Pollution Controlling Board – India

In 2016, India issued a draft notification of Euro-6 equivalent standards to be enforced starting 2020. This proposed standard aligns emission limits for two-wheeled vehicles with the most stringent standards adopted for similar vehicle types in Europe. It also ensures that these vehicles will not exceed pollution standards of equivalent four-wheeled passenger vehicles[65]. Vietnam further aims to skip standards equivalent to Euro 4 and implement Type 5 (Euro 5) standards instead beginning 2022[66].

Many countries have now started incorporating durability requirements for motorcycle emissions as part of their transport regulations. Regulatory programs in China, India, Japan, Taiwan and Thailand include durability requirements ranging between 6.000 and 30.000 km depending on the size of motorcycles[67].

Research carried out in Vietnam[68] indicates that countries need to implement more stringent standards to generate higher co-benefits. Had Vietnam implemented Euro 3 standards by 2008, its fleet emissions would have been reduced by between 50% and 90%. This would have brought very high co-benefits. Implementing more stringent standards is cost-effective, as experience from India shows. Stringent emission standards will likely increase two-and-three-wheeler vehicle prices by no more than 30 to 40 USD[69]. This is equivalent to less than 5% of the total cost of a typical vehicle.

While regulatory frameworks have seen progressive strengthening, their enforcement often remains weak. Since standards for two-and-three-wheelers are not maintained in the form of manufacturer recommendations, implementation of in-use emission control with inspection and maintenance (I/M) remains critical. Most countries in South and South East Asia do not have an effective Inspection & Maintenance programme for two and three-wheelers. The most notable exception is Taiwan, which follows a decentralized inspection system operated by a large number of private centers. This system is quite effective because of the strict government monitoring linking private centers to a centralized computer system. In addition, authorities also perform surprise road-side checks.

We recommend the following with regard to vehicle emission standards:

1. Countries can advance directly to more stringent standards, given that they adequately consider the social costs of air pollution and the speed of technology innovation over the past decade.
2. Countries with serious PM pollution should consider the development of a specific PM standard for two- and three-wheeled vehicles.
3. Countries should strengthen vehicle inspection and maintenance (I/M) programs. This will ensure that vehicles meet manufacturer set durability requirements and that noncompliant vehicles are identified for further necessary action.
4. Countries should develop a national fuel-quality testing program to monitor fuel quality at retail stations.

f. Fuel Economy Standards

Due to their small engines and light-weight frames, two-wheelers have a higher fuel efficiency than passenger cars. This is part of the reason why two-wheelers have thus far been neglected in fuel efficiency improvement agendas in many countries. Even international partnerships such as the Global Fuel Economy Initiative (a partnership between the International Energy Agency (IEA), United Nations Environment Programme (UNEP), International Transport Forum of the OECD (ITF), International Council on Clean Transportation (ICCT), Institute for Transportation Studies at UC Davis, and the FIA Foundation) have only prioritised fuel economy improvement in LDV's so far. However, two-wheeler constitute a significant portion of the total vehicle fleet in middle and low-income countries (50% to 90%). They are also growing very fast. Some estimates suggest that in India, 90% of the two-wheeler fleet will be replaced during the next 10 years[70].

In many countries, including India, Indonesia and Thailand, there has been a major change in the market structure of two-wheelers marked by increasing sales of more powerful two-wheelers *(Figure 20)*. For example, in Japan[71], serviceable two-wheelers with engine sizes less than 125 cc saw a decrease in their share from 85% in 1990 to 69% in 2015. Based on the available data, fuel efficiency is progressively decreasing as engine displacement and kerb weights increase *(Figure 22)*.

Globally, only Taiwan and China have implemented fuel economy standards, while countries like Vietnam and Thailand have made significant progress in establishing the targets. For example, Taiwan has had fuel economy standards in place since 1987; China adopted such standards in 2008. Recently, China introduced new fuel economy targets to be implemented in 2018. These targets set separate standards for two-wheeled motorcycles with manual and automatic transmissions. The implementation of fuel economy standards for two-wheeled motorcycles in China is expected to reduce fuel consumption by 447 million litres annually, generating an estimated economic benefit of approximately 391 million USD[72]. Countries can also implement fiscal policies like the "feebate" system based on the "polluter pays" principle. In such schemes, higher taxes are imposed on more polluting vehicle models and the revenue collected is utilised to subsidise cleaner technologies and fund transport emission mitigation activities. In India, there are some policy discussions on initiating a feebate systems which includes two-and-three-wheelers[73].

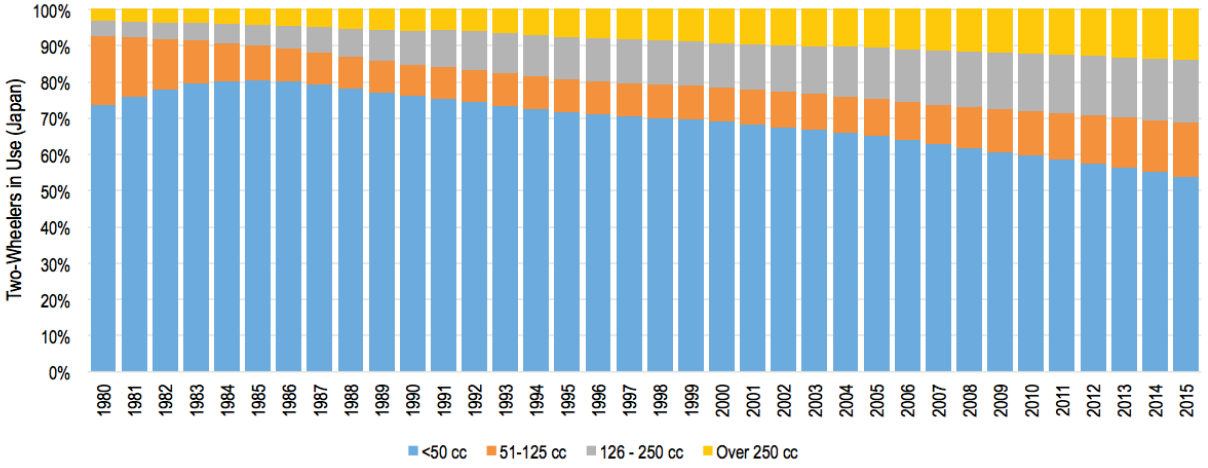


Figure 20 *Two-Wheelers in Use in Japan (move towards more powerful motorcycles)* Source: JAMA

Looking at the examples raised above, it is very clear that there is now a very high demand for more powerful two-wheelers. However, it is now well established that the fuel efficiency of two-and-three-wheelers decreases as engine capacity and kerb weight grow. Further experience suggests that the design and technology of two-and-three-wheelers plays a significant role in improving fuel efficiency in varying models of the same engine capacity and weight. It is also now well known that advanced emission control technologies may have some negative impact on the fuel efficiency. Thus, we recommend that the countries set progressive fuel efficiency standards for two-and-three-wheelers. These need to be established simultaneously with vehicle emission standards to ensure high benefits.

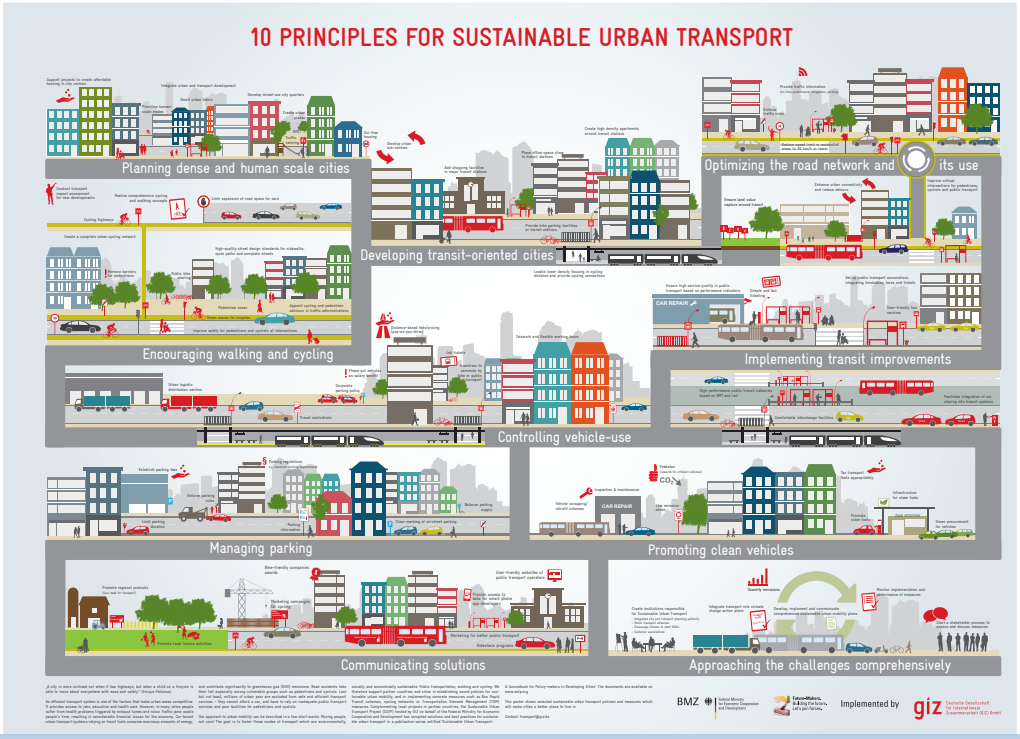


Figure 21 *10 Principles for Sustainable Urban Transport* Source: sutp.org

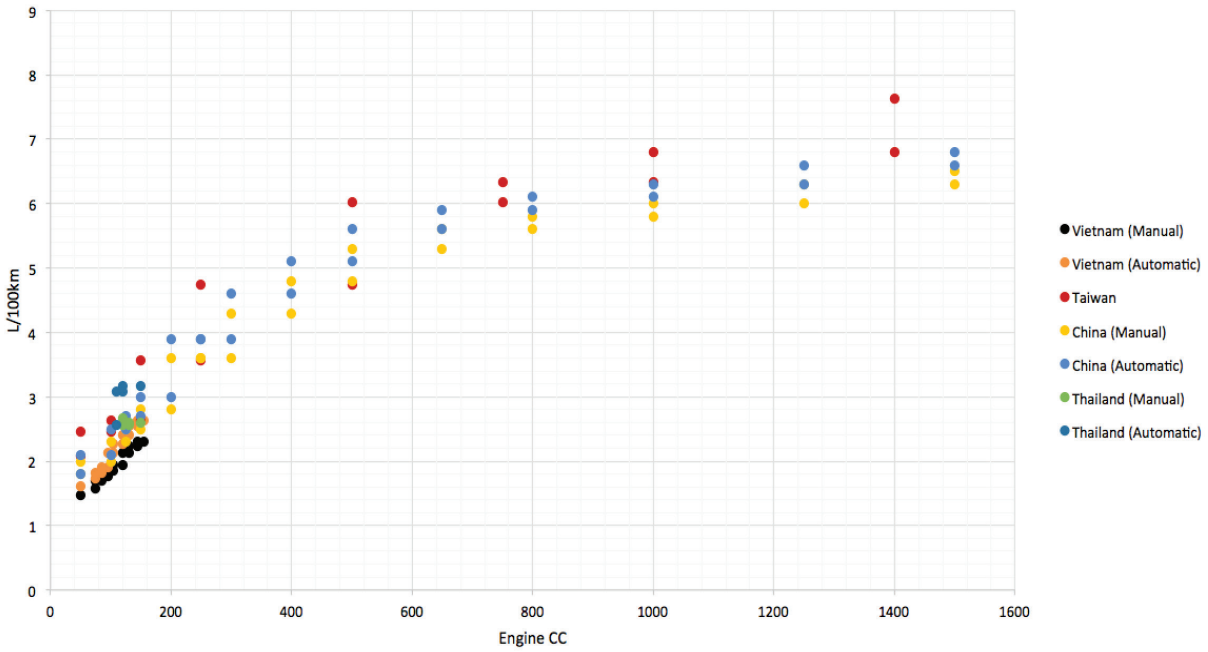


Figure 22 *Fuel Economy Standards for Two-Wheelers (Note: fuel economy values are not directly comparable as testing methods differ)* Source: International Council on Clean Transport (ICCT), GIZ, Ministry of Transport, Vietnam

Figure 23 *Hanoi, Vietnam*

VI. Two-and-Three-wheelers in 2050

Two-and-three-wheelers are likely to continue to play a decisive role in urban mobility. If we were to make a prediction based on historical experiences, we would estimate that there will be 1.5 billion motorised two-and-three-wheelers by 2050 worldwide. This would be considered an incremental development scenario for two-and-three-wheeler mobility services. However, such a prediction may be deceptive as it fails to consider hitherto non-existent challenges and opportunities for other industries. Cities now face enormous challenges, including economic development, climate change, environmental pollution, traffic congestion, and social development. Hence, cities will need to prepare policies and urban infrastructure accordingly, in order to successfully incorporate this mode of transport into sustainable urban mobility concepts.

With more than half a billion two-and-three-wheelers currently serviceable, two-and-three wheelers have now become the victims of their own success. Many cities are beginning to consider them as a non-essential commodity. Given this dynamic and changing environment, the need for appropriate regulation is highlighted.

Technological evolution may also hold one part of the answer. While technological progression in urban transport has been slow, we may be very close to a technological tipping point. It seems plausible for two-wheelers to become key facilitators of long-lasting structural and systematic changes towards shared mobility services, electrification, and autonomous driving. The broad contours of such developments are already visible as technological advancement are shaped within existing regulatory frameworks by companies such as Uber, Gogoro, SmartScooter, SafeBoda, Go-Jek, Grab and Ola. It is likely that three-wheelers may cease to operate as other shared modes out-compete them in terms of service.

Though radical transformation of urban mobility requires lengthy time scales, we are certain that in 2050, mobility will look dramatically different from today.

Our expectation for the future mobility of two-wheelers may be summarized in four words: more electric, more sharing.

Figure 24 *Taipei City, Taiwan*

SUTP.
Sustainable Urban Transport Project

SUTP – Sustainable Urban Transport Project — SUTP supports decision-makers worldwide to plan and to implement innovative and sustainable mobility solutions. SUTP offers a comprehensive knowledge platform, capacity development, hands-on advice and networking opportunities. Within the past 16 years, more than 5 000 decision-makers, planners and students have benefited from our training offers. We've produced a rich library of Sourcebook Modules, Technical Documents, Case Studies, Factsheets, Policy Briefs and Reading Lists. All documents are accessible through our webpage, along with a comprehensive photo collection and a video channel. Be invited to use and distribute them!
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