EMBARQ
The WRI Center for Sustainable Transport

WORLD RESOURCES INSTITUTE

MEASURING THE INVISIBLE

QUANTIFYING EMISSIONS REDUCTIONS FROM TRANSPORT SOLUTIONS

Hanoi Case Study

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EXECUTIVE SUMMARY

The primary goal of *EMBARQ*'s study in Hanoi was to test a methodology for estimating local and global emissions from a series of transport activity scenarios and alternative-vehicle emissions standards prepared for the city of Hanoi. *EMBARQ* worked with local partners from AVL Ltd., the Hanoi University of Technology, and consultants from CONTRANS AB to collect transport activity data, develop emission factors, and assign emission values to past, present, and future emission scenarios. These scenarios were then presented to Vietnamese officials to help them make informed decisions among the various policy choices.

This case study analyzes the emission impacts of two alternative transport policies previously outlined in the Hanoi Integrated Development and Environment Program (HAIDEP) Master Plan. One policy emphasizes improving public transport, while the other is a business-as-usual scenario with higher automobile growth (ALMEC, 2007). These mutually exclusive policies were thought to represent the most probable future scenarios for the city's transport system. Most background data used for emission calculations came from the HAIDEP Master Plan, although some modifications and extrapolations were made based on proxy data from Europe or Turkey. The study includes a series of assumptions about changes in demand and supply of transport services and about policies for investment and vehicle emission standards that have been deemed reasonable by various experts.

Our results showed that if government officials decide to promote public transportation to a higher degree and to mandate stricter fuel quality and vehicle emission standards, it will be possible to stabilize emissions in 2020 at 2005 levels, while still ensuring the same level of mobility to Hanoi residents. However, without measures to restrain the growth in overall vehicle traffic, particularly that of individual vehicles, fuel use and emissions will grow significantly. A continued shift from two-wheelers to cars will mean an enormous increase in fuel use, even if the cars are very efficient. Such a shift is expected to cause enormous congestion problems because of the lack of space in much of the city of Hanoi. Conversely, measures to restrain individual vehicle use in favor of mass transit or non-motorized transport will result in lower emissions and fuel use. Emissions will also be higher in 2020 than today, unless very stringent vehicle emission standards, such as Euro 4, are imposed within several years so as to affect virtually every vehicle on the road by 2020. The sooner emission mitigation measures are implemented, the lower future emission will be.

The team preparing this study presented the results to the city and national authorities in workshops in December 2006 and March 2007. These results caught the attention of city and national government authorities and technical experts because they illustrated the impact of future growth and highlight, above all, the impact of decisions that Hanoi government authorities can make today. Topics of debate among government officials and local experts included the ranking of the severity of the problems and prioritizing the policy measures. In addition to stimulating a public health debate, the Vietnamese parties involved acquired a new appreciation of the value of calculating local emissions and fuel consumption of different kinds of vehicles, as well as the importance of understanding actual traffic patterns and coordinating actions among the various government dependencies. Finally, the local and national experts involved in the project agreed on the need for an observational body dedicated to transport and environment. This is a promising development and reflects the changing attitude toward urban transport planning and long-term environmental and social sustainability. Although Hanoi's future is not yet clear of pollution, it seems to be a little brighter than yesterday.

The present study recommends that further work be done to measure vehicle ownership, activity, fuel use, and emission factors. Such data generation would enable experts and government authorities to achieve a higher level of certainty when comparing the impact of alternative future transport and emission control policies.

1

INTRODUCTION AND BACKGROUND

Since 2005, *EMBARQ* has been developing, testing, and disseminating widely applicable and reliable methodologies for estimating greenhouse gas (GHG) and criteria pollutant emission changes resulting from public transport management projects. The methodologies are intended to give decision-makers an appreciation of the environmental implications of the available transport and emission standard policy options.

As part of this effort, *EMBARQ* selected Hanoi, Vietnam, to apply the methods developed. Hanoi shares characteristics with many other Asian cities with respect to transport modal shares (particularly of two-wheelers), urban growth trends, and economic development. The results of this application can be used in other cities in the region that face urban transportation and air quality challenges. Since many city transport and development plans tend to neglect fuel consumption and emissions management in their scenarios, this project aims to provide this missing link and information.

Furthermore, Hanoi has several pending urban transport projects that offer opportunities for application of the methods, such as programs to improve the maintenance of two-wheelers and the implementation of bus rapid transit or light-rail projects. It is expected that the results of this study will support the work of other bilateral and multilateral agencies working in Hanoi and the Asian region.

Finally, *EMBARQ* has well-established relationships with city officials, academia, and other local stakeholders from previous partnerships with Hanoi, which facilitate data collection and the assimilation of the project results (Schipper et al., 2006).

EMBARQ worked with CONTRANS AB, a Swedish consulting firm; and the Hanoi University of Technology to study the historic and current emission levels from the

PHOTO CREDIT: LEE SCHIPPER

transport sector in Hanoi. They then developed emission forecasts for two future transport scenarios that could result from the implementation of the Hanoi Integrated Development and Environment Program (HAIDEP) Master Plan. HAIDEP is a city plan created by a consultant team from the ALMEC Corporation, a Japanese consulting firm, with the support of the Japan International Cooperation Agency (JICA). Released in 2007, HAIDEP described two possible transport scenarios in 2020 resulting from alternative policies: a Business as Usual scenario and a High Mass Transit scenario. EMBARQ's case study uses these scenarios as the basis for its forecasts.

The present report gives an overview of the city of Hanoi (Chapter 2), describes the methodology used in the Hanoi case study (Chapter 3), explains the data collection and assumptions (Chapter 4), presents the study results (Chapter 5), discusses the study limitations (Chapter 6), and provides the conclusions and recommendations for the city of Hanoi (Chapter 7).

The HAIDEP study was developed by ALMEC for the government of Hanoi. It is an analysis of many of the challenges facing Hanoi, such as water, waste, flooding, and housing. As such, the study offers an interesting perspective on overall growth alternatives for Hanoi, which can be compared to an earlier one completed in 1995 for the same Japanese sponsors. Part of the study is devoted to alternative traffic scenarios for 2020, two of which we have adopted and designated as Business as Usual and High Mass Transit. Our work on emissions is based on these alternative scenarios.

The Business as Usual scenario assumes that 14.5% of the trips in 2020 will be by public transportation, corresponding to an increase of 7.8 points from its 6.7% share in 2005. This represents a more than doubling of current mass transit use without any extra emphasis on public transportation, but is deemed to be reasonable because bus ridership has been rising dramatically over the last several years, as will be seen below.

The High Mass Transit scenario assumes that 30% of the trips will be by public transportation. This assumes a large-scale government initiative to boost the ridership and capacity of the city's public transportation far beyond that projected in the Business as Usual scenario.

The HAIDEP study did not analyze or estimate the impact of these two scenarios on emissions, nor did it consider the implementation of air quality management measures, such as the introduction of higher emission standards. The present study complements the first by filling that gap and supplying policymakers a more complete picture of the linkages between transport, the environment, and public health in Hanoi.

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2

HANOI AND ITS DEVELOPMENT

DEFINING HANOI

The term "Hanoi" can be ambiguous, because it refers to both the city of Hanoi and its surrounding administrative province. Sometimes data from different reports and studies can be confusing and incompatible because definitions have differed. Therefore, this study distinguishes between these two regions and specifies the precise geographic extent of the study.

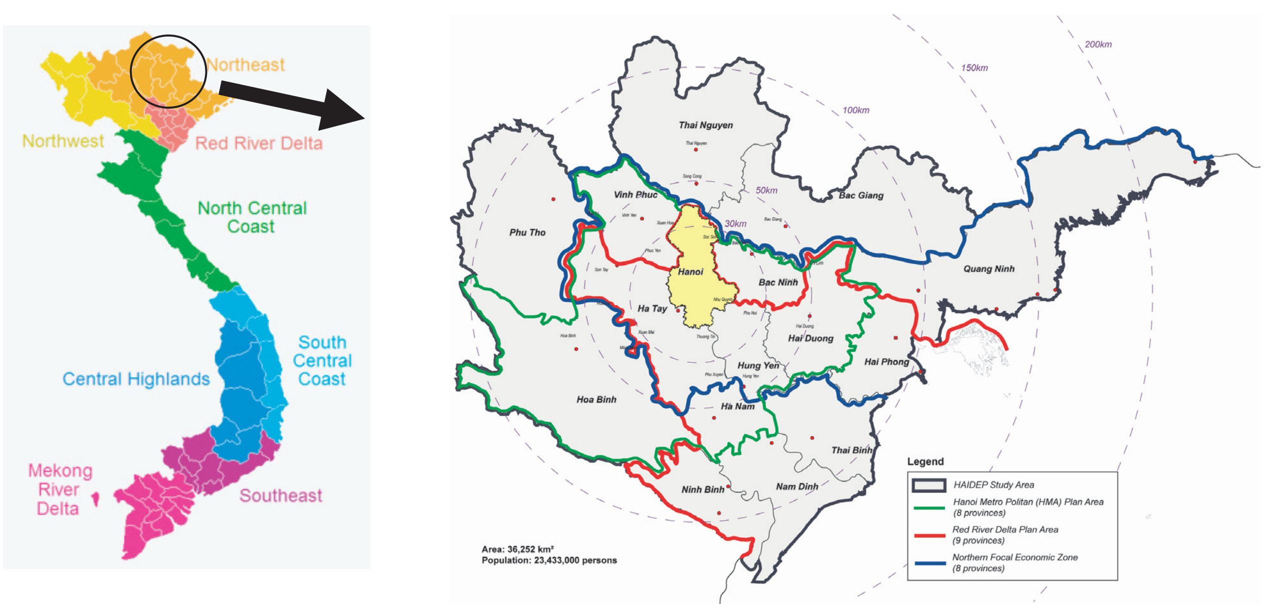
Hanoi region

The region of Hanoi is located in the center of North Vietnam in the Red River Delta, the most densely populated region in Vietnam (Figure 1). It comprises 16 administrative provinces with an area of 36 000 square kilometers (km^2) and a total population of some 23 million people.

Hanoi City

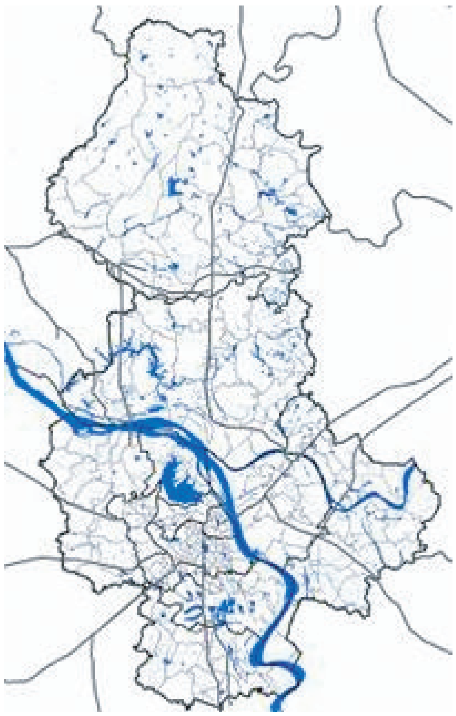
Hanoi City, the capital of Vietnam, lies in the center of the Hanoi region on the bank of the Red River (Figure 2). Hanoi City is an administrative area consisting of four urban core districts (Ba Dinh, Hoan Kiem, Hai Ba Trung, and Dong Da) and multiple outlying districts. Originally numbering five, these outlying districts were redrawn between 1995 and 2005 due to rapid demographic growth. The outlying districts now consist of five urban fringe districts (Tay Ho, Long Bien, Cau Giay, Hoang Mai, and Thanh Xuan), and five suburban/rural districts (Tu Liem, Thanh Tri, Soc Son, Dong Anh, and Gia Lam).

FIGURE 1 | **HANOI REGION**



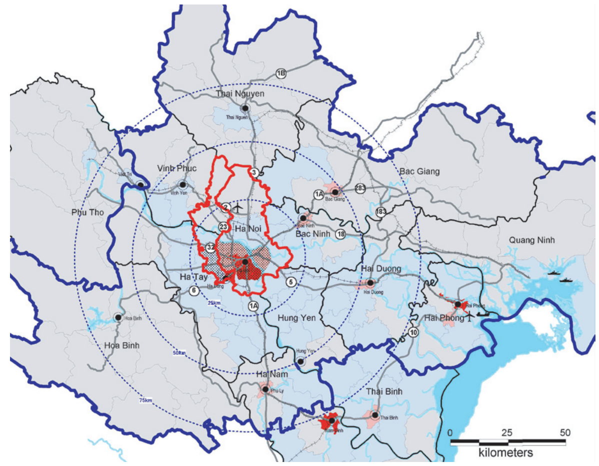
Source: ALMEC, 2007.

FIGURE 2 | **HANOI CITY**



Source: ALMEC, 2007.

FIGURE 3 | **HAIDEP STUDY AREA**



Source: ALMEC, 2007.

The HAIDEP study area: Greater Hanoi

The HAIDEP project defined a study area as depicted in Figure 3, covering Hanoi City, Hai Phong City, and the northern Red River Delta provinces of Ha Tay, Vinh Phuc, Bac Ninh, Hai Duong, Hung Yen, Ha Nam, Quang Ninh, Hoa Binh, Bac Giang, Thai Nguyen, Nam Dinh, Thai Binh, Ninh Binh, and Phu Tho. This study area is the basis for forecasts of future traffic volumes.

Hanoi City itself has a total population of 3,183,000 people (2003) (Figure 4). The population growth of the individual districts is shown in Table 1. The study area population in 2005 was 3,718,000 inhabitants, 14% higher than in Hanoi City itself. Since population estimates often vary even among official national or local sources, for this case study we adopt the data provided by the HAIDEP study for consistency.

TABLE 1 **POPULATION DISTRIBUTION**

		POPULATION (1,000)		
DISTRICT	**Area (km2)**	**1995**	**2000**	**2005**
Ba Dinh	9	219	206	231
Hoan Kiem	5	179	172	179
Hai Ba Trung	10	323	362	312
Dong Da	10	361	342	372
Urban core	34	1,082	1,082	1,094
Tay Ho	24	—	94	108
Thang Xuan	9	—	161	196
Cau Giay	12	—	139	171
Hoang Mai	40	—	—	236
Long Bien	60	—	—	186
Urban fringe	145		394	896
Tu Liem	75	279	199	262
Thanh Tri	63	206	228	165
Suburban	138	485	427	427
Soc Son	307	227	247	266
Dong Anh	182	240	262	288
Gia Lam	115	301	345	212
Rural	604	768	854	766
Total	**921**	**2,335**	**2,756**	**3,183**

Source: Hanoi Statistical Yearbook, 2006

DEMOGRAPHICS

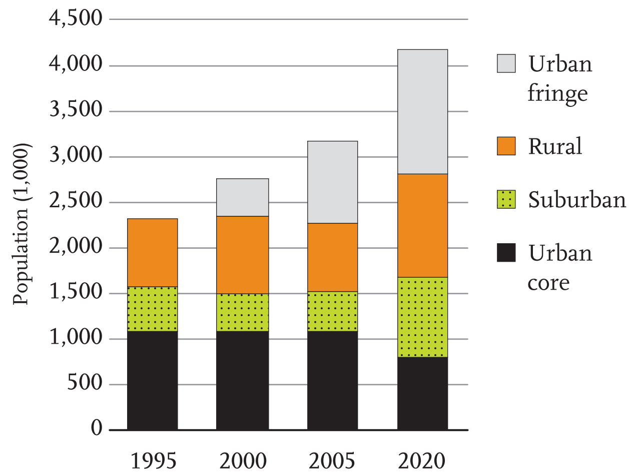
Population growth

Like many other cities, Hanoi is experiencing considerable growth due to migration as well as natural increase. In the period 1995–2005, population growth in Hanoi City occurred predominantly in the urban fringe districts, while the urban core population stayed stable at about one million (Figure 4). (HAIDEP 2007)

In the future it is expected that the urban core population will actually decrease, while the growth rate of the suburban and urban fringe population will accelerate.

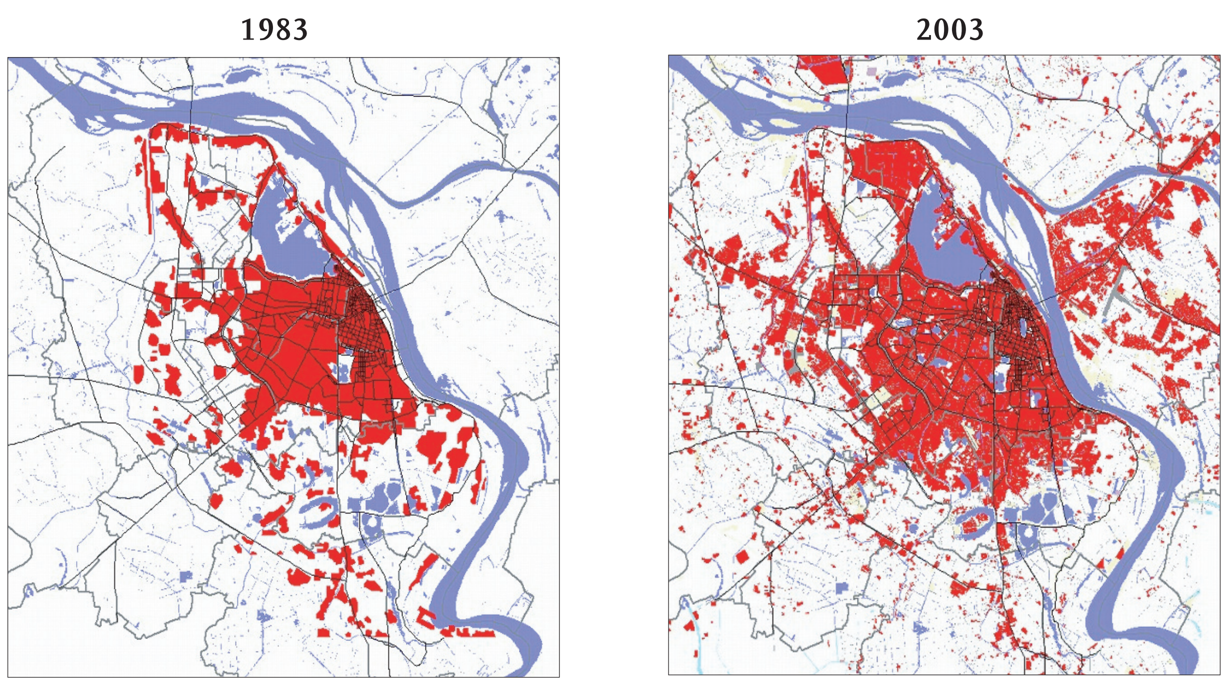
Current forecasts indicate that the Hanoi City population will reach 4.2 million inhabitants by 2020, which is somewhat higher than previous official estimates (Figure 5). The population forecast for the HAIDEP study area predicts that it will reach 5.5 million inhabitants in 2020, and will thus be about 28% higher than the Hanoi City population. Since transportation patterns for Hanoi extend beyond the boundaries of the city itself, this wider area and larger population must be included in our work.

FIGURE 5 | **POPULATION GROWTH IN HANOI**



Sources: Hanoi Statistical Yearbook 1995 and 2005; HAIDEP 2020

FIGURE 4 | **EXPANSION OF URBANIZED AREAS IN 1983 AND 2003**



Source: HAIDEP, 2007.

Population density

The distinguishing characteristic of Hanoi is the compactness of its urban area and high population density. The four urban core districts are only 35 km^2, but have a population of over one million, which yields a gross population density of around 300 people/hectare (ha). In dedicated residential areas, the density increases to over 600 people/ha.

In the urban fringe, the total population density is a more moderate 57 people/ha, but again this masks the uneven population distribution. If only residential areas are considered, the density is over 200 people/ha. A similar pattern is also seen in suburban areas.

In mature, previously developed areas, such as the Hoan Kiem and Hai Ba Trung districts, the average per capita green space is relatively high. But in newer, rapidly urbanizing districts, such as Dong Da and Gia Lam, the average per capita green space is only 0.05 square meters (m^2), much lower than in many other countries. One reason for this imbalance is that extremely rapid demographic growth prevents city authorities from properly controlling urban and residential development. Population is simply outpacing the efforts of city administrators who are no longer able to create the parks and green spaces provided for in the Building Code of Vietnam.

SOCIOECONOMIC CHARACTERISTICS

During the last decade, the Gross Regional Domestic Product (GRDP), as calculated by the National Statistical Agency for Hanoi, has increased by 11% per year, and employment has increased with it. As the country's economy has grown, poverty in the entire Red River Delta where Hanoi is located has decreased from 62.7% in 1993 to 22.4% in 2002 (ALMEC, 2007).

While car ownership is still low, most households now own at least one motorcycle. Some households in the lowest-income group do not own any vehicle. Most electric appliances are still only available for high-income people, the exception being televisions (Hans Orn, private communication, 2007). There are still noticeable disparities in lifestyles between the different economic classes and between the urban and more rural areas of Hanoi City.

Hanoi's total housing floor area increased by 35% over four years, reaching 20 million m^2 in 2003, up from 15 million m^2 in 1999. In Hanoi's urban areas alone, the housing floor area was estimated at 11.7 million m^2, a remarkable increase of nearly 60% from 7.5 million m^2. Illegal development activities are rampant in the city, although the situation has reportedly improved in the last couple of years. While this housing development is important for future transport patterns, it is difficult to capture in a forecast or set of scenarios, since it is essentially illegal.

ENVIRONMENT

Hanoi's water resources and abundant trees and greenery provide a unique and attractive landscape. Moreover, Hanoi is gifted with a strong, rich culture that maintains traditional values in everyday life in both urban and rural areas. The Ancient City with Hoan Kiem Lake is the cultural heart of the city; it will celebrate its 1,000th anniversary in 2010. A unique characteristic of Hanoi's environment is the blend of natural, cultural, and social elements that enhance the city's image. However, rapid urbanization resulting in rampant, unplanned, and uncontrolled development is threatening this delicate, centuries-old balance.

Vietnam faces the well-known development phenomenon of rapid urbanization associated with industrialization, modernization, and globalization. These powerful forces are changing the socioeconomic profile of the country and affecting its citizens' lifestyles. The high urbanization rate is paralleled by an increase in the unregistered population, both of which create problems for urban management. Industrial and traffic pollution is severe in many areas, with low-lying atmospheric dust concentrations, as well as all forms of pollution from vehicles sometimes exceeding international health standards. Most urban areas have insufficient and ineffective sewage and drainage systems, which contribute to the increasingly serious water pollution in urban areas and industrial zones.

Some spotty information on air pollution, ambient air quality, and other environmental aspects related to transport was reported by the Partnership for Sustainable Urban Transport in Asia, or PSUTA (Schipper et al., 2006). Unfortunately, there is no systematic set of ambient air quality data or an emissions inventory that includes transportation based on measurements of in-use vehicle emissions. Very rough estimates of emissions from the transport sector were carried out for the World Bank in 2005 but not published. More recent ambient air sampling in various regions around Hanoi (including traffic hot spots) affirmed the relatively high levels of particulate matter (PM) concentration and quantified a large difference between the concentrations in the wet (lower) and dry (higher) seasons (SVCAP and CENMA, 2007). While knowledge is advancing, Hanoi has much more work to do.

The estimates provided in this document make an approximate but useful step to couple information about vehicle activity and characteristics (including emission factors) to total emissions of GHGs and criteria pollutants. The work presented here shows how to insert environmental considerations into transport planning efforts. This in turn suggests that future transport planning studies should be expanded to include emissions from motor vehicle activities illustrated from the transport plans.

TABLE 2 **TRANSPORT DEMAND BY MODE IN HANOI CITY AND ADJOINING DISTRICTS**

		NO. OF TRIPS (000/DAY)					SHARE OF TOTAL VEHICLE TRIPS (EXCLUDES WALKING) (%)			
		1995	2005				1995	2005		
	TRAVEL MODE	Hanoi City	Hanoi City	Adjoining Districts	Total	Percent Increase in Hanoi City: 1995–2005**	Hanoi City	Hanoi City	Adjoining Districts	Total
Private	Bicycle	2,257	1,598	486	2,084	–29%	73	24	52	28
	M/C* (driver)	632	3,619	331	3,950	545%	21	55	36	53
	M/C (passenger)		459	41	500			7	4	7
	Car	7	178	6	184	2443%	0	3	1	2
	Truck	21	57	9	66	171%	1	1	1	1
	Subtotal	2,917	5,911	873	6,784	103%	95	90	94	91
Semi-public	Taxi	—	57	2	59	—	—	1	0	1
	Bicycle Rickshaw		3	1	4	—	—	0	0	0
	Moped Taxi(*Xe Om*)		74	6	80	—	—	1	1	1
	Private Bus		95	4	99	—	—	1	0	1
	Subtotal		229	13	242	—	—	3	1	3
Public	Bus	165	382	32	414	132%	5	6	3	6
	Rail	—	0	0	0	—	—	0	0	0
	Subtotal	165	382	32	414	132%	5	6	3	7
Others***		—	23	8	31	—	5	0	1	0
Total (excl. walking)		3,082	6,545	926	7,471	112%	100	100	100	100
Walking Trips		3,141	2,176	688	2,864	-31%	50	25	43	28
Total (incl. walking)		6,223	8,721	1,614	10,335	40%				

Sources: VUTAP, 1995; ALMEC, 2007.
Note: Due to all values being rounded to the nearest integer, some nonzero percentages may appear as 0%.
*M/C designates motorcycle.
**The 1995–2005 percentage increase was calculated using *only* Hanoi City data from 1995 and 2005, because data from adjoining districts were not available for 1995.
% increase = [(Hanoi City 2005 – Hanoi City 1995) / Hanoi City 1995] * 100.
***Other forms of transport—boats, etc.

URBAN TRANSPORT

Motorization rates

Parallel to population growth, vehicle ownership in the Hanoi region has increased sharply. Today, 84% of all households own a motorcycle, and 40% of these have more than two, according to the travel survey carried out for the HAIDEP study. Although car ownership is still low—only 1.6 % of households own a car—this figure has increased rapidly, posing a threat to fluid traffic flow in some locations. While bus services have expanded quickly, public transportation's share in the total urban transportation demand is still only 5%. The once important *cyclo* (bicycle rickshaw) started its decline in the early 1990s with the introduction of taxis and the informal but tolerated *xe om* (motorcycle taxi). Rapid economic growth at a rate of 11% per year is expected to further accelerate ownership and use of private vehicles, such as motorcycles and cars.

Infrastructure

Roads represent only a 1.9% of the total land area in the Hanoi region (ALMEC, 2007), which is low compared to other major cities. Hanoi also lacks ring roads, and highways are not linked into an efficient regional road network. While a number of highways are under construction, the linking among them is still not underway. Railway services only operate on long-distance routes, and have limited efficiency, few infrastructure facilities, and poor connectivity.

River transportation is also limited, despite the high density of rivers and water channels. The region lacks proper intermodal transportation terminals for linking different types of transportation modes. In addition, infrastructure development has not kept pace with increasing demand caused by the fast development and urbanization rate. Many areas have underdeveloped infrastructure, hindering an efficient connection to the rest of the region.

Modal share

People's use of transportation has changed drastically in this decade, from walking and riding bicycles to riding motorcycles (see Table 2), to the point where the motorcycle is now the main transport mode in Hanoi. Similar patterns occur in other Asian cities as well, but Hanoi is exceptional in terms of high motorization and degree of private transportation (Schipper at al. 2006). About two-thirds of work commutes are by motorcycle. On the other hand, more than half of school commutes are by bicycles.

In 1995, more than 70% of all trips were by bicycle in Hanoi City, decreasing to 24% over 10 years. The modal share of motorcycles, including passengers, in 1995, as implied by the data in Table 2, was only 21% in 1995, but jumped to 62% in 2005. Therefore, the fundamental concept of infrastructure development is changing, with new modal patterns requiring new infrastructure functions, particularly safety measures with regard to road development.

Results of an interview survey of 10,000 households in urban and suburban districts implemented by the Transport Development Strategies Institute (TDSI) in 2003 showed that buses make the longest trips on average (Table 3).

Average distances traveled by bus users, motorcyclists, and bicyclists are 10.17 km, 5.84 km, and 3.09 km, respectively. Figure 6 shows the modal share of all trips at different distance intervals.

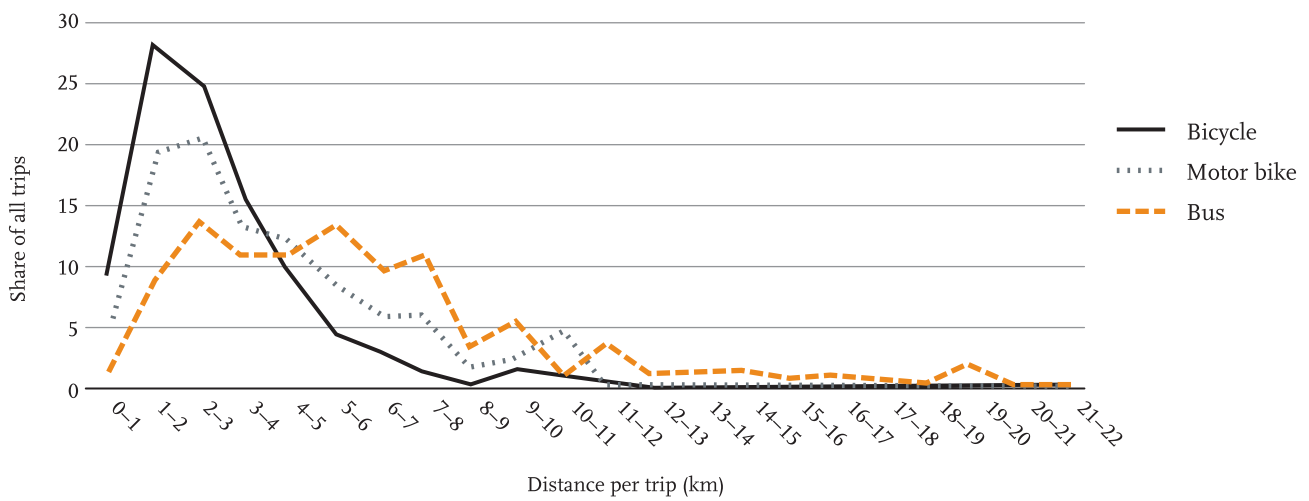
Figure 6 shows that in Hanoi in 2005, bicycles were the preferred mode for short trips (3–4 km), and buses were preferred for longer trips. Actually, the recent revival of the bus in Hanoi (see below) started with students who could not afford motorcycles. Trip distances by bus and motorbike, as reported, range from 1 to 21 km, while those by bike range from 0 to 7 km. Motorcycle trips are typically no longer than 11 km.

TABLE 3 **AVERAGE DISTANCE TRAVELED PER TRIP BY MODE AND PURPOSE (km)**

MODE	WORK	GO HOME	SCHOOL	OTHER	TOTAL
Walk	0.16	0.41	0.12	0.13	0.83
Bicycle	0.61	1.54	0.46	0.48	3.09
Pedicab	0.47	1.18	0.35	0.37	2.36
Car	1.85	4.64	1.38	1.44	9.32
Taxi	1.49	3.75	1.12	1.17	7.53
Bus	2.02	5.07	1.51	1.58	10.17
Moped	1.16	2.91	0.87	0.90	5.84
Other*	0.8	2.01	0.60	0.62	4.03

* Inner-provincial bus
Source: Transport Development Strategies Institute, Hanoi, developed for Schipper et al. 2006

FIGURE 6 | **DISTANCES BY MODE IN 2005**



Source: ALMEC, 2007
Note: The y-axis shows the percentage of trips taken at any given distance by mode.

Based on the same two surveys, Figure 7 shows total passenger km in 1995, 2005, and 2020 under the projected HAIDEP scenarios. Note that passenger kilometers are related to vehicle kilometers adjusted by the vehicle's load factor.

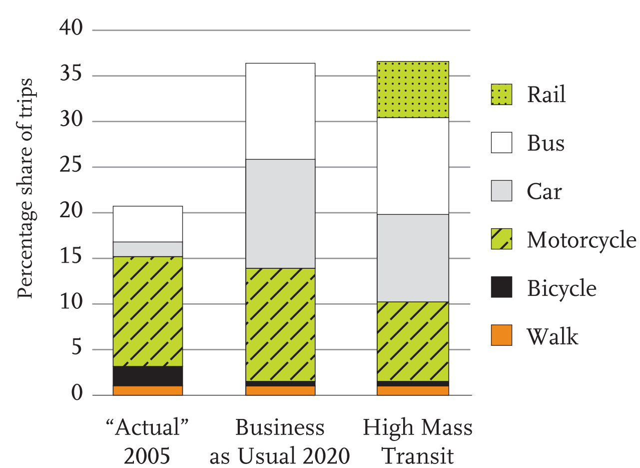
Figure 7 shows that in terms of passenger distances traveled, motorcycles currently transport the most passengers (61%), followed by buses (20%). However, it has been forecast that most of the increase in transportation demand from current levels to 2020 will be captured by a tremendous swell in car and bus use. Walking will stay low, and bicycling will see a strong cutback from already-low levels.

Public transport

Between the third Indochina war in 1979 and the implementation of economic liberalization reforms of 1986—named *Doi Moi*—practically all motorized travel in Hanoi was supplied by public transportation. After *Doi Moi*, the collapse of public transportation was sudden. Ridership dropped from about 40 million per year to almost nothing in only a few years, as the material in the HAIDEP study shows. At the same time, ownership of motorized two-wheelers took off.

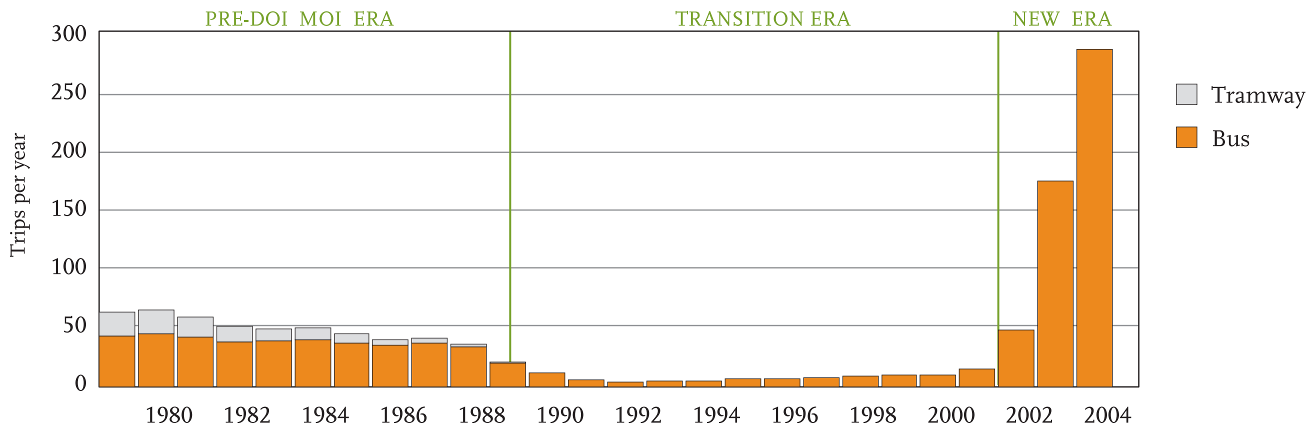
In 2002, Hanoi embarked upon a "bottom up" policy aimed at a substantial improvement of its almost-extinct bus system. New bus routes were established, the vehicle fleet was expanded, and bus shelters and passenger information schemes were introduced. The result of the new policy has been spectacular. Bus ridership in 2005 reached 350 million trips (ALMEC, 2007), roughly six times the 1980 level. This is possibly one of the most dramatic re-

FIGURE 7 | **PASSENGER KILOMETERS BY MODE**



Source: Elaborated from ALMEC, 2007

FIGURE 8 | **RIDERSHIP OF URBAN PUBLIC TRANSPORT IN HANOI: 1979–2004**



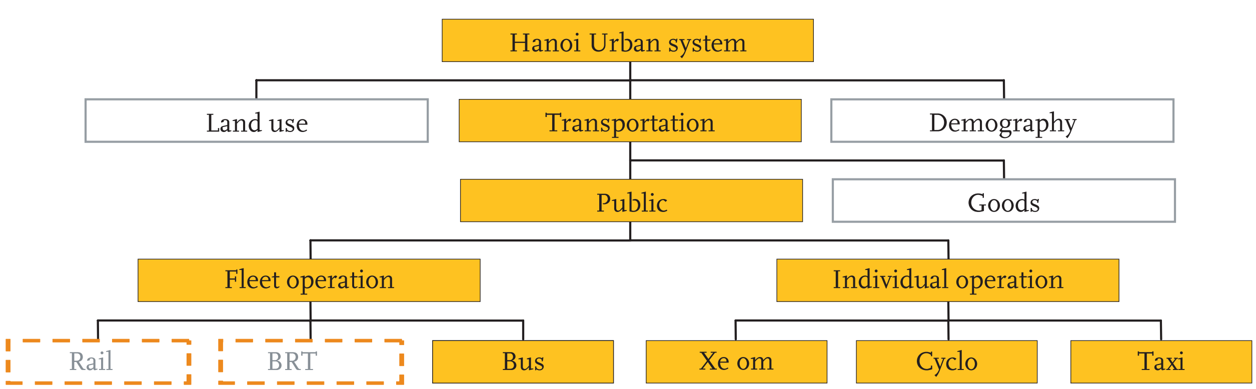
Sources: VUTAP, 1995; ALMEC, 2007
Note that the counting of trips is different from that in Table 2.

coveries of public transportation that the world has ever seen (Figure 8).

Public transportation in Hanoi now contains two fundamentally different systems. One is based on a bus fleet and organized around fixed routes; the other is an area-oriented system, with smaller vehicles operated as individual units and geared toward individual passengers (Figure 9). Various future options have been identified for the “bus fleet operation system” and are in various stages of investigation—notably rail-based systems on one hand, and bus rapid transit on the other.

The “individual vehicle system” contains three different modes; (1) unofficial but thriving motorcycle taxis (*xe om*), (2) traditional bicycle rickshaws (*cyclos*) now largely phased out, and (3) a widespread and well-functioning taxi system.

FIGURE 9 | **STRUCTURE OF THE PUBLIC TRANSPORTATION SECTOR IN THE URBAN SYSTEM**



Source: ALMEC, 2007

3

METHODOLOGY

This study adopted the basic approach developed by Schipper, Marie, and Gorham (2000), and elaborated in Schipper, Cordeiro, and Ng (2007), to estimate the impact of an area-wide transport demand pattern on emissions of carbon monoxide (CO), nitrogen oxides (NO_x), PM, sulfur oxides (SO_x) and carbon dioxide (CO_2). This approach covers direct emissions from exhaust emitted at the tailpipe. The total road transport activity in the study area was classified according to the following transport modes: walking, bicycle, motorcycle, car, truck, bus, and urban rail (the last of which was not treated here because of a lack of data). The approach chosen was dictated by the focus of the HAIDEP study on transport activity (in passenger or vehicle km). This required the present study to estimate emissions per vehicle km in order to determine total emissions.

This study did model the trucking sector, but the primary focus was on passenger transportation. This is not to imply that trucks are unimportant. In fact, the opposite appears to be true for NOx, SOx, and PM, particularly considering Hanoi's importance as a hub for trade and long-distance shipping. Truckers will benefit from lowering sulfur content in diesel from its current 3,000 parts per million (ppm), in terms of both overall engine operation and fuel efficiency. There will be fewer of these pollutants in the air as well, and advanced technology can be used to further reduce pollution from trucks .

MODEL DEVELOPMENT

CO, HC, PM, and NO_x emission calculations

The total emissions of CO, hydrocarbon (HC), PM, and NO_x were calculated using a distance-based methodology: sum of the emissions per transport mode, which are the product of activity level (distance traveled by vehicles) for each transport mode and an emission factor grams (g)/km) (Equation 1). Since emissions are proportional to the distances vehicles travel, recovering vehicle distances was essential. From there we could use the following equation, where the summation is overall vehicle types and fuel types (Schipper, Marie, and Gorham, 2000). There is one equation for each pollutant.

Equation 1

$$\sum \left[\begin{array}{c}\text{Total Distance Traveled} \\ \text{by vehicle type} \\ \text{(km)}\end{array} \times \begin{array}{c}\text{Emission Factor} \\ \text{by vehicle type} \\ \text{(g/km)}\end{array} \right]$$

Since historical data from travel surveys are only available by passenger km, assumptions about load factors were used to translate passenger km into vehicle km to use in the ALMEC model. For example, in the case of bus activity, an average load factor (15 people per bus in 1995) was used to convert passenger km to vehicle km. In the case of motorbikes, the same load factor of 1.4 was assumed across all 2020 scenarios—a decrease from the 1.8 load factor used for 2005. This information could also be related to average distance/vehicle/year using the number of vehicles (vehicle mode and fuel type) and the average annual km traveled (for each vehicle model and fuel type) (Equation 2). Note that splitting of modes (car, truck) into gasoline and diesel was based on assumption, since the transport modeling makes no distinction among fuels that different vehicles use—gasoline, diesel etc.

Equation 2

$$\begin{array}{c}\text{Distance traveled} \\ \text{by vehicle type} \\ \text{(km)}\end{array} \times \begin{array}{c}\text{Number of} \\ \text{vehicles} \\ \text{by mode and} \\ \text{fuel type} \\ \text{(g/km)}\end{array} \times \begin{array}{c}\text{Annual average} \\ \text{km traveled} \\ \text{by mode} \\ \text{and fuel type} \\ \text{(km/yr)}\end{array}$$

CO_2 and SO_x emission calculations

On the other hand, the total emissions of CO_2 and SO_x were calculated using a fuel-based, mass-balance approach that simply translates the available sulfur or carbon in the uncombusted fuel into emissions. Unlike the other pollutants, sulfur in fuel is almost completely converted into sulfates, and the overwhelming majority of carbon in fuel burned results in CO_2. Aside from a small adjustment for carbon that is converted into CO (1% of all carbon), the quantities of fuel combusted times their sulfur or carbon contents give the output in sulfur and CO_2, respectively. The equation used follows:

*Equation 3**

$$FC = (0.1155/r) \times [(0.866 \times THC) + (0.429 \times CO) + (0.273 \times CO_2)]$$

* This equation was derived from the European Commission Directive 1999/100/EC.

FC = estimated fuel consumption in liter per 100 km

THC = measured or estimated emission of total hydrocarbons in g/km

CO = measured or estimated emission of carbon monoxide in g/km

CO_2 = measured or estimated emission of carbon dioxide in g/km

r = density of the test fuel at 15^0C.

Thus, when total energy consumption is known, together with the carbon content of the fuel and the CO concentration of the exhaust gas, we can calculate the CO_2 emitted, depending on whether the fuel term FC is based on diesel, gasoline, or any other fuel. Of course, the amounts of THC and CO will depend on the fuel, vehicle, and emissions controls specified.

We assume that SO_x includes 40% SO_2 and 60% sulfite (SO_4) in molecular ratio. The SO_4 combines with molecules of water, and its weight increases by a factor of 1.39. SO_x emission is then calculated from a simple mass balance, as indicated in Equation 4.

Equation 4

$$SO_x\,[g/km] = \left[\begin{array}{c} 0.4 \times (S \times FC \times \rho / 32) \times 64 \\ + \\ 0.6 \times (S \times FC \times \rho / 32) \times 96 \times 1.39 \end{array} \right] \times 10^{-6}$$

S = sulfur content, [parts per million (ppm)],

FC = fuel consumption, [liter/km],

ρ = fuel density, [g/liter],

Numbers 64 and 96 are, respectively, molecules of SO_2 and SO_4.

Forecasting future SO_x emissions requires an assumption regarding the selection and implementation of government fuel quality improvement policies that mandate fuel sulfur content. This issue is currently under discussion and future standards remain uncertain. Other details of assumptions on emission factors are given in the text below.

The total emissions were written as the sum of the emissions per transport mode, based on the product of the fuel used per vehicle km for each fuel and vehicle type combination, and an emission factor per liter of fuel consumed, as noted above in Equation 2.

SCENARIO DEVELOPMENT

This study analyzed transport activity, fuel use, and vehicle technology data for 1995 and 2005 to calculate the corresponding emissions generated in Hanoi by the transport sector. These dates were chosen based on data availability. In 1995 an origin-destination survey was undertaken as part of the previous Hanoi urban transport study, and the ALMEC study provides activity data for 2005.

This study developed estimates of emissions for 2020, based on two activity scenarios provided in the HAIDEP study and four vehicle emission standards chosen by *EMBARQ*. This time frame is long enough that we can assume that virtually all vehicles in circulation will have been built according to the emission standard defined by government authorities. It also assumes that fuel quality improvements will be mandated to enable the introduction of vehicle technology required to meet the new vehicle emission standards. For example, the adoption of Euro 2 standards for diesel vehicles requires the use of diesel with 50 ppm sulfur content. Failure of the government to impose the vehicle or fuel standards by 2010 means that a significant fraction of those vehicles in use in 2020 will not meet the standards, with that fraction rising for every year the more stringent standards are delayed.

Traffic scenarios for 2020

The HAIDEP study produced two primary traffic activity scenarios for 2020, based on assumptions of spatial development, population growth, economic development, and other factors. The study also gathered information about person-trips and vehicle activity (vehicle km), which we combined with vehicle load factors to generate statistics regarding how far people travel (passenger km). In gross, total passenger km traveled are expected to increase by 43% from around 21 billion km to 36 billion km.

The main difference between the two traffic activity scenarios analyzed was the scale of the public transport system.

- The first traffic scenario, Business as Usual, adopts the current trends in public transportation penetration. Public transport will continue to be supplied by buses in mixed traffic, and the number of trips taken on public transport will continue to increase from 6.7% of all trips today (almost 20% of total distance traveled) to 14.5% in 2020 (nearly 30% of total distance traveled). In terms of distance traveled, bus trips are longer than those on mopeds or by foot, explaining why the share of distance traveled is greater than the share of trips. The 43% growth in passenger km, coupled with continuing trends in a shift from motorcycles to cars (25% changeover by 2020) will lead to severe congestion. This will reduce vehicle speed by 46–55% (ALMEC, 2007) and increase stop-and-go accelerations in traffic jams, thereby increasing the emission coefficient by an estimated 35% (25% for diesel) (Schipper, Unal and Zachariadis, 2007).
- The second traffic scenario, High Mass Transit, considers the implementation of the ambitious program of promotion of public transportation, as described in the HAIDEP study. The HAIDEP study recommends an upgrade of the urban transport infrastructure—urban rail rapid transit, bus rapid transit, and regular bus—fostering increased capacity and safe mobility. An element of transport demand management is also considered—namely, the implementation of economic measures, such as area licensing, registration fees, parking fees, and increased fuel prices, with clear priority given to public transport. Under this scenario, the public transport share of total trips will reach 30%, of which two-thirds are on buses and the rest are on electric rail (metro and tram). Overall, these modes will provide 45.8% of total passenger km traveled—30% on buses and 15% on the electrified rail system.

In the HAIDEP study, CUBE was used to calculate demand. TRIPS was used for highway traffic assignment, while STRADA was used for transit assignment.[1]

In estimating the traffic volumes for the different scenarios, it was possible to derive some of the data directly from the HAIDEP forecast. However, in the forecast model used by ALMEC, data on bicycle and motorcycle trips were collected as one combined figure, and the same was true for bus and rail trips. Thus, the individual modal shares had to be disaggregated by estimating the split between modes and calculating them manually. The same was true for walking trips and for the 1995 HAIDEP data. The result of the calculations for total vehicle km (including walking and cycling) is presented in Table 4.

Average vehicle speeds were inputs to the model—some observed, some predicted. In the High Mass Transit scenario, we assumed that bus rapid transit (BRT) and normal buses achieved an average speed of 25 km/hour.

Emission-level scenarios for 2020

This study modeled alternative emission levels based on various transportation and environmental policies. The study selected two alternative emission standards for the Business as Usual public transportation scenario and three alternatives for the High Mass Transit scenario, generating a total of five different emissions scenarios for 2020, named 2020Case1 through 2020Case5 (Figure 10).

These emission scenarios were generated in a two-step process. First, we selected a legal vehicle emissions standard. Second, we modeled the impact of different congestion levels on vehicle speed and energy efficiency.

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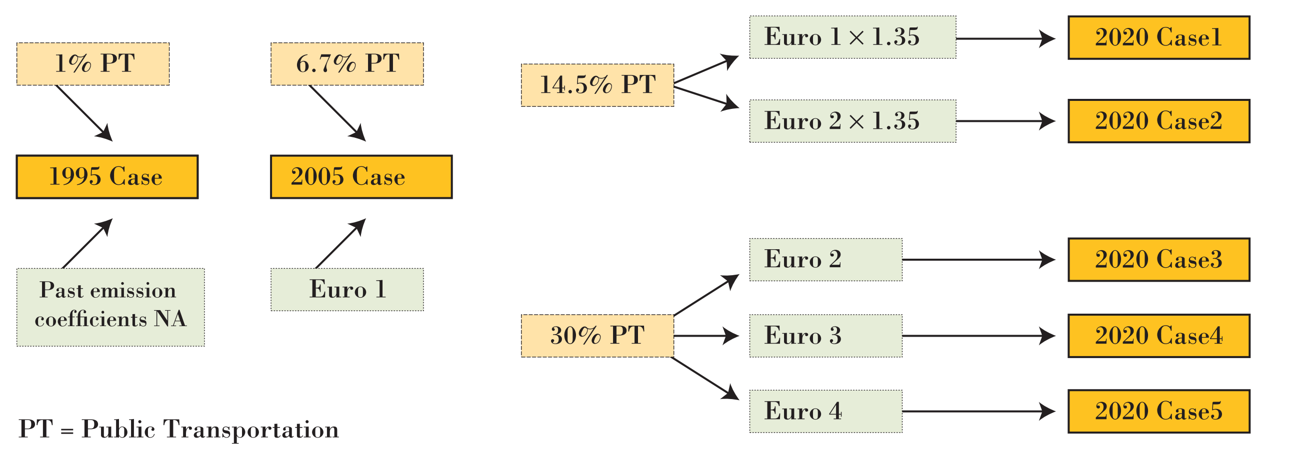
1. CUBE is a model of freight flows (http://www.citilabs.com/cargo/cargomod.shtml), STRADA is a transport planning model used by TDSI (Transport Development and Strategies Institute in Hanoi), and TRIPS is the Transport Improvement Planning System). CUBE and TRIPS are both explained on the same citilabs Web site. STRADA is explained at www.intel-tech.co.jp/strada/products/strada/STRADA3-bro-R.pdf

FIGURE 10 | **SCHEMATIC DIAGRAM OF THE FIVE SCENARIOS DEVELOPED BY THE STUDY**



Part I: Selecting emissions standards

We adopted four alternative Euro vehicle emission standards for our analysis of emissions for 2020: Euro 1, Euro 2, Euro 3, and Euro 4 (see Table 5).[2] These European standards serve as a familiar reference for transportation and environmental planners worldwide.

In choosing these different standards, we assumed that the Business as Usual scenario would be associated with less stringent air pollution controls (Euro 1 and 2), while the superior development of the public transport system in the High Mass Transit scenario suggests more regulatory emphasis on air pollution and, hence, more stringent controls (Euro 3 and 4, with Euro 2 included for comparative power). However, these correlations are not necessarily born out in reality, because policymakers must sometimes make trade-offs due to budgetary restrictions (i.e., choosing either to tighten the legal emission standards or to create a new public bus system). This study chose to assume complementary pro-environmental emissions standards and public transport policy in the optimistic 2020 scenario for illustrative purposes; however, readers should be aware that there is not a causal relationship between these two variables—merely a correlation in the context of sustainable development criteria.

TABLE 4 | **DISTANCE TRAVELED BY PASSENGER BY MODE**

YEAR	1995	2005	2020 BUSINESS AS USUAL	2020 HIGH MASS TRANSIT
Public transport trip share	1%	6.7%	14%	30%
Share of distance traveled by public transport	7.4%	19.0%	29.0%	45.8%
DISTANCE TRAVELED BY PASSENGERS PER TRANSPORT MODE (million pass. km/yr)				
Walk		1,045	1,011	1,011
Bicycle		2,110	518	515
Motorcycle		12,029	12,357	8,678
Car		1,594	11,936	9,599
Truck		1,107	3,956	3,891
Bus		3,924	10,530	10,100
Rail		N/A	N/A	6140
Total		20,702	36,352	34,294

Source: HAIDEP, 2007.

2. Euro standards may be reviewed at: http://ec.europa.eu/environment/air/transport.htm.

TABLE 5 | **VEHICLE EMISSION STANDARDS CHOSEN FOR EACH FUTURE SCENARIO**

YEAR	1995	2005	2020 BUSINESS AS USUAL		2020 HIGH MASS TRANSIT		
Public Transport Trip Share	1%	6.7%	14.5%		30%		
Scenarios	1995 Case	2005 Case	2020 Case1	2020 Case2	2020 Case3	2020 Case4	2020 Case5
Vehicle Emission Standard	N/A	Euro 1	Euro 1	Euro 2	Euro 2	Euro 3	Euro 4

BOX 1 | **CONGESTION AND EMISSIONS**

Congestion and traffic emissions are linked to each other through one fundamental key aspect: vehicle movement in space and time, which is described in terms of vehicle driving patterns. Congestion causes changes in driving patterns of individual vehicles in a traffic stream, and these changes are subsequently reflected in changes in emission levels.

The relationship between level of congestion and average speed is road-type specific. Various studies have shown that congestion has a large effect on composite CO and HC emission factors, especially in most congested inner-city areas. The impact is not as strong for NO_x.

The impact of going from free-flow traffic to congested traffic can range from 1.5 to 2.6. In the present study, the impact was assumed to be small, since the traffic conditions were already congested and the network was near saturation. Thus, a 1.35 factor should be considered a very conservative estimate of emissions factor deterioration.

The speed estimates that we used can be seen in Table 9 as well.

Part II: Effect of congestion on emissions levels

In addition to the legal emission standards, the study had to account for the effect of higher congestion on vehicle speeds, which have been proven to increase emissions per vehicle km traveled.

In the Business as Usual scenario, it is assumed that additional congestion generated by a nearly 45% increase in passenger km from 2005 to 2020 (only 14.5% of which is served by public transportation) would increase emissions per vehicle km by 35%. We modeled this emissions increase due to congestion by using a factor of 1.35 (as noted in section 3.2.1) to generate the emission estimates under the Business as Usual activity scenario. (Table 6)

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The impact of going from free-flow traffic to congested traffic can range from 1.5 to 2.6. In the present study, the impact was assumed to be small, since the traffic conditions were already congested and the network was near saturation. Thus, a 1.35 factor should be considered a very conservative estimate of emissions factor deterioration.

The speed estimates that we used can be seen in Table 9 as well.

PHOTO CREDIT: TDSI

On the other hand, the High Mass Transit scenario implies only slightly more (but larger) buses on the road, and projects rail or metro replacing car or motorcycle vehicle km by as almost 5 billion passenger km/year. In the High Mass Transit scenario, emission factors come close to the mandated standards.

TABLE 6 IMPACT OF CONGESTION ON EMISSION LEVELS

YEAR	1995	2005	2020 BUSINESS AS USUAL		2020 HIGH MASS TRANSIT		
Public Transport Trip Share	1%	6.7%	14.5%		30%		
Scenarios	1995 Case	2005 Case	2020 Case1	2020 Case2	2020 Case3	2020 Case4	2020 Case5
Vehicle Emission Standard	—	Euro 1	Euro 1	Euro 2	Euro 2	Euro 3	Euro 4
Impact of Congestion on Emission Coefficients or fuel use	0	0	35%	35%	0	0	0
Assumed Speeds from HAIDEP Study model							
Walk	4.0	4.0	4.0		4.0		
Bicycle	15.0	15.0	15.0		15.0		
Motorcycle	24.8	24.8	8.1		29.9		
Car	22.0	20.0	8.9		31.9		
Truck	17.6	16.0	7.1		25.5		
Bus	17.6	16.0	7.1		25.0		
Rail	—	—	—		45.0		

Source: Estimated by the authors with input from Theo Zacharides, University of Cyprus, and Alper Unal, EMBARQ. Speeds by the modeling done in the HAIDEP study.

PHOTO CREDIT: LEE SCHIPPER

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DATA SOURCES AND ASSUMPTIONS

For each of the transport modes, Hans Orn, a consultant from CONTRANS AB. estimated the volume of traffic in terms of vehicle km/year for 1995, 2005, and 2020. Orn then estimated the specific characteristics in terms of emissions and energy consumption per mode.

The emission coefficients were developed primarily from existing literature, with some information collected from light-duty vehicle tests in Hanoi carried out by Dr. Tuan Le Anh at Hanoi University of Technology. Fuel economy figures are based on the authors' best estimates of present vehicles in Hanoi and future trends, with one important exception. Fuel consumption for the present generation of buses in Hanoi was provided by TRANSERCO, the Hanoi bus operator. This work was carried out by Dr. Tuan Le Anh of the Hanoi University of Technology.

Finally, the total emissions generated and the energy consumption by mode were calculated for each year by *EMBARQ*.

PERSONAL TRANSPORT ACTIVITY DATA

Total vehicle and passenger travel activity by mode were gathered through household surveys.

In 1995, the first household interview survey in Hanoi was conducted by the Swedish consulting firm CONTRANS AB, with financing support from the Swedish International Development Authority (SIDA). This survey was undertaken as part of Vietnam's Urban Transport Assistance Project (VUTAP). The survey, which covered mainly the four core urban districts of Hanoi, was used in the 1995 Transportation Master Plan (JICA) and formed the base for most subsequent urban transport studies until now.

In 2005, HAIDEP was developed by a Japanese consultant team funded by JICA. HAIDEP is a comprehensive master plan integrating four subsectors: urban development, urban transport, living conditions, and water environment. Within the HAIDEP, a new household interview survey was undertaken.

The estimated number of vehicle km was based on the obtained estimated number of trips, trips distances, and vehicle occupation rates. Though this approach is different from the more common approach, which starts with attempts to define the vehicle population, it provides a better reflection of the real world, since people, not vehicles, decide to make trips and then carry those trips out.

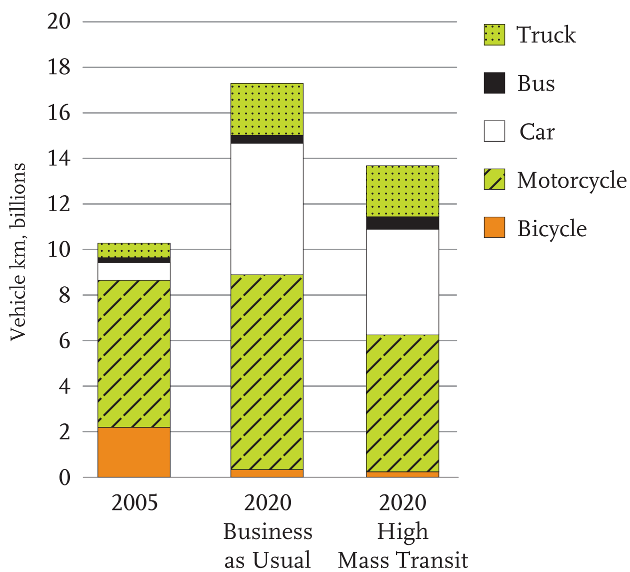
Comparing the results of this new survey to the 1995 data made it possible to understand the changes in personal transport activity that took place over the last decade. With the approval of SIDA and JICA, these two studies formed the basis for the estimations of traffic volumes in the present study.

VEHICLE ACTIVITY DATA

The original travel survey measured travel activity in trips and passenger km. The project team then transformed this information into vehicle activity using assumptions about vehicle load. This extrapolation is important because some of the differences between the traffic scenarios imply differences in the modal mix, or differences between larger, BRT-style buses versus more conventional buses. Knowing *how* people travel from A to B is as important as knowing *how far* they travel in one day.

Figure 11 shows the results of the transformation to vehicle activity. Data are presented for walking, cycling, motorcycles (of all kinds), cars, buses, and trucks. The projections for 2020 come from the projections made in the original HAIDEP study. Interestingly, the High Mass Transit scenario reduces vehicle km of motorcycles more than that of cars. Bus km are only slightly higher because we assume the buses will have higher load capacity, with BRT buses (carrying up to 160 passengers) largely respon-

FIGURE 11 **CURRENT AND PROJECTED VEHICLE ACTIVITY IN HANOI**



Source: ALMEC 2007 (modified by this study)

sible for the higher mass transit. In fact, the World Bank and the Vietnamese Government just approved the first step toward a BRT system, so this representation is useful (Unal et al., 2007).

In harmony with worldwide trends, we have also assumed that a rising share of cars will run on diesel and use only 85% of the fuel per km that gasoline cars do, yielding a roughly 5% savings in total energy, based on comparisons of fleets in Germany, France, and the Netherlands. The small energy savings may be surprising, but can be explained because engines in diesel models of given cars tend to be slightly larger than their gasoline counterparts (Schipper, Marie and Fulton 2002). As long as diesel fuel is not priced lower than gasoline, diesel cars owners may not drive much more than the owners of gasoline; thus, we assumed equal driving distances for this calculation.

Emissions and fuel data

In Vietnam, there are no well-validated country-specific emission factors[1] or specific average energy consumption estimates for the vehicle fleets. To have correct emission and energy data for Hanoi, real measurements must be conducted for a vehicle sample that is representative of the vehicle fleet, following a typical driving cycle. The driving cycle represents the traffic conditions a vehicle encounters. Vehicles are tested in traffic conditions or on a chassis dynamometer using the typical driving cycle, thus simulating the impacts of these variables on emissions.

Since there are no real driving cycle measurements for Hanoi, this study uses proxies. Some literature provides assumptions for emissions factors in Hanoi, but do not reflect the real vehicle types, driving behaviors, and traffic situations, as was verified by EMBARQ's measurements of in-use emissions in Istanbul, Turkey, in 2006 (work in progress). Therefore, the current study uses instead the European driving cycle proxies—ECE R40 for motorcycles, NEDC for cars, and ECE R49 for trucks.[2] Given these limitations, the basis of the emission and energy data collection applied in this research are as follows (see Table 9 for actual figures):

1. An emissions factor is a measure of the rate that pollutants are emitted relative to units of activity and vary with vehicle technology, vehicle maintenance and tuning, driver behavior, temperature, etc. An emission factor can be measured in multiple ways: in units of grams emitted per kilometer traveled by the vehicle (g/veh km), per passenger km (g/pass km), or per liter of fuel consumed (g/liter).

2. The ECE (Economic Commission for Europe) test cycle is a European emissions test cycle performed on a chassis dynamometer for light-duty vehicles "devised to represent city driving conditions, e.g. in Paris or Rome. It is characterized by low vehicle speed, low engine load, and low exhaust gas temperature" (Diesel Net, 2004). ECE R40 stands for ECE Regulation 40—Emission of gaseous pollutants of motorcycles. ECE49 is an older test standard for heavy-duty trucks that the European Commission adopted in 1988 under the Euro II standards. In October 2000 the Euro III standard was adopted, and the R49 cycle was replaced by the European Stationary Cycle schedule (Diesel Net, 2004). The NEDC (New European Driving Cycle) is a new test cycle adopted in 2000 that requires cold-start emissions testing. Emission measurements begin immediately after the engine is started (t=0s), as opposed to the ECE standard, which allows a 40s idling period before measurements begin (Diesel Net, 2004). This new test was adopted to better incorporate HC and CO emissions, most of which are generated during the warm-up idling period.

TABLE 7 ESTIMATED FUEL SULFUR CONTENT (PPM)

YEAR	1995	2005	2020 BUSINESS AS USUAL		2020 HIGH MASS TRANSIT		
Public Transport Trip Share	1%	6.7%	14.5%		30%		
Scenarios	1995 Case	2005 Case	2020 Case1	2020 Case2	2020 Case3	2020 Case4	2020 Case5
Vehicle Emission Standard	—	Euro 1	Euro 1	Euro 2	Euro 2	Euro 3	Euro 4
Gasoline	3,000	1,000	500	500	500	150	50
Diesel	5,000	3,000	500	500	500	350	50

1. *The emission data for 2005 scenarios* were calculated using emission factors taken from the annual measurement reports made by the Laboratory of Internal Combustion Engine, Hanoi University of Technology (Molt, 2006). It is necessary to mention that only measured emissions and fuel consumption of motorcycles, cars, and trucks conducted in 2005 are available from the Laboratory of Internal Combustion Engine. The other 2005 emission factors were taken from Euro 1 values. Since there are probably many old vehicles in Hanoi not meeting Euro 1 standards, the 2005 estimates (and 1995) may represent lower emissions than in reality.
2. *Emission factors for the 1995 and 2020 Case1 scenarios* were calculated based on emission factors from the 2005 scenario, adjusted by coefficients, which took into account average vehicle speed. Increased congestion in 2020 yields lower speeds and thus higher emissions of approximately 35%.
3. *The remaining 2020 scenarios*—2020 Case2, 2020 Case3, 2020 Case4, and 2020 Case5—used measurements of Euro 2, Euro 2, Euro 3 and Euro 4 vehicle standards, respectively. Note that the emission factors of 2020 Case2 were derived from those used for 2020 Case3 (both based on Euro 2), adjusted by a coefficient of 1.35 to account for more traffic congestion, as was done for 2020Case1. This extra congestion arises because there is less mass transit in Cases 1 and 2 than in Cases 3–5. Note that in all cases the Euro standards are markers—no one has measured the real emissions from future vehicle/fuel combinations in Hanoi.
4. *Fuel consumption* data were provided by TRANSERCO (Walter Molt, private communication). Overall the TRANSERCO fleet averaged nearly 3 km/liter in 2005. Some measurements were taken for motorcycles, cars, and trucks. The rest of the energy consumption data were estimated from literature.
5. *The CO_2 emissions* were calculated from fuel consumption via the mass-balance method—i.e., netting out carbon that is bound up in CO, HC, or other compounds, as is obvious from considerations of the mass balance.
6. *SO_x emission factors* were calculated from fuel consumption and the assumed sulfur content in fuel used (Table 7 and Equation 4).

TABLE 8 PROPORTION OF VEHICLES IN HANOI USING DIESEL FUEL (BY MODE)

YEAR	1995	2005	2020 BUSINESS AS USUAL		2020 HIGH MASS TRANSIT		
Public Transport Trip Share	1%	6.7%	14.5%		30%		
Scenarios	1995 Case	2005 Case	2020 Case1	2020 Case2	2020 Case3	2020 Case4	2020 Case5
Vehicle Emission Standard	—	Euro 1	Euro 1	Euro 2	Euro 2	Euro 3	Euro 4
Cars (% Diesel)	6	8	7.5	7.5	15	15	15
Trucks (% Diesel)	65	68	70	70	70	70	70
Bus (% Diesel)	48	50	75	75	90	90	90

Furthermore, for SO_x calculation, the share of diesel cars, buses, and trucks must be assumed, as presented in Table 8.

Heavy vehicles like buses and trucks are much more likely to run on diesel than lighter vehicles.

Since we do not have detailed information on the present or future composition of the stock by vehicle technology, we have used a composite or average emission factor to account for each kind of vehicle (Table 9).

TABLE 9 **COMPOSITE EMISSION FACTORS USED IN THIS STUDY**

YEAR	1995	2005	2020 BUSINESS AS USUAL		2020 HIGH MASS TRANSIT		
Public Transport Trip Share	1%	6.7%	14.5%		30%		
Scenarios	1995 Case	2005 Case	2020 Case1	2020 Case2	2020 Case3	2020 Case4	2020 Case5
Vehicle Emission Standard	—	Euro 1	Euro 1	Euro 2	Euro 2	Euro 3	Euro 4
Congestion Factor*	—	—	1.35 (+35%)	1.35 (+35%)	—	—	—
CO_2 Emission Factor (g/veh km)							
Motorcycle	41.8	39.6	81.3	56.1	41.6	41.3	36.6
Car	234.4	205.5	275.9	265.1	197.3	187.8	179.6
Truck	1,302.5	1,077.4	1,371.1	1,154.6	922.4	882.5	834.7
Bus	1,402.7	1,277.3	1,586.2	1,360.5	1,087.0	1,034.4	956.4
CO Emission Factor (g/veh km)							
Motorcycle	13.07	8.72	11.77	7.43	5.50	2.00	2.00
Car	4.60	3.07	4.14	2.16	1.60	1.47	0.75
Truck	18.47	18.00	24.30	15.30	11.33	5.95	4.25
Bus	10.35	6.90	9.32	2.03	1.50	0.95	0.74
HC Emission Factor (g/veh km)							
Motorcycle	2.55	1.70	2.29	1.62	1.20	0.80	0.80
Car	0.40	0.27	0.36	0.27	0.20	0.10	0.05
Truck	4.50	4.90	6.62	4.20	3.11	1.87	1.30
Bus	0.30	0.20	0.27	0.24	0.18	0.08	0.07
PM Emission Factor (g/veh km)							
Motorcycle	0.03	0.02	0.03	0.02	0.02	0.01	0.01
Car	0.11	0.07	0.09	0.05	0.04	0.03	0.01
Truck	1.47	0.67	0.90	0.57	0.42	0.28	0.06
Bus	0.38	0.25	0.34	0.27	0.20	0.10	0.06
NO_x Emission Factor (g/veh km)							
Motorcycle	5.00	0.34	0.46	0.41	0.30	0.15	0.15
Car	1.06	0.71	0.95	0.54	0.40	0.33	0.17
Truck	32.80	31.60	42.66	26.73	19.80	14.10	9.90
Bus	17.25	11.50	15.53	11.48	8.50	5.50	4.00

* A congestion factor models the effect of vehicle speed on engine performance. High congestion in the 2020 Business as Usual case causes levels of emissions to exceed the legislated emissions standard by a factor of 1.35.

Table 9 shows that the scenario 2020 Case5, which represents the implementation of the Euro 4 standard, shows improvements in emissions rates by almost 30% across the board. We can also see that the scenarios 2020Case1 and 2020Case2 have higher emission levels (+35% over the nominal standard) due to slower vehicle speeds and increased acceleration resulting from congested traffic conditions. The fuel intensities (in liters [l]/km) that correspond to the carbon emissions above are shown in Table 10. The fact that fuel consumption per kilometer in 2020Case1 exceeds consumption in 2005 is a reflection of worsening traffic. In determining these fuel intensities, we have borne in mind that cars on the road 10 years ago were mainly company and government cars, some very old. New cars being purchased today are smaller, reflecting the low (albeit rising) purchasing power of ordinary Vietnamese.

In Table 10, we associate higher fuel intensities with the worst of the traffic scenarios in the Business as Usual case. The better the traffic flow, the lower the emission coefficients and total fuel consumption. Table 9 above gave some indications for average speed in traffic for the different cases. The speed correction is applied only in the lower mass transit scenarios, where it is implied by lower speeds that congestion is a severe problem.

The average traffic speeds by mode emphasize the difficulties facing transport planning in an increasingly crowded Hanoi. If a motorcycle or car can really move faster than a bus, many potential bus riders will stick to individual motorized modes. This is a challenge faced by all transport planners and is often addressed by taxing fuel, access to congested areas, or even total kilometers run by a vehicle. Each of these initiatives would favor collective over private transport.

TABLE 10 **ASSUMED FLEET FUEL INTENSITIES**

YEAR	**1995**	**2005**	**2020 BUSINESS AS USUAL**		**2020 HIGH MASS TRANSIT**		
Public Transport Trip Share	1%	6.7%	14.5%		30%		
Scenarios	1995 Case	2005 Case	2020 Case1	2020 Case2	2020 Case3	2020 Case4	2020 Case5
Vehicle Emission Standard	—	Euro 1	Euro 1	Euro 2	Euro 2	Euro 3	Euro 4
Motorcycle	0.030	0.025	0.046	0.031	0.023	0.020	0.018
Car	0.104	0.090	0.122	0.115	0.086	0.081	0.077
Truck	0.576	0.480	0.648	0.540	0.400	0.380	0.360
Bus	0.648	0.540	0.729	0.621	0.460	0.440	0.420
Diesel (l/km)							
Car	0.088	0.077	0.096	0.091	0.073	0.069	0.066
Truck	0.492	0.410	0.510	0.425	0.350	0.330	0.310
Bus	0.480	0.480	0.574	0.489	0.400	0.380	0.350

Source: Estimated by this study

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RESULTS AND ANALYSIS

FUEL CONSUMPTION AND TOTAL CARBON DIOXIDE EMISSIONS

The typical distance a Hanoi citizen travels each day is low compared to that in OECD (Organization for Economic Cooperation and Development) countries, but remarkably high for a country of Vietnam's income. The ubiquity of the two-wheeler is the reason for this mobility. Indeed, two-wheeler ownership in Hanoi is comparable to car ownership in Europe (Schipper, 2008). Because most of the mobility in Hanoi is provided by two wheelers, CO_2 emissions are much lower than for European cities. At the same time, per capita CO_2 emissions from road transport for Viet Nam as a whole are high relative to per capita gross domestic product, measured in purchasing power parity (IEA 2007 CO_2 Indicators Database). This is because two-wheeler ownership is so much higher than in any other country or region of comparable income. If the two wheelers are replaced by cars, and/or distances traveled by two wheelers increase as the incomes of Hanoi residents grow, CO_2 emissions will grow as well.

In fact, the 2020 Business as Usual scenario represents a 7.5-fold increase in car traffic, while the High Mass Transit scenario predicts a 6-fold increase in car traffic, which is still formidable. Based on the historical relationship between income and car ownership, we believe these increases are realistic (Schipper and Ng, 2004). Yet, it is difficult to imagine how a significant number of cars—say an increase to 100 cars per 1,000 people—could be accommodated given today's congestion levels. Only Hanoi authorities can decide whether the city, under any pattern of expansion, can withstand such an increase in car use, when most of its streets are already saturated with smaller two-wheelers today.

That having been said, our calculations show that an increase in car use will increase fuel use, emissions, and congestion. Figure 12 compares fuel consumption and total CO_2 emissions in each of the six 2020 scenarios to the emissions for 1995 and 2005.

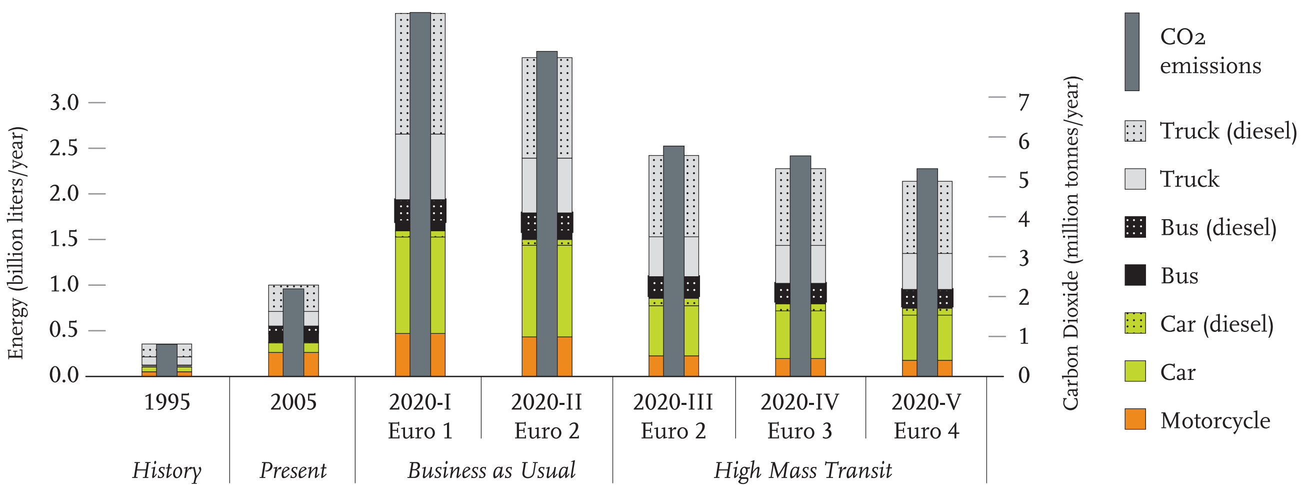
By 2020, total fuel consumption triples from its 2005 value, both because of the growth in truck traffic and because of the increasing importance of cars, which use considerably more fuel per passenger km than motorcycles or today's buses in Hanoi. Motorcycle use was so widespread in 2005 that the projected increase in their energy consumption and emissions is modest. Bus emissions are projected to rise as a result of the great increase in the level of bus activity.

It should not be surprising that fuel consumption in the High Mass Transit scenario coupled with the stringent vehicle emission standards is still higher than fuel consumption in 2005. We anticipate all vehicles to become more fuel efficient in the most aggressive scenarios. However, the disproportionately large increase in car use outweighs the expected gains in fuel economy and drives total emissions up.

Emissions are lower in the High Mass Transit scenario when compared to the Business as Usual scenario because we have assumed buses are well organized into a BRT system with fewer emissions per passenger km, and slightly fewer total bus km, in spite of somewhat higher passenger km on buses. Fuel consumption for cars and motorcycles is lower in the High Mass Transit scenario, both because we have introduced more fuel-efficient cars and because traffic is simply more fluid, permitting more efficient operation.

To some extent, CO_2 emissions depend on fuel type. While diesel vehicles tend to be more efficient than their gasoline counterparts, diesel fuel is denser than gasoline, and each unit of energy contains more carbon, meaning that burning diesel instead of gasoline in small vehicles produces only a small net reduction in CO_2 emissions.

FIGURE 12 | **FUEL USE BY VEHICLE MODE AND TOTAL CO2 EMISSIONS**



IMPORTANCE OF MODAL CHOICE FOR EMISSIONS INTENSITY

Policies that reduce distances traveled, or increase load factors so that fewer vehicle km are required to transport the same number of people, reduce energy consumption and CO_2 emissions. Figure 13 displays the estimated emissions per passenger km by transport mode for 1995, 2005, and 2020 in the Business as Usual (Cases 1 and 2) and High Mass Transit (Cases 3, 4, and 5) scenarios.

The average CO_2 emissions per passenger km for all modes increased between 1995 and 2005 as a result of a significant increase in automobile use. Average CO_2 emissions from two-wheelers also increased between 1995 and 2005, as more powerful engines emitted more grams of CO_2 per passenger km driven.

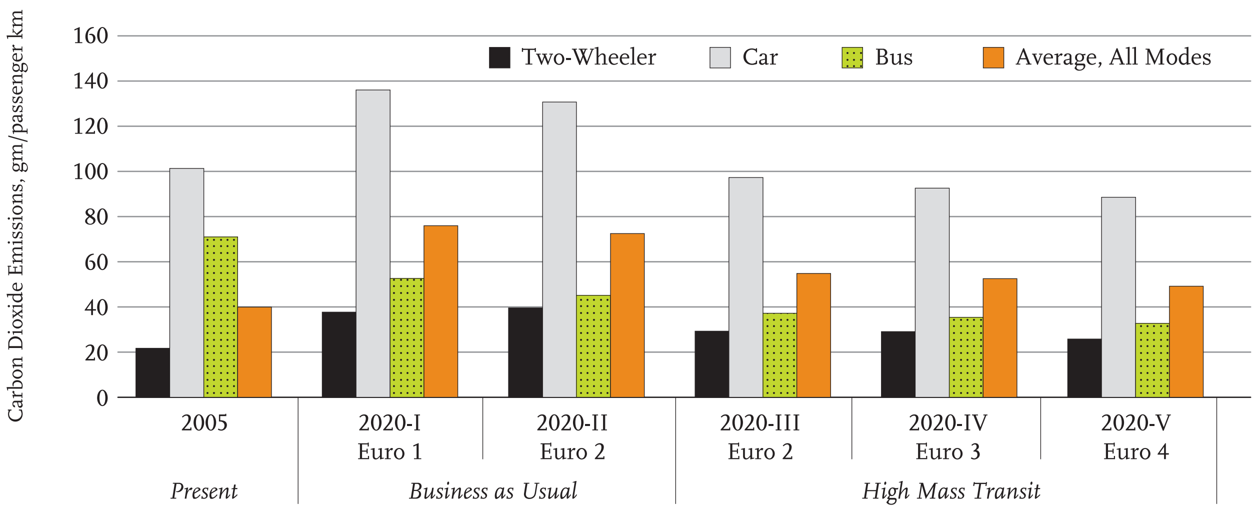
The 2020 Business as Usual scenario suggests that speeds will fall markedly as traffic congestion worsens, which implies either more time spent in traffic (with more exposure to pollution), shorter trips, or some combination of both. Since trends suggest continued urban sprawl that lengthens trips, the most probable outcome is more time spent in traffic and slower, longer trips. This problem is aggravated by the gradual shift to more reliance on car travel, as opposed to motorcycles or buses. The streets of downtown Hanoi are narrow, and cars would demand a large share of the already-cramped road space, forcing motorbikes and bicycles to slow down and snarling traffic further.

Subsequently, the average emissions for all modes are projected to fall for each 2020 scenario, as fuel intensities lower. On a passenger km basis, as displayed here, that effect is even stronger, as more highly loaded buses deliver more passengers. A typical Hanoi bus with 30 passengers (an anticipated doubling from 1995 loads) emits less CO_2 per passenger km than a car with two passengers or a motorcycle with one. Conversely, on a passenger km basis, a nearly empty bus (a sight more common in U.S. cities) emits somewhat more than a car (using the U.S. average of 1.5 persons per car) and much more than a motorcycle. Even the case presented here with relatively high reliance on buses still has a higher share of car travel than 2005, thus creating more CO_2 emissions per passenger km. Only the 2020Case5 scenario, with Euro 4 emission standard and highest share of buses (BRT), has a lower average CO_2 emissions coefficient.

In the future, two-wheelers will be modestly less energy intensive, which will lead to some reduction in emissions per vehicle km. We assume the same load factor of 1.4 across all 2020 scenarios, a decrease from the 1.8 load factor used for 2005.

Note that this study omits the CO_2 impact of rail travel, since little information is available on the traction energy required or the fuel mix and efficiency of electricity production. In the High Mass Transit scenario, we assume that rail passengers use mass transit to travel from home to the train station. If we assume that the energy required

FIGURE 13 | **CO2 INTENSITY BY MODES ACROSS SCENARIOS**



per passenger is comparable between rail and buses, we can treat them uniformly, which would lower the overall averages shown in Figure 14 below by adding more transport with lower-than-average CO_2 emissions per passenger (Schipper and Marie 1999, for OECD countries). In a Business as Usual scenario, the few rail passengers would presumably ride in cars, given the limited bus options.

CRITERIA POLLUTANT EMISSIONS

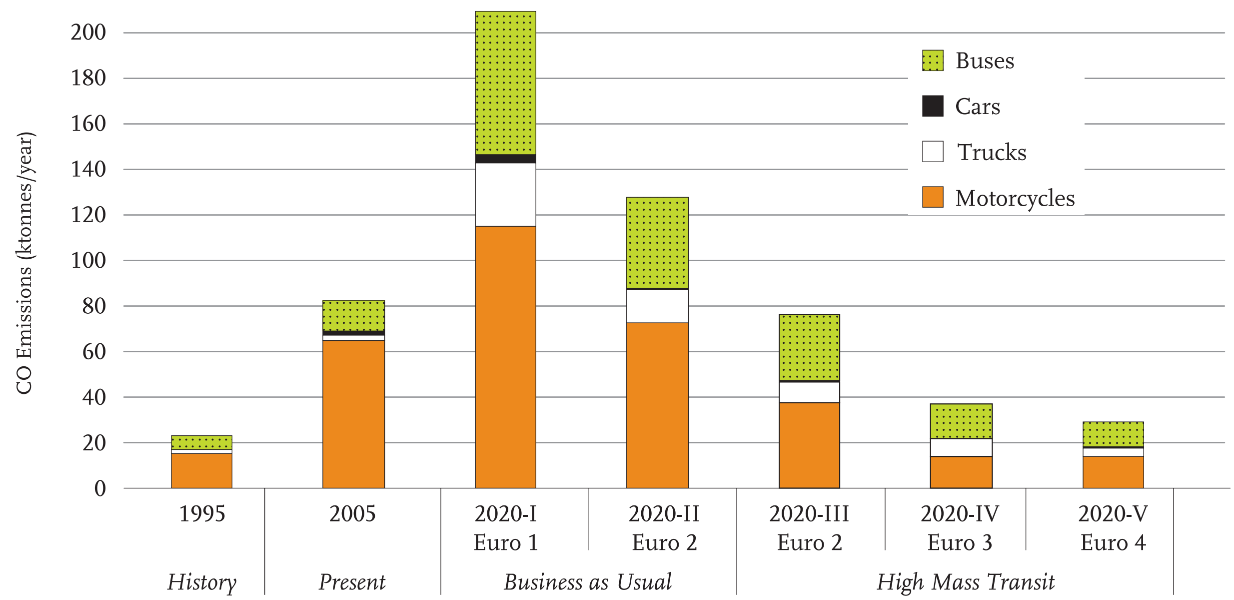
The patterns for total criteria pollutant emissions are driven by the same combination of increased car use, congestion, and vehicle emission factors. Expectations of replacement of fleets with very-low-emission vehicles due to the introduction of stringent emission standards suggest that future absolute levels of local or criteria pollutants, such as CO, NO_x, and PM, could be close to or below the levels of 2005.

The total levels of each of these three pollutants obtained by our projections are shown in Figures 14, 15, and 16. Note that in each pollutant, the emissions factor and total distance traveled (by mode) are multiplied to obtain total emissions for the scenario. In general, the emission level falls between the two traffic scenarios—normal or high mass transit—both because traffic congestion results in low vehicle speed, and because activity by vehicle type changes. The assumptions for the three separate cases in the high Mass Transit scenarios in 2020 is that all vehicles use Euro 2, Euro 3, or Euro 4 standards respectively.

Carbon monoxide emissions are dominated by emissions from motorcycles. Most experts in Vietnam believe emission factors will be reduced markedly over the next few years, so this is one pollutant for which the absolute level of emissions (Figure 14) is lower in 2020 than in 2005 across all three High Mass Transit scenarios with aggressive emission controls.

PHOTO CREDIT: LEE SCHIPPER

FIGURE 14 | **TOTAL CARBON MONOXIDE EMISSIONS**



As might be expected, NO_x emissions are dominated by heavy vehicles—primarily trucks, but also busses to a lesser degree. Euro 4 standard removes much of the NO_x, but the dominance of trucks remains.

Particulate matter emissions in 2005 were dominated by emissions from trucks. In the Business as Usual scenarios this domination continues, but dramatic reductions are possible if trucks (and other diesel vehicles) run with very clean diesel and particle filters. Particulate emissions from motorcycles remain low in the 2020 scenarios despite their prevalence, because most motorcycle engines are four-stroke and cleaner than the two-stroke engines.

FIGURE 15 | **TOTAL NITROGEN OXIDE EMISSIONS**

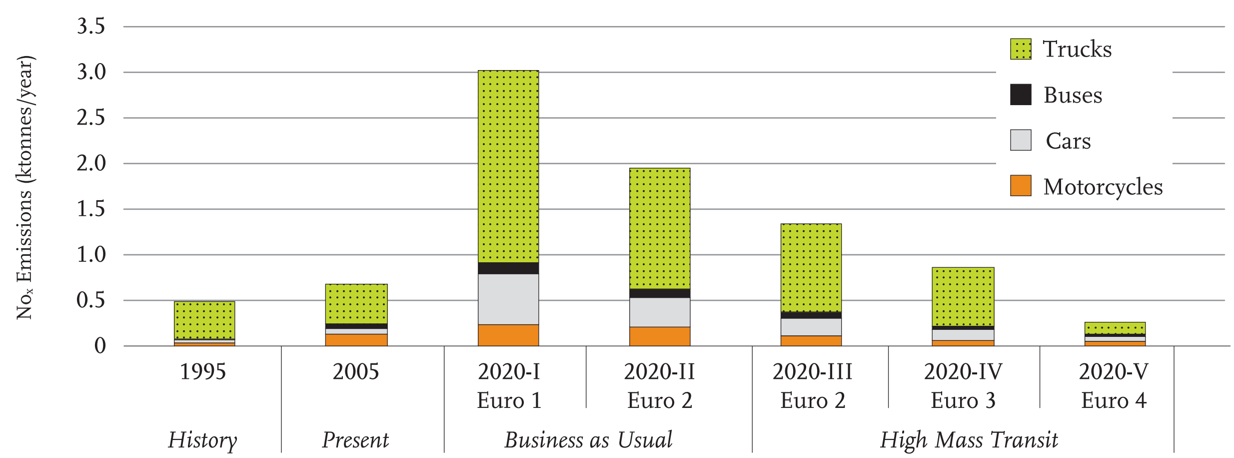


FIGURE 16 | **TOTAL PARTICULATE MATTER EMISSIONS**

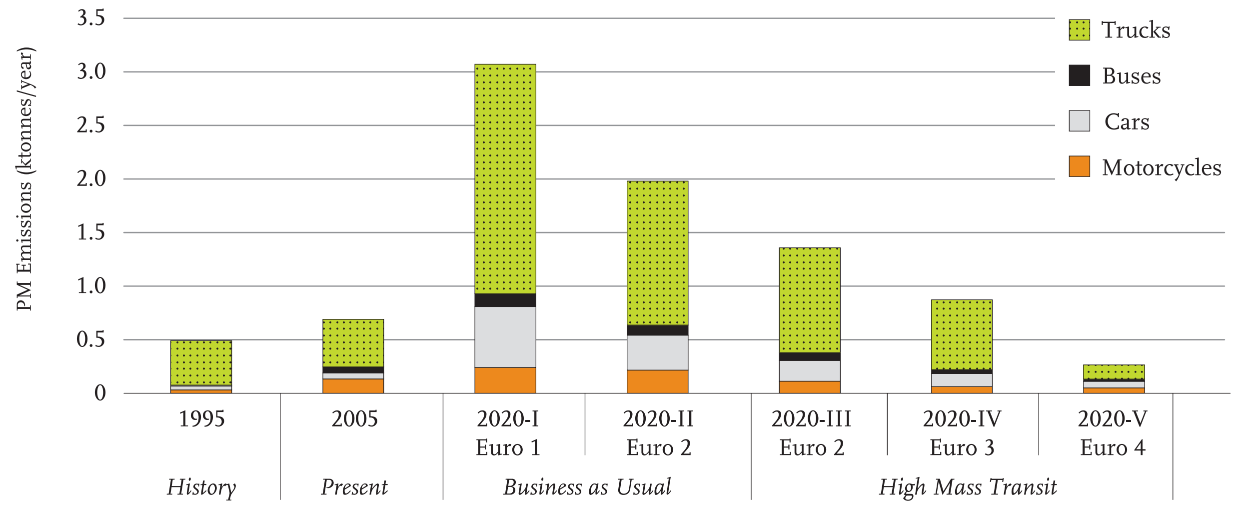


PHOTO CREDIT: LEE SCHIPPER

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LIMITATIONS AND UNCERTAINTIES OF MODEL, DATA, AND RESULTS

PROJECT BOUNDARY

This project concerns only emissions derived from combustion processes of vehicles within the project's regional boundary. This project does not consider the life-cycle emissions for fuels, vehicle types, or vehicle and road construction. This part of the life cycle of emissions typically counts for as much as 15% of the CO_2 emissions from vehicles as the CO_2 emitted to produce, transport, refine, and distribute liquid fuels (Delucchi 2003). The CO_2 emissions from building vehicles and roads are significant. Typically, the emissions from manufacturing a vehicle are roughly somewhat more than the vehicle emits in a year (Delucchi 2003). In any case, the numbers of vehicles or km of roads do not change significantly between the two scenarios—effectively, the criteria pollutant emissions like NO_x and $CO._2$ emissions from traffic activity are those that dominate and those that the city and national authorities can affect by tightening emissions standards, improving fuel quality, and strengthening transport policies, as implied in the High Mass transit Scenario.

We have not modeled the emissions from electric transport (rail or trolleys), as we have no information on the potential electricity consumption of either mode, or on future emissions of power plants in the Vietnamese system.

PHOTO CREDIT: TDSI

LACK OF LOCAL ACTIVITY DATA AND LOCAL EMISSION FACTORS

In many cases, we had to make educated assumptions about the driving cycle and average or composite emission factors for Hanoi's vehicle fleet.

Household surveys and traffic forecasts do not differentiate between different vehicle technology types, requiring the model to use an estimate of the characteristics of "typical vehicle" for each transport mode.

The estimation of the characteristics of an average vehicle needs to consider the specifications of the total vehicle fleet and the way this fleet is used. In some cases, such as for any emissions factor beyond Euro 1, or heavy-duty vehicles, specific data for Hanoi are not available even for the present situation, since no reliable measurements of the different types of vehicles have been taken. Given the lack of reliable data on distances traveled in 1995 and 2005, other than what could be estimated from previous travel surveys, the pictures for those years must remain approximate as well.

Nevertheless, the purpose of this study is to demonstrate the magnitude of emissions and energy consumption that can result from different policy options, not to develop an exact quantification of either current or future emissions. Many studies devote considerable energy to analyzing the existing situation, which is difficult enough. However, it is equally as important to try to demonstrate the effect of possible future policies, even though this can never be a precise exercise. Unfortunately more accurate data from measurements might not affect all of the emission factors equally, and certainly could not affect the annual vehicle distances, in km/year, in different ways. For example, increased congestion raises all emission factors, albeit by different amounts. But that same factor could also discourage vehicle use, which would lower emissions.

LACK OF INFORMATION ON FUTURE LEVELS OF ACTIVITY

The overall differences between 2005 and the 2020 scenarios are significant, because of the “expected” growth in overall traffic and mobility, as reflected in the HAIDEP study. The increases in pollution and CO_2 are thus illustrative of the growth one can expect under the scenario assumptions. Note, too, that each type of pollutant emission does not grow in the same proportion, because different vehicles’ utilizations (in km) grow at different rates, and each type has its own emissions profile.

Similarly, the mitigation or abatement of criteria pollutants and CO_2 emissions through the implementation of policy measures is directly proportional to the assumptions made by this study, as well as those laid out by the HAIDEP study in the original 2020 scenarios.

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PHOTO CREDIT: LEE SCHIPPER

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CONCLUSIONS AND RECOMMENDATIONS

This study demonstrated a process for combining a set of real-world transport activity observations and projections of future activity with estimates of emission factors and fuel intensity to provide present and future estimates of total emissions and fuel consumption. Not surprisingly, a future with demographic and economic growth in Hanoi and without significant improvement in vehicle efficiency or emission controls will lead to almost a doubling of passenger km traveled by 2020, more than twice the amount of current CO_2 emissions, as well as more than triple the emissions for all local air pollutants considered. Given the explosive growth in individual motorization all over Asia, and our judgment that we probably underestimated the real emission coefficients for Hanoi, the outlook there is for much greater air pollution from transport, unless strong measures are taken both to reduce emssion factors and to restrain the shift to more individual motorization, particularly cars.

The HAIDEP Master Plan projects that most of the increase in transportation demand from current levels to 2020 will be captured by a tremendous swell in car use. Walking will remain low, and bicycling will see a strong cutback from already low levels of passenger km. On the other hand, strong government promotion of public transportation and mandates for stricter fuel quality and vehicle emission standards, could significantly limit growth in local emissions, and hold CO_2 emissions to a doubling in 2020 (rather than more than tripling) of estimated 2005 levels. Excluding projected increases in emissions from trucks, the growth in passenger-related CO_2 emissions varies from a factor of 2.5 (if present trends continue) to a factor of less than 1.75 (if transport policies discourage individual vehicle use growth and vehicle efficiency improves).

This study suggests that there are two primary components to mitigating air pollution and reducing CO_2 emissions from a baseline value. Government officials can tighten vehicle tailpipe emission standards and mandate superior fuel quality. Transport management policies can also have a large impact on emissions in and of themselves, for the following reasons:

1. Transport policies can significantly affect the number of vehicle km traveled, which is a key driver of emissions. This point is illustrated by the reduction in total emissions when car and two-wheeler travel is transferred to bus and rail in the High Mass Transit scenario.
2. Transport policies that favor modes with higher load capacity over individual modes, or lead to greater use of the more efficient modes (e.g., two- rather than four-wheeled private vehicles), will lead to reduced fuel use and overall emissions because they will reduce passenger km emissions. This point is illustrated when comparing the results for the Euro 2 emission standards when applied to the 2020 Business as Usual scenario and the 2020 High Mass Transit scenario, as they differ by an order of 20% due to the different levels of public transportation penetration. It should be noted that this ratio is also a result of the following reason.
3. Increased congestion levels both raise emissions and lower the fuel efficiency of individual vehicles, effects that are represented by emission coefficients in the Business as Usual scenario.

As noted at the outset, this work is built from poorly known quantities—numbers of vehicles, yearly vehicle use, vehicle fuel intensity, and vehicle emission factors. Unfortunately, this lack of data characterizes almost every developing urban region. The results illustrate the obvious: more vehicle activity means more fuel use and emissions, while more stringent emission standards and more fuel-efficient vehicles mean less fuel and emissions (relative to the first case). But the development of the scenarios helps to illustrate that if officials decide to promote public transportation to a higher degree and to mandate stricter fuel quality and vehicle emission standards, it will be possible to keep emissions at 2005 levels while ensuring the same level of mobility to Hanoi residents.

This study also showed that the stronger the standards for fuels and exhaust, and the sooner they are imposed, the lower the emissions in the future. Emissions will be higher in 2020 than today, unless very strong measures—i.e., Euro 4—are imposed very soon so as to affect virtually every vehicle on the road by 2020.

This study used emission factors related to European levels, multiplied in one scenario by a constant 35% to reflect the increases from real traffic. Experience from EMBARQ's Istanbul Study (Unal et al., 2008) suggests these corrections may be even greater, and not uniform. Such corrections would raise the base case scenario emissions. The cases with stringent emission controls might also be underestimated, but by a lesser degree, because the traffic in this scenario, by definition, is less congested because of mass transit. Thus, our underestimates of the impacts of congestion on emissions may still capture the real benefits of stronger emission controls.

Without measures to restrain the growth in overall vehicle traffic, particularly that of individual vehicles, fuel use and emissions will grow. Conversely, measures to restrain individual vehicles in favor of mass transit will result in lower emissions and fuel use. The smaller the share of automobiles in passenger traffic, the lower the overall fuel use and emissions will be. A continued shift from two-wheelers to cars will significantly increase fuel use, even if the cars are very efficient. Such a shift would also cause enormous congestion problems, because of the lack of street space in much of Hanoi City.

Faced with the deteriorating air quality in Hanoi City, officials from the transport and environmental sectors are finally starting to worry and coordinate their efforts to improve the situation. Our results caught the attention of city and national government authorities and technical experts, as they illustrate the impact of future growth and, above all, the impact of decisions that Hanoi government authorities can make today. In addition to stimulating a public health debate, the Vietnamese parties involved acquired a new appreciation of the value of calculating local emissions and fuel consumption of different kinds of vehicles, as well as the importance of understanding actual traffic patterns.

PHOTO CREDIT: LEE SCHIPPER

Study team members planning this report in Hanoi in September, 2006 (l to r): Hans Oern, Tuan Le Anh, Lee Schipper, Pham Ngoc Tu of AVL (advisor), Wei-shiuen Ng, together with a colleague working on exposure to emissions from vehicles, Summeet Saksena.

Appendix: Assumptions

<table>
<tr><th>FACTOR</th><th>ASSUMPTION</th><th>SOURCE OF ESTIMATE</th></tr>
<tr><td>Public Transportation Share in 2020</td><td>The Business as Usual (BAU) scenario assumes that 14.5% of the trips in 2020 will be via public transportation, corresponding to an increase of 7.8 points from its 6.7% share in 2005. The High Mass Transit (HMT) scenario assumes that 30% of the trips will be by public transportation.</td><td>HAIDEP Study Prepared by ALMEC for JICA</td></tr>
<tr><td>Vehicle Emission Standards for Different Scenarios</td><td><table>
<tr><td>1995 Case</td><td>None</td></tr>
<tr><td>2005 Case</td><td>Euro 1</td></tr>
<tr><td>2020 Case1 BAU</td><td>Euro 1</td></tr>
<tr><td>2020 Case2 (BAU)</td><td>Euro 2</td></tr>
<tr><td>2020 Case3 (HMT)</td><td>Euro 2</td></tr>
<tr><td>2020 Case4 (HMT)</td><td>Euro 3</td></tr>
<tr><td>2020 Case5 (HMT)</td><td>Euro 4</td></tr>
</table></td><td>Created by this study</td></tr>
<tr><td>Load Factors</td><td><table>
<tr><th></th><th>1995</th><th>2005</th><th>2020 Case1</th><th>2020 Case2</th><th>2020 Case3</th><th>2020 Case4</th><th>2020 Case5</th></tr>
<tr><td>Motorcycle</td><td>1.5</td><td>1.8</td><td>1.4</td><td>1.4</td><td>1.4</td><td>1.4</td><td>1.4</td></tr>
<tr><td>Car</td><td>2.2</td><td>2.0</td><td>2.0</td><td>2.0</td><td>2.0</td><td>2.0</td><td>2.0</td></tr>
<tr><td>Bus</td><td>15</td><td>18</td><td>30.0</td><td>30.0</td><td>19.0</td><td>19.0</td><td>19.0</td></tr>
</table></td><td>Estimated by Hans Orn from HAIDEP study prepared by ALMEC for JICA</td></tr>
<tr><td>Gasoline/Diesel Fuel Split by Mode</td><td>Estimated Share of Vehicles Using Diesel in Hanoi (%)<table>
<tr><th>Year</th><th>1995</th><th>2005</th><th>2020</th></tr>
<tr><td>Car</td><td>6</td><td>8</td><td>25</td></tr>
<tr><td>Truck</td><td>65</td><td>68</td><td>70</td></tr>
<tr><td>Bus</td><td>48</td><td>50</td><td>55</td></tr>
</table></td><td>Estimated by Dr. Tuan Le Anh</td></tr>
<tr><td>Fuel Efficiency</td><td>Gasoline combustion engines were assumed to get only 85% of the fuel efficiency that diesel engines do.</td><td>See Schipper et al. 2002.</td></tr>
<tr><td>Vehicle Speed</td><td><table>
<tr><th>Mode</th><th>1995</th><th>2005</th><th>2020 BAU</th><th>2020 HMT</th></tr>
<tr><td>Walk</td><td>4.0</td><td>4.0</td><td>4.0</td><td>4.0</td></tr>
<tr><td>Bicycle</td><td>15.0</td><td>15.0</td><td>15.0</td><td>15.0</td></tr>
<tr><td>Motorcycle</td><td>24.8</td><td>24.8</td><td>8.1</td><td>29.9</td></tr>
<tr><td>Car</td><td>22.0</td><td>20.0</td><td>8.9</td><td>31.9</td></tr>
<tr><td>Truck</td><td>17.6</td><td>16.0</td><td>7.1</td><td>25.5</td></tr>
<tr><td>Bus</td><td>17.6</td><td>16.0</td><td>7.1</td><td>30.0</td></tr>
<tr><td>Rail</td><td>0.0</td><td>0.0</td><td>0.0</td><td>45.0</td></tr>
</table></td><td>Hans Orn from HAIDEP study pre-pared by ALMEC for JICA</td></tr>
<tr><td>Congestion Factor</td><td>A factor of 1.35 was applied to the BAU scenario, reflecting an assumed 35% increase in traffic congestion from the 2005 base. All modes of transportation were assumed to be subjected to this congestion, so there was no adjustment within modes.</td><td>Tuan Le Anh, T. Zacharides, Univ. of Cypris (priv. comm.)</td></tr>
<tr><td>Vehicle Km per Year, by Mode</td><td><table>
<tr><th>Mode</th><th>1995</th><th>2005</th><th>2020 BAU</th><th>2020 HMT</th></tr>
<tr><td>Walk</td><td>1,261</td><td>1,045</td><td>1,011</td><td>1,632</td></tr>
<tr><td>Bicycle</td><td>1,806</td><td>2,237</td><td>345</td><td>242</td></tr>
<tr><td>Motorcycle</td><td>1,039</td><td>6,608</td><td>8,741</td><td>6,139</td></tr>
<tr><td>Car</td><td>339</td><td>789</td><td>5,909</td><td>4,752</td></tr>
<tr><td>Truck</td><td>277</td><td>651</td><td>2,327</td><td>2,289</td></tr>
<tr><td>Bus</td><td>22</td><td>219</td><td>351</td><td>364</td></tr>
<tr><td>Rail</td><td>0</td><td>0</td><td>0</td><td>194</td></tr>
</table></td><td>1995 and 2005 from travel surveys of Hanoi carried out by Hans Orn. 2020 from the HAIDEP study</td></tr>
</table>

<table>
<tr><th>FACTOR</th><th>ASSUMPTION</th><th>SOURCE OF ESTIMATE</th></tr>
<tr><td>Emission Factors</td><td>See Table 1, below.
The current study used the European driving cycle as proxies—ECE R40 for motorcycles, NEDC for cars, and ECE R49 for trucks.
Some 2005 emission factors were measured for motorcycles, cars, and trucks at the Laboratory of Internal Combustion En-gine, Hanoi University of Technology. All other modes were estimated from Euro 1 limited values.</td><td>Tuan Le Anh</td></tr>
<tr><td>SO_x Emission Calculations</td><td>• 40% of the SO2 emitted is not oxidized further, and is ac-counted for as SO2 in the computation of the total weight of SOx emissions.
• 60% of the SO2 emitted is further oxidized and converted to SO4.
• The SO4 combines with molecules of water, and increases its weight by a factor of 1.39.</td><td>Tuan Le Anh</td></tr>
<tr><td>CO_2 Emission Calculations</td><td>CO2 emissions were calculated using the carbon-balance me-thod.
• CI. engines: FC=(0.1155/D) x [(0.866 x THC) + (0.429 x CO) + (0.273 x CO2)]
• SI. engines: FC=(0.1154/D) x [(0.866 x THC) + (0.429 x CO) + (0.273 x CO2)]</td><td>Tuan Le Anh</td></tr>
<tr><td>Sulfur Content in Fuel</td><td>
<table>
<tr><th>Year</th><th>1995</th><th>2005</th><th>2020 Euro1 and Euro2</th><th>2020 Euro3</th><th>2020 Euro4</th></tr>
<tr><td>Motorcycle</td><td>1.5</td><td>1.8</td><td>1.4</td><td>1.4</td><td>1.4</td></tr>
<tr><td>Car</td><td>2.2</td><td>2.0</td><td>2.0</td><td>2.0</td><td>2.0</td></tr>
<tr><td>Bus</td><td>15</td><td>18</td><td>30.0</td><td>30.0</td><td>19.0</td></tr>
</table>
</td><td>Tuan Le Anh, based on published and prospective Vietnamese standards</td></tr>
<tr><td>Fleet Fuel Intensities</td><td>We associate higher fuel intensities with the worst of the traffic scenarios in the BAU case. The better the traffic flow, the lower the emission coefficients and total fuel consumption.
<table>
<tr><th>Scenarios</th><th>1995 Case</th><th>2005 Case</th><th>2020 Case 1</th><th>2020 Case 2</th><th>2020 Case 3</th><th>2020 Case 4</th><th>2020 Case 5</th></tr>
<tr><td>Gasoline (l/km)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Motorcycle</td><td>0.030</td><td>0.025</td><td>0.046</td><td>0.031</td><td>0.023</td><td>0.020</td><td>0.018</td></tr>
<tr><td>Car</td><td>0.104</td><td>0.090</td><td>0.122</td><td>0.115</td><td>0.086</td><td>0.081</td><td>0.077</td></tr>
<tr><td>Truck</td><td>0.576</td><td>0.480</td><td>0.648</td><td>0.540</td><td>0.400</td><td>0.380</td><td>0.360</td></tr>
<tr><td>Bus</td><td>0.648</td><td>0.540</td><td>0.729</td><td>0.621</td><td>0.460</td><td>0.440</td><td>0.420</td></tr>
<tr><td>Diesel (l/km)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Car</td><td>0.088</td><td>0.077</td><td>0.096</td><td>0.091</td><td>0.073</td><td>0.069</td><td>0.066</td></tr>
<tr><td>Truck</td><td>0.492</td><td>0.410</td><td>0.510</td><td>0.425</td><td>0.350</td><td>0.330</td><td>0.310</td></tr>
<tr><td>Bux</td><td>0.480</td><td>0.480</td><td>0.574</td><td>0.489</td><td>0.400</td><td>0.380</td><td>0.350</td></tr>
</table>
</td><td>Estimated by Tuan Le Anh and Lee Schipper for this study</td></tr>
</table>

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