The role of motorized 2-wheelers in an energy efficient transport system

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Abstract

In Middle and Northern Europe motorcycling is mainly seen as leisure or sport activity. However, in many South European cities motorcycles play a vital role in daily transport. In the Asian mega cities they are even the backbone of the transport system. Some experts have expressed the opinion that motorcycles are the appropriate compromise to find a sustainable balance between the necessity to decrease the consumption of fossil fuels and the human desire for motorized mobility. One main advantage of motorcycles in comparison with private cars is their lower consumption of space. This allows higher densities and hence less congestion on the road network. While motorcycles with low cubic capacity definitely consume less fuel (per person-kilometers) than cars, the situation might be reverse for more powerful motorcycles with bigger engines. Additionally, the overall energy efficiency of the transport system decreases if short non motorized trips are replaced by longer motorcycle trips. The proposed paper aims at discussing what the circumstances are under which motorcycles can play a significant role in creating an energy efficient and sustainable transport system. Results from case studies in Hanoi (Vietnam), Bari (Italy) and Ho Chi Minh City (Vietnam) will be used for this purpose.

Introduction

DEFINITIONS AND HISTORY

A motorcycle is a two-wheeled, single-tracked vehicle powered by an internal combustion engine. First attempts to power bicycles with steam engines are recorded from the mid 19th century. In the year 1885 Gottlieb Daimler took out a patent for the first motorcycle with an internal combustion engine. 26 cubic centimeters produced about 0.4 kW. This was sufficient for about 20 km/h maximum speed. The first motorcycles produced in serial form came on the market at the end of the 19th century. In the 20th century motorcycles became a means of transport accessible for all social classes. In Europe and North America the importance of motorcycling as a means of transport gradually declined since the 1950s, when affordable cars came on the market. Motorcycling was reduced to a leisure activity for a smaller group of users. During the 1990s motorcycling started a comeback and sales numbers boomed, e.g. the number of licensed motorcycles in Germany grew at a rate of about 6 per cent per year. Today the term motorcycle comprises a wide range of different types: from mopeds powered by 50 cubic centimeters, scooters with 50 to 250 cubic centimeters and motorbikes with cubic capacity up to 1,000 cubic centimeters and even more. Motorbikes can be subdivided into several types: chopper, touring bikes, cross country bikes, naked bikes, racers, etc. Today most motorcycles are powered by four stroke engines. Two stroke engines are only common in smaller motorcycles up to about 250 cubic centimeters. Motorcycling as a sport comprises cross country competitions (moto-cross, trial, enduro, rally, hill climbing), speedway on ash, sand or grass tracks, road races in different formulas and with different cubic capacities, and acceleration competitions. During the last decade the specific power increased from 1.5 kW per liter for Gottlieb Daimlers patent to about 50 kW per liter for middle class motorbikes and to about 100 kW per liter for the most powerful motorcycles available for use on public roads. Fuel consumption ranges from about 1-2 liters per 100 kilometers for mopeds to about 3-5 liters per 100 kilometers for middle class motorcycles.

THE MOTORCYCLE IN TRANSPORT PLANNING AND SCIENCE

In the recent past motorcycling as a means of transport was out of sight for the majority of transport planners and scientists. If at all motorcycles were considered as a traffic safety problem (Assing 2002; Damen 2000; Ecker 2006; Schmidt et al. 2005). Research was focused on issues like making roadside installations less dangerous for motorcyclists (Gärtner et al. 2006; Gerlach and Oderwald 2007), improving safety equipment as motorcycle helmets (Adolph et al. 2007) or improving methods for accident investigations (Peldschus et al. 2007). (Gerlach and Oderwald 2007) developed a tool for planners to identify potentially critical road section and to select appropriate measures to mitigate the risk for motorcyclists. They showed that the risk is above average if a road section fulfills the following criteria (Gerlach and Oderwald 2007) p. 4:

a. the angle changing throughout the entire section is more than 200 gon/km,
b. a maximum of 15 changes in the road direction per kilometer occur,
c. at least 50% of the road is straight and
d. the road section is longer than 2 kilometers.

(Adolph et al. 2007) describe the results of a project which was analyzing the physiological effects of the aerodynamics and aeroacoustics of motorcycle helmets. (Peldschus et al. 2007) describe the use of finite element methods to analyze motorcycle accidents. In this work the model HUMOS (Human Model for Safety) was used to replicate cadaver tests and a fatal motorcycle crash.

As motorcycling increasingly became a life style item for wealthy middle aged males some sociologists became interested in motivational issues (Bietry-Bächly and Ewert 2008; Ohle et al. 1982). During the period from 1998 to 2007 (Bietry-Bächly and Ewert 2008) carried out a panel analysis. 600 persons were repeatedly interviewed about there motorcycling specific habits, attitudes and experiences with accidents. About 16% of the sample experienced an accident with injuries during the observation period. The majority was constantly very critical about motorcycling and consuming alcohol but less critical about speeding. (Ohle et al. 1982) studied the recreational activity and accident involvement of motorcyclists which were organized in motorcycling clubs. The main aim was to investigate the effect of peer group pressure on driving behavior and accident involvement.

Recently researchers of the National Technical University of Athens investigated the mobility patterns of motorcyclists in Greece (Yannis et al. 2007). A nationwide travel survey targeted at active 2-wheeler and passenger car drivers was carried out. The results suggest that motorized 2-wheelers are preferred for particular types of trips (e.g., traveling in residential areas and weekdays during the daytime), whereas passenger cars may be used in all cases.

Alarmed by the increasing number of motorcycles causing emission problems in Asian mega cities transport researcher picked up the topic (Ahmed et al. 2008; Chang and Yeh 2006; Lin et al. 2008). (Ahmed et al. 2008) analyze and compare the transport and air pollution problems of Beijing, China and Karachi, Pakistan, two cities which are currently passing through a rapid phase of urbanization and motorization. The work described in (Chang and Yeh 2006) combines a motorcycle usage survey from the year 2000 with corresponding records from Taiwan's Vehicle Registration System. The aim is to study the relationship between motorcycle disposal age and the implementation of motorcycle inspection and maintenance programs at the regional level. The mean disposal age of motorcycles was about 13.3 years. This indicates the possibility of a serious emission problem. In addition, the mean age of motorcycles in districts with poor inspection performance was higher than in districts with good inspection performance. (Lin et al. 2008) examines the relationship between characteristics of motorcycles and hydrocarbon emissions in the Central Air Quality Basin of Taiwan. Engine size and type, age and manufacturer of a motorcycle significantly affect hydrocarbon emissions. Larger- size engines emit smaller amounts of hydrocarbons, whereas older motorcycles emitted greater amounts. In addition, two-stroke-engines produce significantly higher hydrocarbon emission levels than four-stroke engines.

Another important topic in the Asian context is the emergence of large numbers of electric bikes especially on the roads of Chinese mega cities (Weinert et al. 2007). Annual electric bike sales in China grew from about 40,000 in 1998 to about 10 Million in 2005. Electric bikes clearly have the advantage of high efficiency and zero local emissions. The latter was the reason for local and national government bodies to promote their use by banning gasoline powered motorcycles in large city centers. Nevertheless there are also some setbacks like lead emissions from battery production and recycling and safety concerns due to their silent nature and increasing speed and weight.

THE CURRENT ROLE OF MOTORCYCLES IN DIFFERENT REGIONS OF THE WORLD

Motorcycling in developing countries

The role of motorcycling in developing countries is quite different from Europe and North America. Especially in Asian cities motorized two wheelers are the dominant mode of transport. In India the number of registered motor two wheelers was growing at a rate of 15 to 20 per cent per year from the 1950ies on. This growth rate was much higher than that of other motor vehicles. During the 1990ies 60 to 70 percent of all registered motor vehicles were two wheelers. Today in big metropolitan areas like Hanoi, Vietnam, more than 50% of all trips including non-motorized modes, and more than 85% of all motorized trips are made by motorcycle (Derstroff and Rossmark 2004; Derstroff and Rossmark 2005). Between 2002 and 2006 the number of registered motorized 2-wheelers in Vietnam grew at a rate of about 14% per year or about 70% in just four years (JAMA 2007; JAMA 2008). Motorized 2-wheelers are not only the backbone of passenger transport in these countries. As

(Kamp 2003) demonstrates in his impressive photo essay they are also the backbone of goods transport and hence the economic boom.

Motorcycling in Europe

Also in Europe motorcycles are not only used as leisure or sports vehicles. Especially in the urban agglomerations of Southern Europe motorcycles play a substantial role in transport (Yannis et al. 2007). E.g. in Athens about 7 per cent of all trips are made by motorcycle. In agglomerations with a high level of congestion like Paris the relevance of motorcycling is increasing, with motor scooters becoming in particular very popular. There is a clear trend towards bigger, more powerful motorized 2-wheelers. While in 2002 about 47% of the motorized 2-wheeler fleet were mopeds, their share decreased to about 39% in 2006 (ACEM 2008) p. 17. The total number of motorized 2-wheelers was increasing at a rate of about 2% per year.

Comparison of the situation in different regions of the world

Figure 1 and Figure 2 summarize data about motorcycle ownership and use in different regions of the world according to the World Road Statistics (IRF 2006). Figure 1[1] shows the share of motorized 2-wheelers within the fleet of motorized private vehicles, giving an indication of the relative importance of motorized 2-wheelers within the system of motorized private transport. The share of motorcycles ranges from 0.8% in the Arabian Peninsula to 73.7% in Asia. The share in Europe is about 11%. Figure 2[2] shows the share of motorcycles in the mileage traveled using individual motorized transport. The share of vehicle kilometers traveled using motorcycles ranges from 0.6% in the United States to 42.2% in Asia. The share in Europe is about 3%. These data show that as expected the average distance per trip is shorter using motorcycles than using cars.

Car ownership and to a certain extent motorcycle ownership is of course lower in countries with lower GDP per capita (Africa, Asia, South America) than in countries with higher GDP per capita (Europe, United states, Australia and New Zealand). Nevertheless if a combined motorization rate adding motorized 2-wheelers and cars is considered then some Asian countries like Malaysia or Thailand reach about the same levels than European countries (Pfaffenbichler et al. 2007). This observation is especially valid for Asian mega cities like Hanoi or Ho Chi Minh City (TDSI 2004)

A comparison of basic characteristics of motorcycles and cars

Fuel consumptions of motorcycles are, on average, considerably lower than those of cars. Besides, the lower purchase costs of motorcycles increase the access to these private vehicles even among lower income classes of users. In addition, although usually with a reduced comfort, if compared with cars, motorcycles allow avoiding congestion ensuring lower travel times and more reliable transportation even in more congested areas.

ENERGY CONSUMPTION AND CO_2 EMISSIONS

Production and operation

Figure 3 compares the primary energy consumption for the production and the use of different modes of transport on a per trip basis[3]. Summarized over their life cycle average motorcycles require only about half the primary energy per trip for the vehicle production than an average car. The operation of an average motorcycle requires only about a quarter of the primary energy than for an average car.

(DMRB 2003) summarizes a rage of speed dependent emissions factors for different vehicle types, engine sizes and emission legislations. Figure 4 compares the range of the specific CO_2-emission factors for passenger cars and motorcycles as calculated according to (DMRB 2003).

SPACE CONSUMPTION

Motorcycles consume less space than cars as well when they are in operation as when they are parked. Figure 5 illustrate the very dense parking strategy for motorcycles in Ho Chi Minh City. In operation motorcycles only occupy about 15% to 20% the space per person required by a car[4].

PURCHASE PRICE

In general motorcycles are cheaper than cars. In 2006 the purchase price of an average motorcycle in Vietnam was about $2,500-3,000. The price of a car was about ten times the price of a motorcycle. The huge difference between the two goods was mainly due to high tolls and taxes in this market. However, after the admission to the World Trade Organization tolls and taxes have to be ceased. In the Vietnamese market, this caused expectations for a heavy reduction in costs of private cars, with the purchase price of the cheapest cars falling as low as about $7,500[5].

Case studies

HANOI, VIETNAM

The project SPARKLE (Sustainability Planning for Asian Cities making use of Research, Know-How and Lessons from Europe), funded by the EU-Commission under its EU Asia EcoPro program, focused on the analysis of the transferability of European planning practice and methods to South East Asia (Emberger et al. 2007; Pfaffenbichler et al. 2007). Among the activities it included adapting the integrated land use and transport interaction model MARS (Metropolitan Activity Relocation Simulator) to the South East Asian circumstances (Pfaffenbichler 2008). An essential part of this work was the introduction of motorcycles as mode of transport on its own right (Emberger et al. 2005). A user-friendly MARS model of the Vietnamese capital Hanoi was implemented in SPARKLE (Pfaffenbichler 2008). Figure 6 illustrates the traffic conditions as observed in the Vietnamese mega city Ho Chi Minh City. The majority of the motorcycles used in Vietnam has four stroke engines which are cleaner than two stroke engines. Nevertheless their tremendous quantity and density produces very high concentrations of carbon monoxide and hydrocarbons especially in urban canyons. Figure 7[6] shows a screenshot of a simple Systems Dynamics model of the interaction between

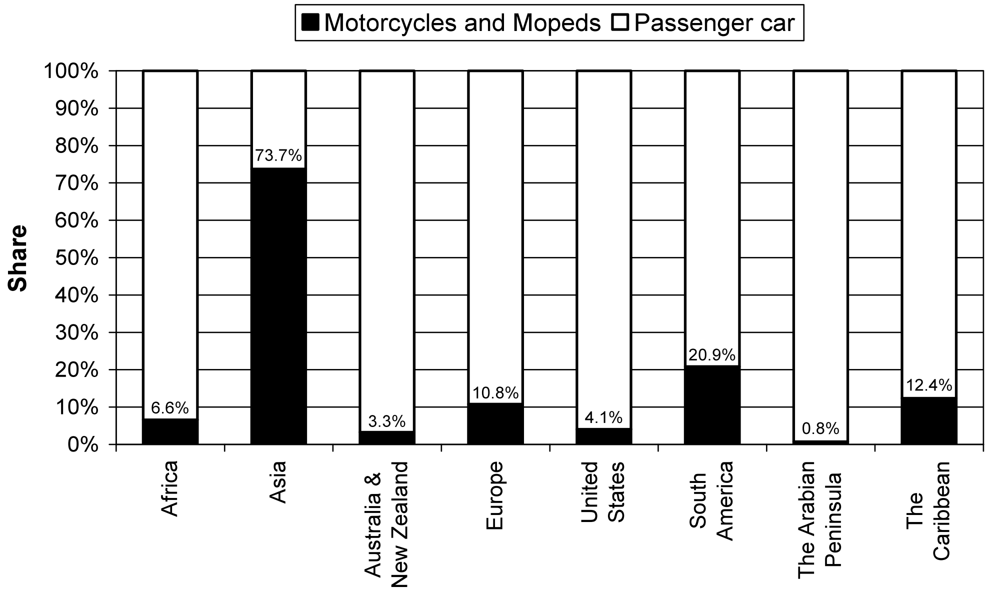

Figure 1: Share of motorcycles and mopeds and passenger cars in the fleet of motorized individual vehicles in different regions of the world. Source: (IRF 2006) p. 126 ff.

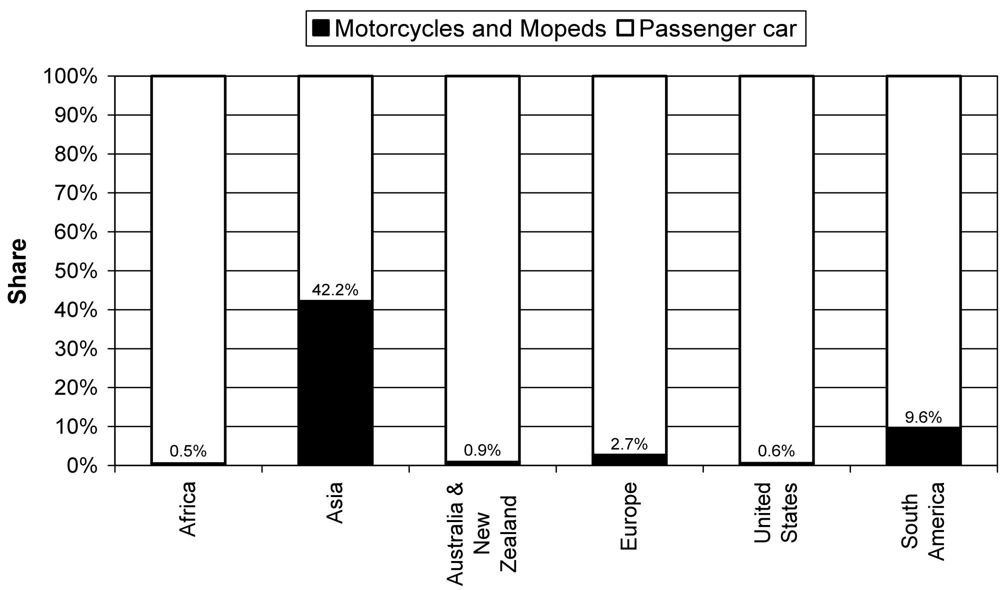

Figure 2: Share of vehicle kilometers of motorcycles and mopeds and passenger cars in motorized individual travel in different regions of the world. Source: (IRF 2006) p. 87 ff.

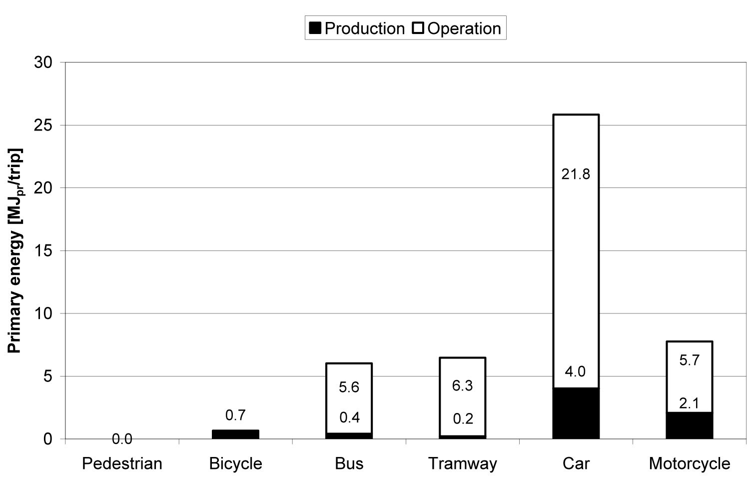

Figure 3: Primary energy consumption production and operation; Source: (Pfaffenbichler 1998; Pfaffenbichler 2001), own calculations.

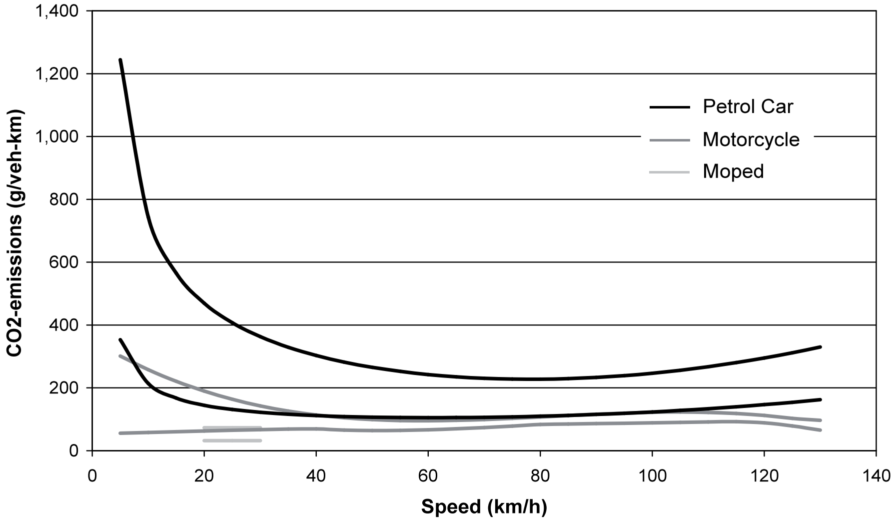

Figure 4: Range of speed dependent CO_2-emission factors for motorcycles and passenger cars. Source: (DMRB 2003)

Figure 5: Parked motorcycles in Ho Chi Minh City; © Paul Pfaffenbichler 2006

speed and flow of motorcycles and cars developed within this work. Figure 8 illustrates the speed flow relationship resulting from this model. Part of the work of the ongoing Megacity Research Project TP Ho Chi Minh – Integrative Urban and Environmental Planning Framework Adaptation to Global Climate Change will be to test and verify this simple model with data observed in Ho Chi Minh City (see also section about the Ho Chi Minh City case study below).

BARI, ITALY

A MARS model of the Italian city Bari was used in the PhD thesis of one of the authors (Circella 2007; Circella 2008). Italy is one of the European countries where motorcycles play a significant role in the (urban) transport system. In 1999 nearly a fifth of motorized individual vehicles in Italy were motorcycles (IRF 2006) p. 127. Hence it was seen as essential to cover them as a distinct mode of transport in the Bari model. The transport model of MARS-Bari considers 5 different transportation modes in the definition of choice behavior of travelers: slow mode (including cycling and pedestrian), car, motorcycle, bus, and railway. MARS-Bari simulates mode choice of travelers depending on the household availability of private vehicles. The transport model identifies four main travelers' groups, depending on their access to private vehicles (Table 1). Travelers who do not have access to a private vehicle have the following available travel options: slow mode, bus and railway. Other travelers have specific travel mode choice set depending on their availability of private vehicles. Every measure related to transportation in MARS-Bari is consequently carried out for each one of the different groups of users.

The availability of private vehicles is defined separately for cars and motorcycles, in dependence of two separate indicators for each mode: the number of people who are allowed to drive respectively a car and a motorcycle (percentage of travelers with a driver license for respectively cars and motorcycles); and the availability of cars and motorcycles in the household (access to the private vehicles, separately identified by the number of cars and the number of motorcycles per 1000 inhabitants).

The application of the model MARS-Bari to the city of Bari allowed modeling the use of the different means of transportation in this metropolitan area of Southern Europe. Results showed the high significance of motorcycles in the mode share for short/medium range trips in the area. Particularly, these results envision the relevance of this means of transportation for the future development of the area, due to the relevant number of motorcycles in this area, which is still sharply increasing. Current trends have shown that motorcycle ownership in the

Figure 6: Mixed traffic flow in Ho Chi Minh City; © Paul Pfaffenbichler 2006

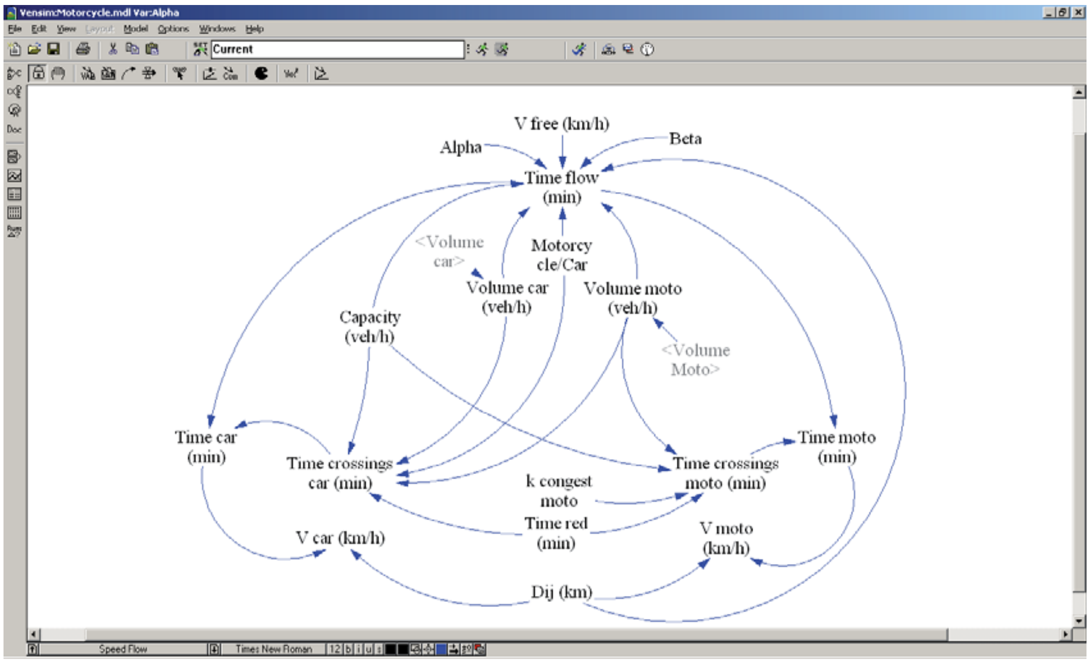

Figure 7: System Dynamics model of the interaction between speed and flow of motorcycles and cars

area of Bari has been increasing with an average growth rate of more than 6% per year in the last decade.

HO CHI MINH CITY, VIETNAM

The objective of work package 5 – Urban Transport of the Megacity Research Project TP Ho Chi Minh – Integrative Urban and Environmental Planning Framework Adaptation to Global Climate Change is to assess the potential of different urban development and transport strategies to increase energy efficiency and reduce green house gas emissions (Storch et al. 2008). A MARS model of Ho Chi Minh City will be built within this project. Part of the work will be to test and refine the consideration of the interaction between motorcycles and cars and the built up environment. As the project started only recently an operational MARS model is not yet available to assess the energy efficiency of a motorcycle based transport system. As a first step some simpler calculations have carried out.

Figure 9 shows the modal split as observed in Ho Chi Minh City in 2002 and the planned/predicted modal split of the transport system in Ho Chi Minh City in 2020. According to these plans the non motorized mode bicycle will be insignificant in 2020. The share of public transport should increase sevenfold and the share of car even tenfold. These data are used for a first estimation whether the changes would make the transport system more energy efficient or not.

The CO_2-emission is calculated using equation (1) from (DMRB 2003). It is assumed that the average motorcycle has an engine size smaller than 250 cc and is a 4-stroke engine following the 97/24/EC regulations. The average car is assumed to have an engine of 1.4 to 2.0 liters and follows the Euro II regulations. The parameters of these vehicles types as used in equation (1) are shown in Table 2. Furthermore it is assumed that busses emit 31.7 g CO_2/person kilometer and that the electricity necessary for the metro emits 8.7 g CO_2/person kilometer.

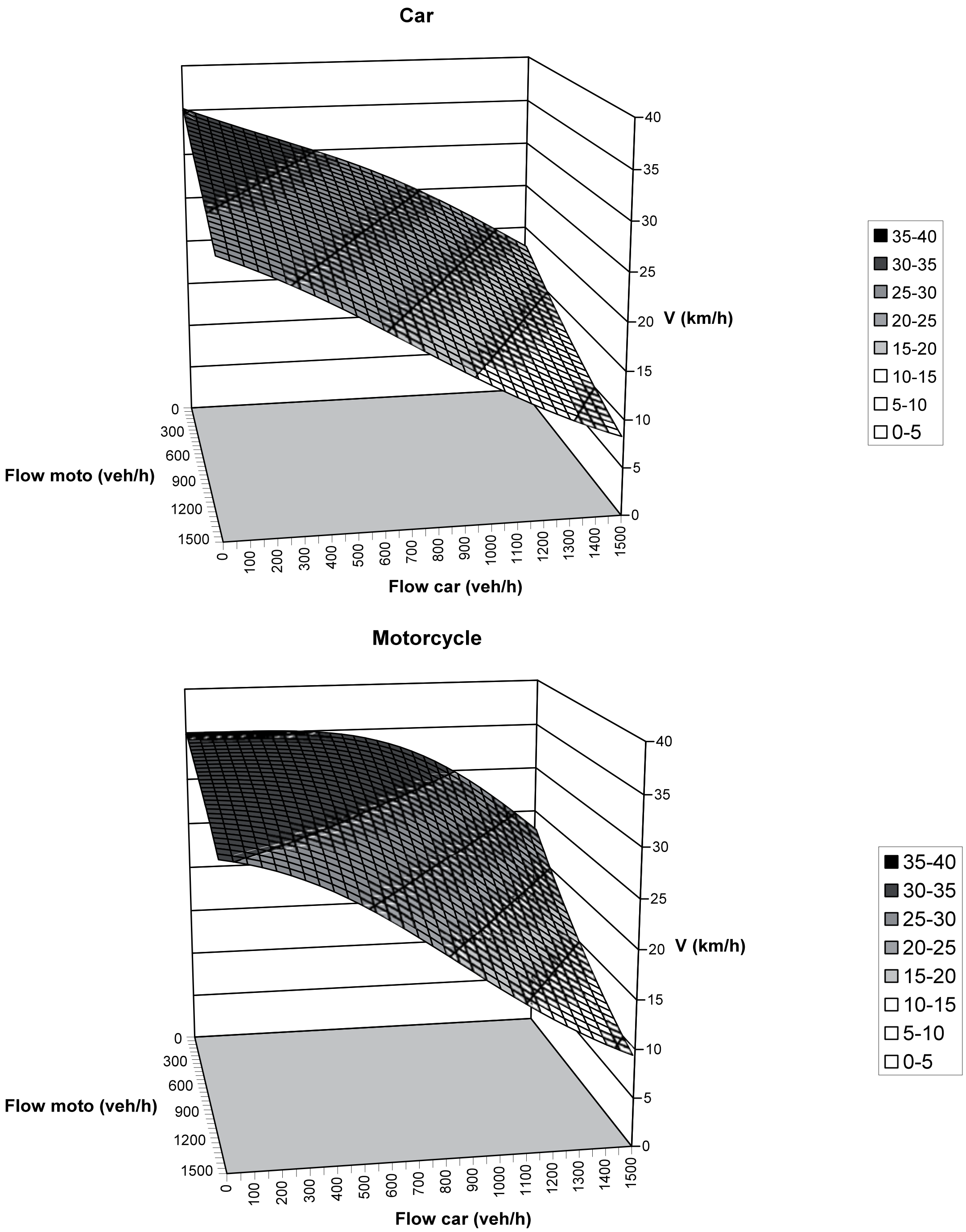

Figure 8: Diagrams of the speed flow relationship of motorcycles and cars as resulting from the simple Systems Dynamics model

Table 1: Travel modes available to different groups of users in MARS-Bari

		Access to a Motorcycle	
		Yes	No
Access to a Car	Yes	5 available travel modes*	4 available travel modes**
	No	4 available travel modes***	3 available travel modes****

Note:
** travelers can chose among car, motorcycle, bus, rail and slow mode*
*** travelers can chose among car, bus, rail and slow mode*
**** travelers can chose among motorcycle, bus, rail and slow mode*
***** travelers can chose among bus, rail and slow mode*

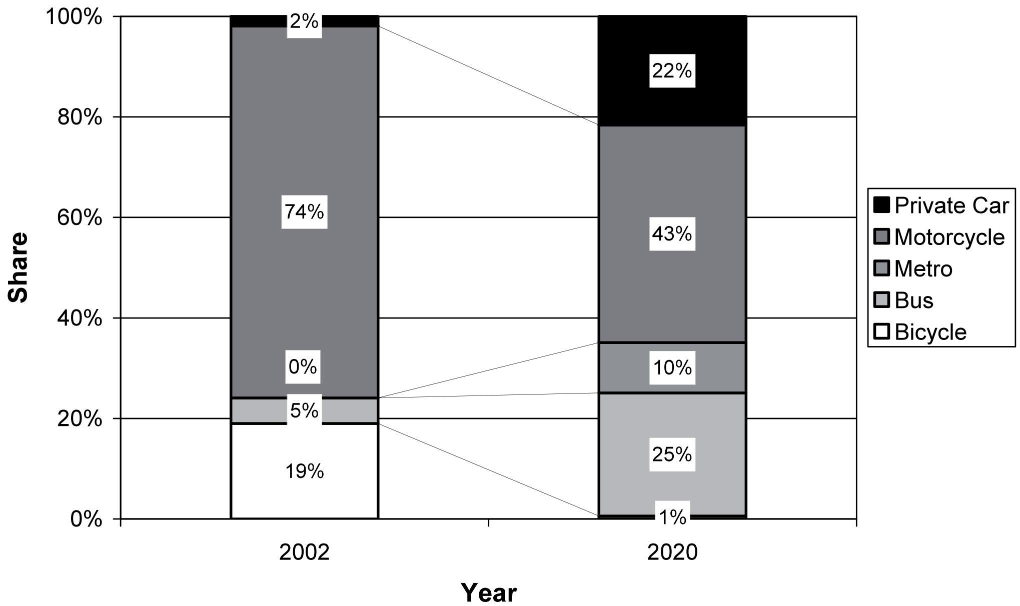

Figure 9: Modal split in Ho Chi Minh City in 2002 and 2020; Source: (Gomez-Ibanez 2008; JICA et al. 2004)

Table 2: CO2 exhaust emission factors average motorcycle and average car

Regulation	Engine size	a	b	c	g	h	i	j	x
97/24/EC	<250 cc (4-stroke)	79.9	-2.46	0.034	-1.40E-04	0	0	0	2.933
Euro II	1.4 - 2.0 l	36.25	0	0	1.32E-05	655	12.2	0	2.933

Source: (DMRB 2003)

$$E=\left(a+b*V+c*V^2+g*V^3+\frac{h}{V}+\frac{i}{V^2}+\frac{j}{V^3}\right)*x \quad (1)$$

Where:

E is the emission rate expressed in g/km
V is the average vehicle speed in km/h
a to *j*, and *x* are coefficients

The average trip length in 2002 was about 6.6 km (JICA et al. 2004). If the average trip length for each mode is kept constant then the mode share increases the trip length to about 13 km. Under the assumption that the occupancy rates and the specific emissions per vehicle kilometer are staying constant the CO_2-emissions for an average trip increase by about 100% from 377 grams to 764 grams. Part of it is caused by the move from the non motorized mode bicycle to motorized modes but part is also caused by the shift from motorcycle to cars and by the higher congestion due to the space requirements of additional cars and buses.

Conclusions

Some experts have expressed the opinion that the use of motorized 2-wheelers might be able to contribute significantly towards making the transport system of mega cities more efficient and more sustainable. While motorcycling is mainly seen as a leisure or sport activity in the US and in Europe, it is the backbone of the transport systems in the vast majority of the Asian mega cities. On the basis of commonly observed occupancy rates motorcycles use less energy and produce less greenhouse gas emissions per person kilometer than cars. Additionally, motorcycles consume less space in operation and while parked. Hence a motorcycle based transport system suits better with very high urban densities than a car based transport system. Lower densities in car oriented environments increase the average trip lengths and therefore have an adverse effect on fuel consumption and greenhouse gas emissions per trip.

Despite the important role of motorcycles in Asian (and South European) cities research into that topic is limited to issues of safety and exhaust emission regulations. The authors have worked on a series of projects which aimed at the integration of motorcycles into land use and transport interaction models. Despite the achievements made it is to early to use these models to fully asses the question of the efficiency of a motorcycle based transport system. Nevertheless we expect to make a great leap forward with new model of Ho Chi Minh City which will be created in the Megacity Research Project TP Ho Chi Minh – Integrative Urban and Environmental Planning Framework Adaptation to Global Climate Change.

In the meantime we made some first rough assessments of modal split changes as predicted in the Urban Transport Master Plan of Ho Chi Minh City (JICA *et al.*, 2004). The calculations show that the CO_2-emissions for an average trip more or less double from 377 g in 2002 to 764 g in 2020. Hence the transport system is getting less efficient. These first results indicate that motorcycles can be part of an energy efficient transport system although the details have to be clarified with more detailed models and calculations within our ongoing and future research.

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Endnotes

1 "Different regions of the world": **Africa** (Botswana, Ethiopia, Israel, Jordan, Kenya, Mauritius, Morocco, Namibia, Occupied Palestinian Territory, Senegal, Sierra Leone, South Africa, Swaziland, Syria, Tunisia, Uganda, Zimbabwe), **Asia** (Azerbaijan, Bangladesh, Bhutan, Cambodia, China, China, Hong Kong, China, Macao, Chinese Taipei, India, Kazakhstan, Korea, Republic of, Kyrgyzstan, Malaysia, Mongolia, Myanmar, Pakistan, Philippines, Singapore, Sri Lanka), **Australia and New Zealand** (Australia, New Zealand), **Europe** (Albania, Austria, Belarus, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Moldova, Netherlands, Norway, Poland, Portugal, Romania, Serbia & Montenegro, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom), **United States, South America** (Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, Guatemala, Honduras, Nicaragua, Peru), **The Arabian Peninsula** (Bahrain, Brunei Darussalam, Kuwait, Qatar), **The Caribbean** (Anguilla, Barbados, Jamaica, Maldives, Netherlands Antilles, St Vincent & Grenadines, Suriname).

2 "Different regions of the world": **Africa** (Egypt, Israel, Jordan, Senegal, Tunisia), **Asia** (Cambodia, China, Hong Kong, Kyrgyzstan, Singapore), **Australia and New Zealand** (Australia, New Zealand), **Europe** (Austria, Belgium, Croatia, Cyprus, Denmark, France, Germany, Greece, Ireland, Lithuania, Netherlands, Norway, Poland, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom), **United States, South America** (Costa Rica, Guatemala, Peru).

3 The purpose of mobility is not to cover distance but to make it possible to satisfy basic needs like working, shopping, education, leisure, recreation etc. Hence a comparison on a per trip basis is seen more appropriate than a comparison on a per kilometer basis.

4 Own calculations based on Pfaffenbichler, P. (2001). "Verkehrsmittel und Strukturen." *Wissenschaft & Umwelt Interdisziplinär*(3), 35-42.

5 Personal information. See also Pfaffenbichler, P., Emberger, G., Jaensirisak, S., and Timms, P. (2007). "Decision making processes and their interaction with transport energy consumption: A comparison between Europe and South-East-Asia." *eceee 2007 Summer Study*, La Colle Sur Loup.

6 The commercial software Vensim® from Ventana Systems, Inc. (http://www.vensim.com/) was used to build this model.

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