CHEMICAL ENGINEERING TRANSACTIONS
VOL. 72, 2019
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Jeng Shiun Lim, Azizul Azri Mustaffa, Nur Nabila Abdul Hamid, Jiří Jaromír Klemeš

ISBN 978-88-95608-69-3; **ISSN** 2283-9216
DOI: 10.3303/CET1972015

Mitigating Greenhouse Gas Emissions from Passenger Transport Sector in Megacities: A case of Ho Chi Minh City

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This research aims to propose mitigation measures to reduce the greenhouse gas emissions from passenger transport sector for Ho Chi Minh City, Vietnam. The Extended Snapshot tool is used to calculate the socio-economic development indicators and transport demand for base year 2013, and then estimate the transport demand based on the socio-economic development in target year 2030. In the base year 2013, the air pollutants (NO_2, CO, PM_{10}, Pb, etc.) are monitored at the six main stations to analyse the air pollution situation due to transportation activities. In the target year 2030, two scenarios are developed with the same socio-economic development and transport demand projections. Business-as-usual scenario does not consider the mitigation measures to reduce the greenhouse gas emissions while the countermeasure scenario does. Among the 940.5 kt CO_2-eq reduction (15.0 % of emissions from passenger transport in 2030's business-as-usual scenario), the promotion of energy-efficient vehicles helps to reduce 631.0 kt CO_2-eq, followed by 146.7 kt CO_2-eq reduction by modal shift from motorbike to mass rapid transports. The shift from fuel-motorbike to electric motorbike helps to reduce 83.2 kt CO_2-eq, together with 41.4 kt CO_2-eq reduction by shifting from conventional bus to compressed natural gas bus. The promotion of eco-driving with digital tachograph in passenger car helps to reduce 38.2 kt CO_2-eq. As the co-benefit, the air pollution due to transportation activities might be reduced thanks to the implementation of mitigation measures to reduce the greenhouse gas emissions.

1. Introduction

Transport sector is one of the main energy consumer in the world, accounts for 40 % of total energy consumption in each country, leading to the greenhouse gas (GHG) emissions and air pollution (Schwela et al., 2006) as well as serious exposure (Han and Naeher, 2006). Previous studies have shown the role of driving forces in understanding the air pollution (Driving Forces, Pressures, States, Impacts, Responses (DPSIR) framework) (European Environmental Agency, 1999) as well as the importance of advance technology in reducing air pollution (Figure 1).

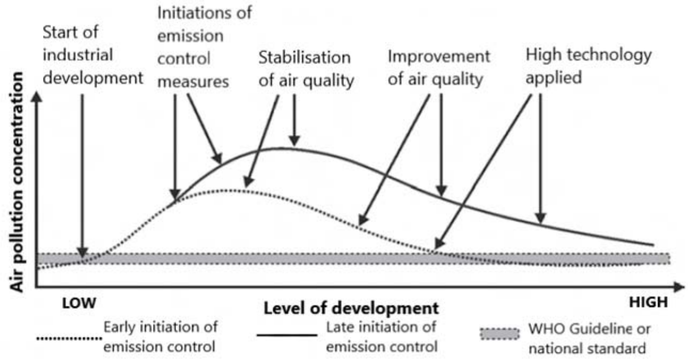

Figure 1: Development of air pollution problems in cities (UNEP/WHO, 1992)

Paper Received: 27 February 2018; Revised: 06 September 2018; Accepted: 10 December 2018

Please cite this article as: Tran T.-T., 2019, Mitigating greenhouse gas emissions from passenger transport sector in megacities: a case of ho chi minh city, Chemical Engineering Transactions, 72, 85-90 DOI:10.3303/CET1972015

The implementation of sustainable transport is essential through the advance technology for energy savings, shift to clean energy vehicles and public transport, application of smart transportation and smart supporting equipment to reduce the GHG emissions and air pollution from this sector (Contreras et al., 2016) The Extended Snapshot (ExSS) tool, which is developed by the Asia-Pacific Integrated Modelling (AIM) team, has been applied for low carbon studies in Asia such as Japan (Gomi et al., 2010), Malaysia (Ho et al., 2013), China (Cheng and Wang, 2014), Cambodia (Hak et al., 2017), etc.

There is still lack of accurate projection of transport related air pollution using driving forces information at city-level. To implement the low-carbon transport projects effectively, this research proposes an accurate estimation for passenger transport demand that is appropriated with the socio-economic development (driving forces) and transport development policy of a city. The emission reduction potential of those low-carbon projects is quantified precisely to prioritize and implement suitable projects.

As the most emerging megacity in Vietnam, Ho Chi Minh City (HCMC) is being seriously affected due to air pollution. Under the impact of climate change (Tran and Vilas, 2011), air pollution, especially from transport activities, is causing extreme consequences to the socio-economic development of the city. The air pollution due to transport activities is becoming more and more serious. The air pollution projection is important and necessary for the policy-makers and management authorities to development appropriate transport development plan (Emberger, 2016), especially the environmental friendly transportation, reduce the GHG emissions. The projection also provide the background to realize the reduction target of the city as declared in the HCMC Climate Change Action Plan (Vietnam-Prime Minister, 2013a). The targets of sustainable development (Vietnam-Prime Minister, 2015a) as well as the green growth strategy (Vietnam-Prime Minister, 2012), renewable energy development strategies (Vietnam-Prime Minister, 2015b), and the Intended Nationally Determined Contribution of Vietnam (Vietnam-Prime Minister, 2015c) are achievable. The mitigation projects for passenger transport being considered in this research are: shift from private vehicles to public transport such as mass rapid transport (MRT) (Vietnam-Prime Minister, 2015d) and bus rapid transport (BRT); shift from fossil-fuel vehicles to clean-energy vehicles and energy-efficient motorbike (Ministry of Transportation, 2015) and energy-efficient car (Ministry of Transportation, 2017); apply smart supporting devices such as digital tachographs (DT). It is expected that the reduction of GHG emissions in HCMC will gain the co-benefit to air quality and human health.

2. Methods

ExSS is a designing tool of a future society, in which socio-economic indicators, energy demand, and GHG emissions will be the results of the calculation. Its structure is highly flexible to design a wide range of future societies (Gomi et al., 2010). The results strongly depend on inputs, since the endogenous variables are inter-connected through parameters, the results are always internally consistent. Important aspects for ExSS tool are demography, economy and transport. As a low-carbon emissions measure, control of transport structure (trip distance, modal share) mainly focuses on more use of public transports. Possible transport volume by public transports strongly depends on its capacity. In ExSS tool, the passenger transport demand is driven by the population, the number of households, and the income that affecting the module’s parameters such as trip per person, trip distance, and modal share, etc (as described in Eq(1) under condition Eq(2)).

$$PTD_{ptm} = \sum_{td}\sum_{age}\sum_{hht} Pop_{age,hht} \times Ptg_{age,td} \times Pts_{td,ptm} \times Ptad_{td,ptm} \times 365 \times (\frac{1}{10^6}) \quad (1)$$

$$\sum_{ptm} Pts_{td,ptm} = 1 \quad (2)$$

ptm: passenger transport mode (walk, bicycle, motorbike, car, bus, MRT, aviation)
age: age cohort
hht: household type
td: transport destination
PTD_{ptm}: passenger transport demand (M passenger-km)
$Pop_{age,hht}$: population by age cohort and household type (population)
$Ptg_{age,td}$: trip per person per day by age cohort and transport destination (passenger-trip/population/d)
$Pts_{td,ptm}$: modal share of passenger transport (share, trip/trip)
$Ptad_{td,ptm}$: average trip distance of passenger transport (km)

The year 2013 is selected as the base year due to the availability of required data for the calculation, and the target year is 2030. Two scenarios are developed for target year 2030 with the same socio-economic

development and transport demand projection (as summarized in Table 2). Scenario 1 (business as usual – BaU scenario) does not consider the mitigation measures to reduce the GHG emissions while the scenario 2 (countermeasure – CM scenario) does. The background assumptions for scenario development is based on the master development plan for socio-economic indicators (Vietnam-Prime Minister, 2014) and the transport development plan for transport demand indicators (Vietnam-Prime Minister, 2013b). In the CM scenario, seven mitigation projects are considered under main factors: energy efficiency (the use of energy-efficient vehicles: Projects 1 and 2), driving forces (modal shift: Projects 3 and 4), energy service intensity (average travel distance, fuel shift: Projects 5 and 6), and technology support (DT: Project 7). Those assumptions are calculated together with the fuel consumption and GHG emissions calculated by ExSS tool to estimate the reduction potential of each project.
The mitigation contribution of promoting energy-efficient vehicles (EEV: car, motorbike) is calculated in Eq(3).

$$GHG\ reduction_{ptm}^{EEV} = FC_{ptm} \times \frac{DR_{ptm}}{100} \times (1 - \frac{FEC\_C_{ptm}}{FEC\_E_{ptm}}) \times EF_{"oil"} \quad (3)$$

FC_{ptm}: fuel consumption by passenger vehicles in 2030BaU (ktoe) (calculated by ExSS tool)
DR_{ptm}: diffusion rate of energy-efficient vehicles in 2030 (%) (assumed following technology changes)
FEC_C_{ptm}: fuel economy of conventional vehicles (km/L) (Report of JCM feasibility study (GEC, 2014))
FEC_E_{ptm}: fuel economy of energy-efficient vehicles (km/L) (assumed following technology changes)
$EF_{"oil"}$: emission factor of oil (kt CO_2eq/ktoe) (Intergovernmental Panel on Climate Change, 2006)

The mitigation contribution of shifting from motorbike to public transport (PT: MRT, BRT) is calculated in Eq(4).

$$GHG\ reduction_{ptm}^{PT} = MT_{"motorbike"} \times \frac{DR\_PT_{ptm}}{100} \times (EU_{"motorbike"} - EU_{"PT"}) \quad (4)$$

$MT_{"motorbike"}$: motorbike trips in 2030 (M trip) (calculated by ExSS tool)
DR_PT_{ptm}: rate of modal shift from motorbike to PT compared with BaU (%) (assumed following preference changes and policy implementation)
$EU_{"motorbike"}$: GHG emissions per transport demand by motorbike (kt CO_2/M.person.km) (calculated by ExSS tool)
$EU_{"PT"}$: GHG emissions per transport demand by PT (kt CO_2/M.person.km)
The mitigation contribution of fuel shift to electric motorbike (FS_E) and CNG bus (FS_CNG) is calculated in Eq(5) and Eq(6).

$$GHG\ reduction_{"motorbike"}^{FS\_E} = PTD_{"motorbike"} \times \left[\frac{1}{FEF\_C_{"motorbike"}} \times EF_{"oil"} - \left(\frac{FEF_{"EMB"} \times 10^6}{TU_{"motorbike"}} \times F\right) \times EF_{"electricity"}\right] \times \frac{DR_{"EMB"}}{100} \quad (5)$$

$$GHG\ reduction_{"bus"}^{FS\_CNG} = EM_{"bus"} \times \frac{DR_{"CNG"}}{100} \times \frac{ER_{"CNG"}}{100} \quad (6)$$

EMB: electric motorbike
$PTD_{"motorbike"}$: transport demand by motorbike in 2030 BaU (M.person.km) (calculated by ExSS tool)
$FEF\_C_{"motorbike"}$: fuel efficiency of existing motorbike (M.person.km/ktoe) (calculated by ExSS tool)
$FEF_{"EMB"}$: fuel efficiency of electric motorbike (kWh/km) (Terra Motors Corporation)
$TU_{"motorbike"}$: number of passengers per motorbike (person/unit) (Report of JCM feasibility study)
F: conversion factor from kWh to ktoe
$EF_{"electricity"}$: emission factor of electricity (kt CO_2eq/ktoe) (calculated by ExSS tool)
$DR_{"EMB"}$: diffusion rate of electric motorbike in 2030 (%) (assumed following preference changes and policy implementation)
$EM_{"bus"}$: GHG emissions by bus in 2030 BaU (kt CO_2eq) (calculated by ExSS tool)
$DR_{"CNG"}$: diffusion rate of CNG bus (%) (assumed following preference changes and policy implementation)
$ER_{"CNG"}$: GHG emissions reduction rate by CNG bus (%) (calculated by ExSS tool)
The mitigation contribution of promoting eco-driving with DT is calculated in Eq(7).

$$GHG\ reduction_{"car"}^{DT} = FC_{"car"} \times \frac{DR_{"car"}^{DT}}{100} \times \frac{FEF\_IR_{"car"}^{DT}}{100} \times EF_{"oil"} \quad (7)$$

$DR^{DT}_{"car"}$: diffusion rate of eco-driving with DT (%) (assumed following preference changes and policy implementation)

$FEF\_IR^{DT}_{"car"}$: improving rate of fuel efficiency by eco-driving with DT (%) (JCM project in HCMC)

3. Results and discussion

3.1 Driving forces of transport related air pollution in HCMC

In 2030 the population of HCMC is assumed to increase 1.37 times, and the gross domestic products (GDP) will increase 4.41 times (Table 1), leading to the rapid increase in transport demand.

Table 1: Main socio-economic indicators in HCMC

	Unit	2013	2030	2030/2013	Calculated Annual Growth Rate
Population	person	7,939,752	10,869,565	1.37	2.1%
No. of households	household	1,277,338	2,717,391	2.13	5.4%
GDP per capita	M. Dongs	96	310	3.22	7.5%
GDP	B. Dongs	764,560	3,373,415	4.41	9.8%

The volume of passenger transport will increase 1.83 times, from 75,357 M.person.km in 2013 to 138,204 M.person.km in 2030 (Table 2). In which, there is a rapid increase of demand on car (including taxi) to 5.06 times, although motorbike still dominates. The modal share (by trip) of public transports increases from 4.9 % in 2013 to 30.0 % in 2030BaU and reaches 37.0 % in 2030CM due to the contribution of public bus and MRT system as substitution of private vehicles (motorbike and car), following the targets in urban transport development plan for HCMC. This research assumes only the modal shift from motorbike to public bus and MRT, so the passenger transport demand of other modes (walk, bicycle, car, aviation) are the same for BaU and CM scenarios (Table 2).

Table 2: Projection of passenger transport volume in HCMC

	2013	2030BaU	2030CM	2030BaU/2013	CM/BaU
Passenger transport (M.person.km)	75,357	138,204	138,204	1.83	1.00
Walk	338	514	514	1.52	1.00
Bicycle	1,424	2,166	2,166	1.52	1.00
Motorbike	59,546	52,370	44,038	0.88	0.84
Car	7,227	36,598	36,598	5.06	1.00
Bus	4,673	36,073	43,287	7.72	1.20
MRT	0	7,215	8,332	-	1.15
Aviation	1,893	2,879	2,879	1.52	1.00

3.2 Transport air pollution and GHG emissions in HCMC

The results of transport air pollution of HCMC in 2013 from six main semi-auto monitoring stations within the city (Figure 2) are collected from the HCMC Environmental Protection Agency with relevant standards (Table 3). Except Pb and CO, other air pollutants exceeds the standards, especially at the AS station. In term of average value, the PM_{10} exceeds the standard, while other pollutants are still under the national standard (QCVN 05:2013/BTNMT).

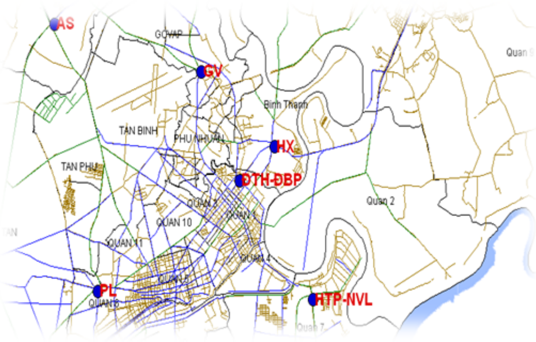

Figure 2: Location of six main semi-auto monitoring stations (AS, GV, HX, DTH-DBP, PL, HTP-NVL) in HCMC

As calculated by ExSS tool, the GHG emissions from passenger transport sector in HCMC is around 3,705 kt CO_2-eq (2013), accounts for 12.3 % of total GHG emissions in HCMC. Due to the driving forces shown in Table 1 and Table 2, the GHG emissions from passenger transport sector in HCMC is projected to be 6,414 kt CO_2-eq (2030BaU), which is around 1.70 times increase as compared to 2013. The increasing of transport demand and GHG emissions in the atmosphere will lead to the significant increase of air pollutants and may exceed the air quality standards.

Table 3: Air pollution situation in HCMC

	Monitored value in 2013 *(Unit: μg/m³ per h)*							Standard
	AS	GV	HX	DTH-DBP	PL	HTP-NVL	Average	(Vietnam-MONRE, 2013)
CO	12,810	15,660	9,670	13,260	9,100	9,139	11,600	30,000
PM_{10}	620	520	430	500	500	480	508	300
NO_2	200	170	160	190	170	170	180	200
Pb	0.39	0.33	0.31	0.4	0.37	0.37	0.36	1.5

3.3 Mitigation measures for passenger transport in HCMC

The total reduction potential in passenger transport sector is 940.5 kt CO_2-eq, from 6,414 kt CO_2-eq in 2030BaU to 5,473 kt CO_2-eq in 2030CM (15.0 % reduction). This reduction is estimated based on the change in energy efficiency (the use of energy-efficient vehicles: Projects 1 and 2), driving forces (modal shift: Projects 3 and 4), energy service intensity (average travel distance, fuel shift: Projects 5 and 6), and technology support (Project 7). In Project 1 (promotion of energy-efficient car), the diffusion rate of energy-efficient car is assumed to be 30 %, together with the assumed fuel economy of energy-efficient car is 20 km/L (8 km/L more efficient than conventional car). The increase in diffusion rate and fuel economy helps to reduce the fuel consumption of passenger car (925.6 ktoe in 2030BaU) and thus reduce 327.7 kt CO_2-eq. In Project 2 (promotion of energy-efficient motorbike), the diffusion rate of energy-efficient motorbike is also assumed to be 30 %, together with the assumed fuel economy of energy-efficient motorbike is 50 km/L (19 km/L more efficient than conventional motorbike). The increase in diffusion rate and fuel economy helps to reduce the fuel consumption of passenger motorbike (902 ktoe in 2030BaU) and thus reduce 303.3 kt CO_2-eq. In Project 3 (shift from motorbike to MRT), the rate of modal shift from motorbike to MRT is assumed to be 5 %. This shift helps to reduce the travel demand using motorbike (52,400 M trip in 2030BaU). As the GHG emissions per transport demand of MRT is only 0.53 % of motorbike (calculated by ExSS tool), the shift from motorbike to MRT helps to reduce 62.9 kt CO_2-eq. In Project 4 (shift from motorbike to BRT), the rate of modal shift from motorbike to BRT is also assumed to be 5 %. This shift also helps to reduce the travel demand using motorbike (52,400 M trip in 2030BaU). As the GHG emissions per transport demand of BRT is only 0.37 % of motorbike (calculated by ExSS tool), the shift from motorbike to MRT helps to reduce 83.8 kt CO_2-eq. In Project 5 (shift from conventional motorbike to electric motorbike), the diffusion rate of electric motorbike is assumed to be 5 %. The fuel efficiency is drastically improved leading to the reduction of energy consumption. The shift to electric motorbike helps to reduce 83.2 kt CO_2-eq. In Project 6 (shift from conventional bus to CNG bus), the diffusion rate of CNG bus is assumed to be 30 %. With 20 % of GHG emissions reduction by CNG bus, the shift to CNG bus helps to reduce 41.4 kt CO_2-eq. In Project 7 (promote eco-driving with DT), the diffusion rate of eco-driving with DT in passenger car is 20 % and the iimproving rate of fuel efficiency is 7 %. The increase in diffusion rate and fuel efficiency helps to reduce the fuel consumption of passenger car (925.6 ktoe in 2030BaU) and thus reduce 38.2 kt CO_2-eq.

4. Conclusion

This research bridges the gap of using driving forces information (socio-economic development, development strategies and policies) to project the air pollution and propose mitigation measures for passenger transport sector at city-level. The implementation of sustainable transport is essential through the advance technology for energy savings, shift to clean energy vehicles and public transport, application of smart transportation and smart supporting equipment to reduce the GHG emissions and air pollution. As the population increases 1.37 times and the GDP increases 4.41 times, the passenger transport demand in HCMC increases 1.83 times, leading to 1.70 times increase of GHG emissions from passenger transport sector. The air pollution in HCMC is also getting worse and exceeding the national standard due to the rapid increase in transport demand and frequent traffic congestion. By successfully implementing the seven mitigation projects proposed in this research, HCMC might reduce 15.0 % (940.5 kt CO_2-eq) of GHG emissions in this sector, and thus reduce the air pollutant such as NO_2, CO, PM_{10} and Pb. To achieves more stringent reduction potential in transport sector, HCMC should increase the diffusion rate of energy-efficient vehicles; increase the shift to public transport (MRT, BRT), electric motorbike and CNG bus; as well as promoting the use of digital tachograph for eco-driving as assumed in this research. Although these projects are in the list of HCMC Climate Change Action Plan, the feasibility of these projects is very much depended on the technology availability of transport sector and cost effectiveness in HCMC.

Acknowledgments

This research is funded by International University - VNUHCM under grant number T2017-02-DEE.

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