Macroscopic Design of Measures to Realise Low-Carbon Land-Use Transport Systems in Asian Developing Cities

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Abstract

Developing a low-carbon system has become an important constraint in land-use transport planning. Although many cities in Asian developing countries have not prioritised the development of low-carbon land-use transport systems yet, their rapid economic growth increases their responsibility for CO₂ emissions from transport. In order to realise such systems, it will be necessary to introduce advanced technologies and drastic land-use transport measures actively in a leap-frog manner. Such a policy package can be comprehensively designed with strategies to avoid unnecessary travel demand, shift travel to lower-carbon modes and improve the intensity of transport-related emissions, as part of the thus-named ASI (Avoid, Shift, Improve) framework. This paper proposes a backcasting method to design measures macroscopically within the ASI framework for the realisation of a low-carbon land-use transport system in the long-term future of Asia’s developing cities. This method sets a future vision of a land-use transport system with instrumental measures suitable for Asian developing cities, such as transit development (shift), land-use development control (avoid), and vehicle technology advancement (improve). Then, it applies a macroscopic urban model for the approximate estimation of long-term changes in transport demand and for capturing the necessary level and timing of measures to achieve the challenging CO₂ mitigation target by 2050 in megacities. This paper also discusses opportunities for advancing macroscopic urban models further for a more comprehensive design of measures for Asian developing cities by clarifying the existing limitations of the model.

Key words: Asian developing city, backcasting, low-carbon land-use transport system, macroscopic urban model

1. Introduction

In coming decades, significant growth in CO₂ emissions is expected to be caused by Asian developing countries. While they still have many low-carbon cities in the early stage of motorisation, their rapid economic growth could cause more serious environmental problems than developed countries. The growth in the transport sector is notably larger than that in other sectors. In particular, the level of transport-related CO₂ emissions depends on the level of motorisation. Thus, it is an important and urgent issue to decouple growth in CO₂ emissions from economic growth by designing measures to develop a low-carbon land-use transport system. Such a system should be developed in a leap-frog manner by extensively applying advanced technologies along with strong intervention in land-use transport planning.

Transport planning in Asian developing cities, however, takes insufficient account of these issues. To reduce traffic congestion caused by growing motorisation, many of their transport policies have prioritised road development over railway development. Road development could contribute to a reduction in traffic congestion if roads are used mainly by mass-transit systems, such as buses. This approach, however, often encourages more private car traffic in the long term and consequently more CO₂ emissions. Recently, although they have increased their investment in railway infrastructure development, the level of development is still overwhelmed by that of road development. Furthermore, a lack of land-use planning has resulted in promotion of urban sprawl in an unplanned manner, which makes car use more convenient. The existing approach is far from the leap-frog development of a low-carbon transport system. This failure may result in significant damage not only to the environment and but also to the economy through more serious congestion.

A backcasting approach would be useful for designing measures necessary for the realisation of a low-carbon land-use transport system in the long-term future.
Traditionally, land-use transport planning has paid more attention to short-term measures by estimating their probable impacts on existing urban land-use transport systems as a forecasting approach. On the other hand, as more countries are required to set challenging long-term targets for CO₂ mitigation, it has become more important to identify the measures necessary to achieve them by using a backcasting approach. This approach has been applied in various fields for the last 20 years, and was introduced into transport research in the late ‘90s (POSSUM, 1998; OECD, 2000). More recently, the VIBAT <http://www.vibat.org/index.shtml> project has quantitatively analysed low-carbon transport systems with this approach by testing the possibility of emissions mitigation under scenarios combining technological improvement and behavioural change.

There are two key aspects to a backcasting approach: setting future visions of transport systems and designing policy packages to realise these visions (Banister & Hickman, 2011). The policies are generally classified into three types of low-carbon transport strategies: to avoid unnecessary travel demand (AVOID), to shift travel to lower-carbon modes (SHIFT) and to improve the intensity of transport-related emissions (IMPROVE). These strategies were originally proposed as the ASI framework (GTZ, 2007), and since then, they have become popular in academic research and policy making. Various policy and technology options in the ASI framework were summarised in a project called CUTE (Comparative study on Urban Transport and the Environment) conducted by WCTRS (World Conference on Transport Research Society) SIG11 for Transport and Environment. The CUTE project classified them further as instruments in a systematic way as the CUTE matrix (Nakamura et al., 2004).

This study aims at proposing a method of macroscopic design of long-term measures within the ASI framework to realise low-carbon land-use transport systems which would be generally applicable to Asian developing cities. First, it summarises the conceptual framework of how to design measures suitable for Asian developing cities using a backcasting approach. Then it applies a macroscopic urban model to backcasting the necessary levels of transit development and urban compaction, given technology advancement, to achieve the target of 70% CO₂ mitigation from passenger cars in Bangkok, Beijing, Shanghai and Delhi from 2005 to 2050. Finally, it discusses how to develop tools for comprehensive design of measures for Asian developing cities by advancing a macroscopic urban model.

2. Framework for Designing Measures to Realise a Low-carbon Urban Transport System

2.1 A vision of the future socioeconomic background

Future visions of transport systems consist of A) one for the socioeconomic background and B) another for physical land-use transport systems (Fig. 1). While the former is a fixed background scenario based on future prospects, the latter can be controlled by patterns of policy implementation. A socioeconomic vision covers expected trends of economic and population growth and targets for benefits to be achieved by the development of a future land-use transport system. It is suggested that large-scale economic growth is expected in Asian developing countries for the next few decades. On the other hand, population growth may be relatively limited as the shift toward an ageing society accelerates. For instance, the UN world population forecast (2010) shows that the population in Thailand may start decreasing from 2035.

The targeted benefits include not only CO₂ mitigation for climate change, but also reduced air pollution, traffic noise and traffic accidents, with increased mobility, amenities and so on, as co-benefits (POSSUM, 1998; OECD, 2000; Herran & Matsumoto, 2012). Although all the benefits should be comprehensively taken into account in the assessment for development, which benefits should be prioritised depends on social acceptance. Research on low-carbon transport systems is generally interested in CO₂ mitigation and mobility improvement. Nevertheless, while many Asian developing countries care about air pollution as a cause of health problems, CO₂ mitigation has received much less attention. Moreover, as their transport planning is likely to prioritise mobility improvement through time saving with conventional cost-benefit assessments, it does not favour low-carbon transport measures which would compromise economic growth. Banister (2011) pointed out the limitation of such conventional assessments in a backcasting approach, and suggested that it is more important to assume a future scenario based on a different ideology from the current situation, in which the necessity of CO₂ mitigation would be generally recognised even in Asian developing countries.

Economic growth may also change travel behaviour through changes in demand for mobility. In the early stages of urban growth, a trend toward motorisation is clearly shown with a significant increase in car ownership both in developed and developing countries. On the other hand, in large, developed cities in Japan and Europe,
per-capita car ownership has recently started to decline. This implies that preferences for transport modes become increasingly diverse according to urban growth. Such behavioural changes may be attributed to economic growth and the development of land-use transport systems.

2.2 A vision of a low-carbon urban transport system and measures to realise it

Various visions of low-carbon transport systems have been analysed in previous studies, paying more attention to changes in transport demand and vehicle technologies (POSSUM, 1998; OECD, 2000; Hickman & Banister, 2007; Crozet & Lopez-Ruiz, 2010). These visions are generally based on a decrease in travel distance, an increase in public transport use, and advancement of LEV (Low-Emission Vehicle) technology, corresponding to the strategies of *avoid*, *shift* and *improve*. The Institution for Transport Policy Studies (ITPS, 2011) examined the balances of necessary policy implementation among the ASI strategies by global region, taking account of the local contexts of planning policies and technology levels.

However, these studies do not sufficiently specify instruments to realise visions of low-carbon land-use transport systems by identifying the necessary amount of policy implementation rather than simply assuming changes in transport demand. This may be attributed to the uncertain relationship between supply and demand in a future land-use transport system. As instruments are more useful for decision makers in planning, it is important to set physical visions with more specific measures, such as the levels of urban compaction (*avoid*), public transport networks (*shift*) and LEV penetration (*improve*) (Fig. 2).

Measures for ASI strategies are classified by the CUTE matrix into technological, regulatory, informational and economic instruments. What combination of measures would be more desirable for Asian developing cities is decided mainly by the level of economic growth and the existing land-use transport system. Technological and regulatory instruments may be more effective for them because they need to expand transport capacity for growing demand in a planned way in the early stages of urban growth (Hayashi *et al*., 2011; Nakamura & Hayashi, 2012). Typical transport measures are reviewed below to identify what measures would be suitable for Asian developing cities (Table 1), considering their contexts.

a) *AVOID*

High-density development has been strategically introduced along transit lines in some developed cities. In Japan, urban railway companies have taken the initiative to develop new towns around their lines to secure railway ridership since the early 20th century. Singapore and Curitiba implemented development plans to expand the city by concentrating land-use development along newly-developed mass-transit lines with help of strong regulation of land-use control from the 1970s (Goodman *et al*., 2006). These can be seen as early examples of Transit Oriented Development (TOD).

However, urban sprawl has been overwhelming due to rapid growth of motorisation in Asian developing countries. In the Bangkok Metropolitan Region (BMR), the built-up area has expanded by four times during the last 40 years. This is attributed to weak land-use control and lack of coordination between agencies in transport planning and land-use planning. Nevertheless, while the effects of such compact development on CO₂ mitigation are suggested to be limited in developed cities (TRB,

Table 1  CUTE matrix measures suitable for Asian developing cities.
2009), they may be more effective in Asian developing cities which are likely to have an exceptionally large amount of prospective development in the early stages of urban growth. Once development takes place in a sprawling manner, it requires much more money and time to regulate land use in built-up areas. Thus, earlier compact development may be much more effective in developing cities than in developed cities.

b) SHIFT

While many transport policies in Asian developing countries have prioritised road development, megacities have started to develop large-scale urban railway networks since the late 20th century. In Bangkok, the development of urban railways has amounted to approximately 80 km with further planned extension of the total lines to 500 km by 2030. Shanghai has developed the largest-scale underground network in the world, 420 km in total as of 2010, and it is still being developed through further extensions. Hosting international mega events, such as the Olympics in Beijing and the EXPO in Shanghai, has significantly contributed to such large-scale developments.

Mega infrastructure development is not always affordable, however. In particular, as Asian developing countries may become ageing societies by 2050, tax revenue may become less available for such investment. Bus Rapid Transit (BRT), which is a bus system with an extensive network of dedicated lanes, is popular among developing cities as a low-cost mass-transit mode. While a BRT network is as large as an urban railway network, it does not need extensive infrastructure construction. Moreover, BRT can be flexibly integrated with railway trunk lines and feeder buses to form a hierarchical transport network. Thus, it can provide a city-wide transport system at a reasonable cost, which amounts to around 10%-30% of that of a normal urban railway. Technically, BRT is not categorised as railway development, but rather needs road development for bus lanes. Nevertheless, BRT and railways have a similar characteristic in that both use dedicated transit space. Furthermore, most roads are initially developed for private cars. Thus, this study includes BRT development in railway development, in which development of on-road BRT lanes is regarded as railway development.

BRT was introduced into Curitiba, Brazil, in 1974 as the earliest example, and into Bogota in 2000. These systems have successfully shifted car use to BRT use with less reliance on public subsidies (Robinovitch & Hoehn, 1995; Goodman et al., 2006; Hidalgo, 2008). BRT has become popular in Asian developing cities. It is reported that approximately half of the world’s BRT systems are currently operated in Asia, including Chinese cities, Bangkok and Jakarta (Sutomo et al., 2012). Jakarta’s BRT, which was opened in 2004, has been developed to the largest-scale network in the world.

c) IMPROVE

The improve strategy depends less on planning, but more on technology levels, as vehicle technologies have kept improving for lower CO₂ emissions. Conventionally, the regulation of emissions standards has been introduced into many Asian countries. However, CO₂ is unlikely to be covered by these emissions standards. In Japan, both fuel economy and emission intensity have been regulated by a top-runner programme, in which the latest technology levels are set as minimum requirements for future production in five years. These regulations have helped to develop low-emission vehicles, such as EVs and HVs.

Recently, economic instruments to promote low-emission vehicles have become increasingly popular in combination with regulatory instruments. Asian car industries have been strong, led by Japan and Korea, and have become stronger with the growing market in developing countries, particularly China. The high potential of LEV development is recognised by governments with strong support. In Japan, the government has provided subsidies and tax discounts for purchasing low-emission vehicles. Thanks to them, the number of HVs was doubled from 2009 to 2010. The high level of vehicle technologies may increase their availability for nearby Asian developing countries.

2.3 Modelling long-term impacts of measures on CO₂ emissions from urban transport

In order to identify the level of measures necessary for realising a low-carbon land-use transport system, their long-term impacts on CO₂ emissions from urban transport need to be estimated. Although there are various co-benefits, this study focuses on CO₂ mitigation as a primary concern in modelling.

As land-use and transport databases are not well-established in Asian developing cities, transport-related CO₂ emissions have been estimated in a simple way. Comparative studies on CO₂ emissions among international cities have been likely to analyse the cross-sectional relationship between factors of an urban land-use transport system affecting emissions, as in the well-known relationship between population density and energy consumption (Newman & Kenworthy, 1989). Kaya’s Identity (1990) simply accounted for the level of emissions with population, GDP per capita, energy use per unit of GDP and emissions per unit of energy consumed. In a similar way, key factors affecting transport-related emissions are identified as trip generation (travel distance), car dependency (modal split) and technology level (emission factor), which respectively correspond to the avoid, shift and improve strategies. Each trip generation and car dependency factor needs to be further broken down to more detailed factors of the land-use transport system affecting them, such as railway/road development, car ownership, built-up area and density.

These approaches, however, do not sufficiently consider paths of the dynamic nature of changes in a land-use transport system. The paths reflect the development process of a land-use transport system and consequent changes in travel behaviours. Transport infrastructure development and spatial development are long-term pro-
cesses, which makes them almost irreversible. Earlier implementation of measures in land-use transport planning would make it more possible to realise paths for lower emissions, and vice versa. The study on Japanese cities found that cities with more railway development had lower rates of expansion of built-up areas (Nakamura et al., 2011a). While there are already differences in the paths of Asian developing cities from developed cities due to differences in existing land-use transport systems, prospective economic growth could lead to a wide range of changes in their future paths. Therefore, the causality mechanism of dynamic changes in a land-use transport system needs to be captured by identifying key factors affecting trip generation, car dependency and technology level (Fig. 3).

To model these dynamic changes, an urban model could be useful for a backcasting analysis, as well as for a forecasting analysis. Urban models have been established that are well able to capture the causality mechanism of land-use transport changes, as in land-use transport models. These models range from simplified macroscopic models using aggregate data to detailed microscopic models using disaggregate data. The former model is advantageous for analysis of the impact of economic growth on travel demand thanks to better coverage of data, while differences in individual behaviours can be better considered by the latter model.

Nevertheless, urban models are poorly developed for long-term estimation of travel demand, which is required more by backcasting analyses. Wegener (2010) modelled the impacts of fuel price rises on long-term changes in travel behaviours by applying constraints of cost and time budgets for individual travel as relatively stable indicators over the long term to a microscopic urban mode. However, the analysis is designed for case-study analyses with extensive data on individual travel behaviour. It is not easy to collect such detailed data in Asian developing cities.

Moreover, in developing the model for long-term estimation, it is more important to set a scenario of behavioural changes in the long-term future than to calibrate parameters for them with current data. Particularly in Asian developing countries, analysis relying on current data is inappropriate for representing drastic changes in land-use transport systems. A model for backcasting is aimed not at improving the accuracy of forecasting, as in conventional models, but at illustrating the range of future scenarios, based on the assumption that the long-term future is uncertain. Crozet (2010) developed a nationwide transport model for France, which introduced explanatory scenarios of long-term behavioural changes in travel. Nevertheless, the scenarios were too hypothetical, directly setting transport demand to capture the impact of measures on transport demand.

On the other hand, a scenario of long-term behavioural changes in Asian developing cities can be designed by referring to the experience of developed cities. Although the rate of economic growth in Asian developing countries is expected to be larger than that experienced in Japan for the past 40 years, their forecast of per-capita GDP in 2050 is not beyond the current level of Japan (Fujimori et al., 2011). Thus, it is reasonable to assume that the general mechanism of motorisation would be similar between developing and developed countries. If Asian developing cities invest in public transport development, such as railway and BRT, taking advantage of economic growth, a corresponding drastic shift to public transport use may be expected.

3. Application of a Macroscopic Urban Model to Backcasting Necessary Measures

3.1 Case study cities

This study develops a simplified macroscopic urban model to represent the long-term paths of changes in key factors of a land-use transport system for the period up to 2050. The case study cities are Bangkok, Beijing, Shanghai and Delhi as Asian mega-cities with rapid eco-

![Fig. 3 Dynamic tracking of transport-related CO₂ emission mechanism (WCTRS, 2011).](image-url)
nomic growth. The population of these cities is more than 10 million people. Nevertheless, they have chosen completely different development processes from Japanese cities for their land-use transport systems.

In Asian developing megacities, car ownership is much higher than it was in Tokyo in the motorisation period at the same economic level of Gross Regional Product (GRP) (Fig. 4), despite their similar levels of city size. There are two key reasons for this: road-oriented development and urban sprawl. The level of road development is comparable between Asian developing cities and Japanese cities (Fig. 5). While Bangkok and Shanghai still have a lower level of development than Tokyo, those in Delhi and Beijing are higher. Despite the high level of road development, the capacity in Bangkok does not keep up with the growth of road traffic demand and roads are fully packed with cars (Hayashi, 1996).

On the other hand, Asian developing megacities have much lower levels of urban railway development than Tokyo. Asian developing cities have significant growth in railway development, as Beijing and Shanghai have doubled the number of stations from 2005 to 2009 (Fig. 6). Nevertheless, despite the growth, their station density in built-up areas is much lower than in Tokyo, 1.26 (stations/km²), and Nagoya, 0.59 (stations/km²). Although extensive extension of urban railways to 509 km is planned in Bangkok by 2030, the prospective station density would be only 0.29.

Road-oriented development promotes urban sprawl by extensively improving mobility in the suburbs. Indeed, many Asian developing cities are still high-density, low-carbon cities in the middle of urban growth. In Shanghai and Delhi, population density in built-up areas is more than 20,000 (people/km²), which is higher than the density of Tokyo, which has around 15,000 (people/km²) in 2005. However, urban sprawl is more serious in Bangkok and Beijing, which are relatively low-density, with around 10,000 and 13,000 people/km², respectively.

3.2 Model flow

A simplified macroscopic urban model has been developed to estimate the impact of economic growth on CO₂ emissions from passenger cars in the case study cities (Nakamura et al., 2011b). Figure 7 shows the input-output flow of this macroscopic urban model. The model is designed to analyse the long-term impacts on CO₂ mitigation of urban mass-transit development (shift), land-use development control (avoid), and vehicle technology advancement (improve). Mass-transit modes include urban railways and BRT. The dynamic process of motorisation and urban sprawl according to economic growth is modelled to estimate travel demand, considering the impacts of transit development and land-use development control to slow the process. After that, CO₂ emissions from passenger cars are estimated from the travel demand and given emission factors based on a technology advancement scenario. This model is run for each five-year period from 2005 to 2050.

To develop the model, this study used the Japanese panel data of these factors from travel surveys and statistics for eleven large Japanese cities. The model was developed with city-level panel data on Japanese cities over the 40 years from the 1960s to 2000s as their motorisation period under the assumption that Asian developing cities would show similar long-term changes in travel behaviour due to development of land-use transport
systems during economic growth. The advantage of this model is better applicability without detailed input data, which are unlikely to be available in Asian developing cities.

### 3.2.1 Car ownership model

The mechanism of motorisation is modelled in such a way that economic growth, road development and urban sprawl increase car ownership (1 in Fig. 7). Car ownership \( C \) (cars per capita) is estimated by the model expressed in equation (1) using population density \( d \), road length per capita \( r \) and household income standardised by vehicle price \( I \). The upper part of the equation represents potential demand for cars with the Cobb-Douglass-type function of low density and road development. Car ownership is affected not only by the potential demand but also by affordability. Thus, the bottom part of the equation represents the logistic function of income level. The \( \gamma \) parameters decide the impacts of these factors on car ownership.

\[
C = \frac{\gamma_1 \cdot r \cdot d^{2} \cdot I^{3}}{\left(1 + \gamma_4 \cdot \exp\left(-\gamma_5 \cdot I\right)\right)}
\]  

(1)

The parameters of models (1) and (2) are calibrated by regression analysis using the panel data of Japan’s largest cities (Toga et al., 2010) and are adjusted to match the existing data of Asian cities.

### 3.2.2 Modal split model

An increase in car ownership leads to an increase in car use (2 in Fig 7). The model estimates the aggregate modal share \( P_m \) of each transport mode \( m \) with their city-wide characteristics \( chr_m \) (2). It uses a set of binary logit models: a choice between walking and motorised modes, one between private and public transport modes, one between cars and motorcycles, and one between conventional buses and urban railways. The city-wide characteristics \( chr_m \) include population density \( d \) for walking \( chr_{walk} \), motorcycle ownership \( MC \) for motorcyclists, car ownership \( C \) for car use \( chr_{car} \), and station density in built-up areas \( st_b \) for railway use \( chr_{rail} \). The share of bus use is estimated as the remaining share of public transport minus the share of railways. Motorcycle ownership \( MC \) is assumed to decrease according to economic growth, as people increasingly prefer cars in private transport. The parameter \( \pi \) represents the impact of each characteristic on the modal share. The model is developed with data on railway use, but it intends to represent use of mass-transit modes, including BRT. In the model, while car use is increased by growth in car ownership, transit use is increased by transit development.

\[
P_m = \exp\left(\pi_{m_1} \cdot chr_m + \pi_{m_2}\right) \sum_{k=1,2} \exp\left(\pi_{k_1} \cdot chr_k + \pi_{k_2}\right)
\]

\[
chr_{walk} = d
\]

\[
chr_{car} = C
\]

\[
chr_{rail} = st_b
\]

(2)

As in the car ownership model, this model uses long-term Japanese data for calibration. Car use is likely to be higher in Asian developing cities than in Japanese cities at the same economic level. Thus, the initial values of vehicle price and the mode parameters \( \pi_{m_2} \) are adjusted to meet the current level of preference for each mode. For long-term forecasts, the model assumes that transit use becomes more popular as the networks are developed further. Accordingly, the parameters are set to be changed proportionally to the ratio of station density in Bangkok to that in Tokyo in 2005.

### 3.2.3 Urban sprawl model

Urban sprawl is modelled (3 in Fig. 7) by estimating growth in built-up areas \( \Delta S_b \) according to growth in population \( \Delta POP \) and standardised income \( \Delta I \) in equation (3), in a way that leads to lower population density.
(Nakamura et al., 2011a). On the other hand, transit development could slow sprawl according to the number of stations $s_{th}$ in habitable areas by locating more people around stations. By modelling the growth rate, rather than the built-up areas themselves, it can capture the cumulative change in built-up areas, which are hard to reduce once developed. This is a linear regression model, in which the parameter $\delta$ represents the impact of each factor on growth in built-up areas. As in the previous models, this model uses long-term Japanese data for calibration. Population density can be calculated from the estimated built-up areas. To model the interaction between urban sprawl and motorisation, the estimated population density is fed back to the car ownership model (1) and the modal split model (2). Land-use development control can be introduced into the amount of new development by controlling the percentage of development not allowed to expand built-up areas and lower population density.

$$\Delta s_{ht} = \delta_1 \cdot \Delta pop + \delta_2 \cdot \Delta I - \delta_3 \cdot s_{ht} + \delta_4$$

(3)

In this model, the urban structure is simply captured using the total built-up area and the average population density of a city, without considering their spatial distribution. To take account of urban structure, the model can also be advanced by introducing a spatial model to estimate the location choices of the population by modal split. In the model for Bangkok (Nakamura et al., 2012), household location behaviours of rail users and non-rail users are modelled for the proximity to stations based on the different preferences.

3.2.4 Car travel distance model

The expansion of built-up areas makes travel distance longer (4 in Fig. 7). The car trip distance $l_{car}$ is estimated with a linear regression model, using the inputs of built-up area $S_b$ and road length per capita $r$ in equation (4). The parameter $\delta$ represents the impacts of these factors on car-travel length, with calibration from long-term data (Nakamura et al., 2011a).

$$l_{car} = \delta_1 \cdot S_b + \delta_2 \cdot r + \delta_3$$

(4)

3.2.5 Emission factor model

$CO_2$ emission factors are estimated based on traffic congestion, fuel economy and LEV penetration (5 in Fig. 7). Traffic congestion is modelled in a simple way to estimate the average on-road vehicle speed $v$ with a single-linear function, using a variable to represent the balance between demand of the total car distance $L_{car}$ and supply of the total road length $R$ in equation (5), along with the parameter $\varepsilon$ for the impact on the speed.

$$v = \varepsilon_1 \cdot \ln \left( \frac{R}{L_{car}} \right) + \varepsilon_2$$

(5)

$$L_{car} = C \cdot \varepsilon$$

$$e = \frac{CF}{f(v,tec)}$$

(6)

The emission intensity depends on the composition of vehicles by fuel type, where LEV penetration can reduce emission intensity. This model classifies passenger cars as gasoline vehicles, HVs and EVs, differentiated by levels of fuel economy and emission intensity. While the emission intensity of gasoline is fixed in the model, the intensity of electricity is estimated using the intensity of electric power generation, considering changes in the composition of power generation sources over time, such as coal, petroleum, natural gas, nuclear, water and biomass. The level of total $CO_2$ emissions from passenger cars is calculated by multiplying the emission factor by car travel distance.

The model ends up with estimation of changes in $CO_2$ emissions from passenger cars from changes in car travel distance and emission factors by vehicle type.

3.3 Policy options and technology scenarios

The model is applied to the case study cities, with the study area of Bangkok covering the BMR region, including the hinterland. Future scenarios of socio-economic changes and technology advancement are set as exogenous inputs to the model. First, a socio-economic scenario for Asian developing cities is set based on existing forecasts for GRP and population (Fig. 8). Population growth in Thailand is not significant, and is expected to decline by 2050. As no official data on the floating population are available in Bangkok, this study assumes that 5% of the population of Thai regions outside the BMR would live in the BMA as a floating population. As a result, the whole population of the BMR is set at 14 million in 2005, to increase by 7% from 2005 to 2050.

This study compares two types of future scenarios, a Low-Carbon Society (LCS) scenario, in which the targeted level of $CO_2$ mitigation would be achieved through implementation of policies and technologies for low-carbon transport strategies, and a BAU scenario, in which no technology advancement, transit development or land-use development control would take place from 2010 (Do-Nothing). BAU is an extrapolative scenario based on the current trend of Asian developing megacities, in which travel distance increases as built-up areas expand and car use becomes more dominant. On the other hand, LCS assumes that transit development is
promoted over road development and transit use becomes increasingly extensive, as was experienced in Tokyo. Policy and technology options in each scenario are listed in Table 2.

In LCS, land-use development control and urban transit development would be implemented for avoid and shift. For avoid, land-use development control would be introduced outside existing built-up areas to control the rate of expansion of the built-up areas with greenbelts. Many Asian cities are not familiar with strong land-use development control and overwhelmed by the land market, therefore, this option might be less favourable for them. For shift, future development would increase the number of stations at the same pace. As in the recent extensive development of railways, this option might be more acceptable, although there might be financial and organisational issues for implementation.

To identify effective processes of policy implementation for avoid and shift, the impact of railway development timing on car ownership is analysed with the model in the case the study cities. In the case that railways are developed up to the level of the station density of the habitable area of Tokyo, 1.13 (stations/km²), the result shows that earlier development from 2010 would reduce car ownership by nearly 10%, compared to later development from 2030, although the levels of development are the same by 2050 (Fig. 9). This suggests that urban transit development and a compact urban form should start earlier before they become car-dependent cities. Accordingly, this study assumes that land-use development control and urban transit development have started from 2010.

In terms of improve, although technology advancement in Asian developing cities may be less than in developed countries, a leap-frog approach is required for designing low-carbon transport systems by actively applying advanced technologies in developing countries. Therefore, the future level of technology advancement, such as Tank to Wheel (TtW) and vehicle weight, and LEV penetration is set based on the forecast for Japan (Yamamoto et al., 2010). In Asian developing countries, Japanese cars are popular, and this may contribute to the spread of technology advancement from Japan to Asian developing countries. This study assumes that the same level of technologies in Japan will be available in Asian developing countries from 2020. The future composition of power generation for EVs is also set based on the existing forecast for each Asian country (Fujimori et al., 2011). In this forecast, the power source shifts from petroleum and coal to nuclear and biomass, although nuclear generation is no longer favourable due to the serious incident in Fukushima caused by the Great East Japan Earthquake.

Figure 10 shows changes in the emission factors of LEVs and their composition in LCS, in which the emission factors do not consider the impact of traffic congestion on speeds and fuel economy. BAU assumes no changes in vehicle technologies and LEV composition from 2005 to 2050, although the change in power generation is assumed to be the same as in LCS. Considering the impact of traffic congestion on fuel economy, the average emission factor among LEVs in BAU would rise by 51% from 0.315 (kg-CO₂/km) in 2005 to 0.476 in

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**Table 2** Policy and technology options.

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<th>BAU (Do Nothing) Scenario</th>
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<tr>
<td>No technological advancement from 2010</td>
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<td>No transit development from 2010</td>
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<td>No land-use development control from 2010</td>
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<th>Low-Carbon Society (LCS) Scenario</th>
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<td>AVOID</td>
<td>Land-use development control</td>
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<tr>
<td>SHIFT</td>
<td>Urban transit development</td>
</tr>
<tr>
<td>IMPROVE</td>
<td>Tank to Wheel improvement</td>
</tr>
<tr>
<td></td>
<td>Lighter vehicle weight</td>
</tr>
<tr>
<td></td>
<td>LEV penetration</td>
</tr>
<tr>
<td></td>
<td>Low-carbon power generation</td>
</tr>
</tbody>
</table>

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**Fig. 9** The impacts of urban railway development timing in Asian developing megacities.
2050. On the other hand, in LCS, the average emission factor would significantly improve to 0.085 in 2050.

3.4 Identifying necessary measures

The required contribution of each strategy to targeted CO\textsubscript{2} mitigation is identified as a backcasting approach. The model estimates growth in CO\textsubscript{2} emissions of 119\% in Bangkok, 524\% in Beijing, 714\% in Shanghai and 776\% in Delhi from 2005 to 2050. Bangkok’s emissions growth is relatively lower than those of the other cities because the prospective population growth is lower there. This study sets a target of 70\% reduction in CO\textsubscript{2} emissions from passenger cars in 2050 from the level of the year 2005.

While there are a number of ways to combine these strategies as a policy package, this study simply introduces each strategy in the order of social acceptance, improve, shift and avoid. First, the scenario of technology advancement for the improve strategy is applied. Then, transit development for shift is applied up to the level of station density in built-up areas of Tokyo in 2005, which follows the application of land-use development control for avoid up to no urban expansion. If the application of all the strategies is insufficient, transit development is further increased to meet the target mitigation.

The contributions of the ASI low-carbon transport strategies to the 70\% mitigation of CO\textsubscript{2} emissions are identified for Bangkok, Beijing, Shanghai and Delhi (Fig. 11). Improve would significantly reduce CO\textsubscript{2} emissions by around 75\% from BAU in 2050. The details of the technology advancement scenario include TiW efficiency to be improved by 284\% and vehicle weight to be lighter by 24\% from 2005 to 2050. For LEV penetration in 2050, the shares of HVs and EVs in passenger cars are set to be 35\% and 65\%, respectively, while the current share of EVs is quite small. A source shift of electric power generation from coal to nuclear and biomass would reduce the emissions factor of electric power.

![Fig. 10 Emission factor improvement and LEV spread in LCS.](image1)

![Fig. 11 The necessary contribution of the ASI strategies to 70\% CO\textsubscript{2} mitigation.](image2)
generation by 32% in Thailand, 51% in China and 47% in India from 2005 to 2050.

However, the application of improve by itself would be insufficient to meet the mitigation target. More contribution is required from shift and avoid. Figure 12 shows how much car ownership growth needs to be reduced with the avoid and shift strategies to achieve the 70% mitigation. Beijing, Shanghai and Delhi need to reduce car ownership growth by around 40% from BAU in 2050. In Bangkok, the necessary reduction of car ownership growth is smaller, around 20%, as their emissions growth is relatively lower than those of the other cities.

According to the contribution of each strategy to the 70% mitigation, this analysis identifies the necessary levels of transit development and land-use development control as a policy package (Table 3). It reveals that drastic changes both in transit development and spatial development are required to achieve the mitigation target.

### Table 3 Necessary levels of policy implementation for LCS.

<table>
<thead>
<tr>
<th></th>
<th>SHIFT</th>
<th>AVOID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stations/km² of built-up area (times higher than 2010 level)</td>
<td>% of allowed expansion of built-up area to total demand</td>
<td></td>
</tr>
<tr>
<td>Bangkok</td>
<td>1.26 (34)</td>
<td>14.8</td>
</tr>
<tr>
<td>Beijing</td>
<td>2.91 (29)</td>
<td>0.0</td>
</tr>
<tr>
<td>Shanghai</td>
<td>2.24 (9)</td>
<td>0.0</td>
</tr>
<tr>
<td>Delhi</td>
<td>1.26 (9)</td>
<td>2.7</td>
</tr>
</tbody>
</table>

The results for all the cities suggest that railways need to be developed at least up to the current level of Tokyo, with new development hardly allowed to expand built-up areas.

In particular, the largest changes will be required for Beijing, where the necessary station density is three times higher than that of Tokyo, and no expansion of built-up areas should be allowed. This implies that Beijing is already too sprawling to be made compact, and it will require much more implementation of transit development for low carbonisation than the level of the current extensive development.


While a macroscopic urban model is advantageous for applicability to multiple cities in general, more consideration is needed for comprehensively designing measures to realise low-carbon land-use transport systems in Asian developing cities. This chapter summarises what the limitations of a macroscopic urban model are and how it can be developed further to a more comprehensive tool integrated with other analyses.

#### 4.1 Scenarios of future behavioural changes in location and travel

One of the biggest difficulties in estimating transport demand in the long-term future is how to take account of behavioural changes in location and travel in an urban model. While a macroscopic urban model can hardly incorporate detailed behavioural models, it needs to
introduce simplified scenarios regarding behavioural changes. This study assumes that the future modal split in Asian developing countries will depend on transport infrastructure development in a simple way based on the experience of Japan.

However, the local contexts of behaviours are not captured well in these scenarios. For instance, people in Southeast Asia may prefer driving more to avoid hot weather. People are also eager to own cars as a symbol of their status. These local contexts generate captive demand for car use and make the model developed with data on Japanese cities less applicable to representing current trends in transport in Asian developing cities. On the other hand, car use can be controlled by local policies. Beijing and Shanghai have controlled car ownership by limiting the number of car license plates allowed to be used on the roads. It is not certain how future economic growth will change the demand for car use attributable to these local contexts, which cannot be captured from Japanese experience. Accordingly, such behavioural differences in location and travel need to be considered more in the behavioural assumptions.

Moreover, Japanese experience represents only one possible future scenario for Asian developing cities. As the process of infrastructure development may generate different types of land-use transport systems, long-term behavioural changes in cities all over the world, such as Europe and South America, need to be referred to for setting various future scenarios. Also, future scenarios need to be creative to cover what nobody has experienced yet. Particularly, the future aged society may change behaviours in location and travel even in Asian developing countries.

4.2 Nationwide analyses of urban transport

CO₂ emissions from urban transport need to be analysed in different types of cities. Asian developing countries consist of a few megacities and many small towns with completely different characteristics. It is difficult to define the proper boundary of a megacity within which most trips are completed, as they often have large areas of surrounding hinterland areas in the suburbs. Analyses of intra-city travel demand should include these hinterland areas because urban sprawl brings more people there and generates longer trips to cities. Whether the travel demand from hinterland areas to city areas is made by public transport or by cars makes a large difference in traffic congestion and the resulting CO₂ emissions. While Tokyo has quite a large hinterland area outside the 23 inner-city wards area, 94% of commuting trips from the hinterland area to the inner city area use railways thanks to the high level of suburban railway development. Therefore, the boundaries need to be carefully set in analyses.

On the other hand, a macroscopic urban model for megacities is hardly applicable to small towns in Asian developing countries. Railways may not be a desirable low-carbon transport mode for all cities if they do not secure sufficient levels of ridership. In small towns, the size of transport vehicles needs to be appropriate for the demand for ridership, where buses and paratransit vehicles can be low-carbon transport modes for trunk lines. Accordingly, a more comprehensive macroscopic model than the one for megacities needs to be developed with nationwide data on cities.

4.3 Design of urban forms and hierarchical transport networks

As a low-carbon land-use transport system cannot be realised only with railway development and land-use development control, more details of the system need to be considered. Due to the low level of railway development in Asian developing cities, their railway systems require more complementary on-road public transport systems to establish hierarchical transport networks integrating trunk lines and feeder transport. The trunk lines of railways can be complemented by bus and paratransit depending on the level of demand, where BRT and paratransit are appropriate for the highest demand in trunk lines and lower demand in feeder systems, respectively.

However, such integration of public transport systems is extremely poor in Asian developing cities, due to lack of coordination among transport agencies. Therefore, there is a great opportunity for improvement by designing integrated networks of on-road public transport linked to railway networks in a way that reduces obstacles to transfers and improves the levels of traffic congestion. In Seoul, where excessive provision of buses caused serious traffic congestion in the city centre, the traffic situation was significantly improved by separating bus routes for the city centre and suburbs, and introducing a smart card for payment for both buses and railways along with a distance-based revised fare system.

Moreover, the considerable amount of prospective development from economic growth makes it possible to change land-use systems drastically in Asian developing cities into the TOD forms, as in Curitiba. Accordingly, a macroscopic urban model needs to be integrated with case-study analyses to take account of the impacts of these complementary measures, which may reduce the necessary level of transit development for the low-carbon system.

4.4 Urban growth scenarios from inter-regional transport analyses

As economic growth in Asia will result in development of not only urban transport systems but also inter-city transport systems, the impacts of national and international development on urban transport demand need to be considered. Currently in Asian developing countries, most economic activities are likely to be concentrated in megacities. Whether future growth will be concentrated in existing megacities or dispersed into other small cities will depend on the pattern of international and national levels of transport network development. In China, coastal cities have grown more thanks to the advantages of shipping transport, and the develop-
ment of high-speed railways and airlines is expected to shift further growth into inland cities. It is worthwhile to analyse which types of national and international development would reduce CO₂ emissions, with mono-centric growth to develop existing megacities further or poly-centric growth to develop more middle-sized cities. Accordingly, a macroscopic urban model needs to be integrated with an inter-regional transport analysis to take account of patterns of future growth in cities.

4.5 Assessing feasibility of policy implementation

While the primary aim of a backcasting approach is to identify the necessary levels of policy implementation, how feasible their implementation will be needs to be assessed to some extent. Key elements of the feasibility of low-carbon transport systems for Asian developing cities are institutional capacity, financial feasibility and social acceptance. The institutional capacity to manage advanced integrated land-use transport systems is qualitatively assessed, particularly for lack of coordination among transport operators, transport planners and land-use planners.

On the other hand, financial feasibility and social acceptance are assessed more quantitatively in terms of international financial schemes for development of low-carbon systems and distribution patterns of accessibility improvement benefits among different income groups. Such extensive development of railways, as identified in this paper, may not be self-financed by the governments of Asian developing countries. Cost-effective BRT development may be a more favoured option for them unless the development makes traffic congestion worse by reducing road capacities for private traffic. This is often the case in Asian developing cities, as BRT development has become popular in Asian developing cities. Moreover, financial schemes play an important role in their development. While the international scheme of carbon trading introduces an additional carbon price into transport fuel consumption, the marginal cost of CO₂ mitigation from railway development could be lower than the carbon price. This suggests that railway development is more effective for investments. It is also necessary to compare the mitigation costs in developed countries and developing countries in order to promote the application of a CDM (Clean Development Mechanism) to long-term transport projects.

Furthermore, social acceptance needs to be assessed by ascertaining whether the development of low-carbon transport systems would improve liveability, including accessibility, as a co-benefit. Attention should be paid to any gaps in accessibility levels between rich and poor people in Asian developing countries due to economic disparities. High-income people are likely to live in city centres, which exclude lower-income people, who move into suburbs with lower access to public transport, although they may need it more. They need to be taken into account when assessing levels of policy implementation, with further analysis of financial feasibility and accessibility.

5. Conclusions

This study proposes a method of designing measures to realise a low-carbon transport system for Asian developing cities. The method is designed to analyse the impacts of economic growth on motorisation and urban sprawl on CO₂ emissions and the policy package of measures on mitigation in Asian developing countries. Their characteristics are summarised as the identification of suitable instruments, the application of a simplified macroscopic model and consideration of dynamic paths of policy implementation.

Development of a low-carbon land-use transport system for Asian developing cities requires not only setting a future vision but also identifying the measures necessary for its realisation. In research on transport and climate change, future scenarios often include both a future vision of a transport system and a roadmap of measures. Transport demand, such as travel distance and modal split, however, is more likely to be set in the roadmap scenario without considering the level of policy implementation. In designing measures for a low-carbon transport system, consideration of what measures are needed is more useful for policy makers. The ASI framework has become popular even in Asian developing countries (UNCRD, 2010). Further classification by instrument, as in the CUTE matrix, can help identify suitable measures for Asian developing cities in a more systematic way.

To identify the necessary level of policy implementation, transport demand in the long-term future needs to be estimated using an urban model. Although data for urban modelling are not sufficiently available yet in Asian developing cities, an increasing number of studies have developed urban models there. As data become more available, it may be easier to develop more detailed models. Urban modelling, however, is often time-consuming when details are modelled. The issues of climate change require urgent actions, which cannot wait for such detailed models to be developed. Particularly in Asian developing countries, considerably more actions are needed in a leap-frog way than in developed countries, as this study shows. More simplified macroscopic models may be useful to Asian developing countries for roughly identifying the necessary level of measures as evidence for the initial stage of policy making.

The design of measures also needs to identify quantitatively the timing of policy implementation as well as the level of implementation. As changes in a land-use transport system, including technology advancement, take a long time, later implementation of measures would make it more difficult to achieve the targeted mitigation of CO₂ emissions from transport. This is not only the case for the benefit of CO₂ mitigation. When it comes to the benefit of mobility, future aged societies would significantly change mobility demand. To meet changes in mobility demand, more precautionary planning of land-use transport systems is needed. Accordingly, the method this study proposes is expected to contribute to such planning for Asian developing cities.
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References


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