

Strategic land-use transport planning to realise low carbon systems in Asian developing cities

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STRATEGIC LAND-USE TRANSPORT PLANNING TO REALISE LOW-CARBON SYSTEMS FOR ASIAN DEVELOPING CITIES

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ABSTRACT: In Asian developing countries, low-carbon transport systems need to be decoupled with economic growth to avoid rapid growth in CO₂ emission. This requires developing cities to introduce new transport systems as much as developed cities in a leapfrog manner. However, their existing transport policies have hardly taken such new systems into account, but many of them have been engaged with a palliative approach by constructing roads to reduce traffic congestion against growing motorization. Accordingly, it is important to know what should be done for desirable transport systems there so as to realize Asian low-carbon society in 2050.

This study is aimed at identifying the desirable combination of low-carbon strategies for urban passenger transport to achieve the target of CO₂ mitigation in Asian developing cities in 2050 with a backcasting approach. First, measures of land-use transport planning suitable for Asian developing cities are classified to their strategies as options to design their low-carbon transport systems. The classification is made with the CUTE matrix for strategies to reduce travel demand (AVOID), to shift travel to lower-carbon modes (SHIFT) and to improve intensity of transport-oriented emission (IMPROVE).

Then, the potential effects of measures by transport strategy on CO₂ mitigation from intra-city car trips is estimated by modelling motorisation according to economic growth, transport infrastructure development and technology advancement in Asian developing cities. To model leapfrog changes in systems and behaviour in Asian developing cities, hypothesised future changes are modelled by referring to the experience of Japanese cities. Finally, by applying the model to Beijing, Shanghai and Delhi, this analysis examines the required levels of contributions of low-carbon strategies to achieving the target of CO₂ mitigation for Asian developing cities. The results suggest that policy packages among transport strategies need to generate drastic changes in urban land-use transport systems, including technologies, to achieve the challenging target of CO₂ mitigation.

KEYWORDS: Asian developing cities, low-carbon transport strategies, backcasting

1. INTRODUCTION

It is likely that growth in the global CO₂ emission will increasingly be dominated by Asian developing countries for coming decades. The growth from the transport sector is specially expected to be larger than that from the other sectors. While Asian

developing countries still have many low-carbon cities at the early stage of motorisation, their rapid economic growth could cause more serious environmental problems than developed countries.

Thus, it is an important and urgent issue to decouple growth in CO₂ emissions from economic growth. A key transport approach to it in transport is

to develop low-carbon transport systems for Asian developing countries. Such a low-carbon transport system should be designed in a leap-frog manner by extensively applying of advanced technologies along with strong intervention to transport infrastructure development and spatial development.

This study sets the vision of a desirable low-carbon transport system by combining three types of low-carbon transport strategies; to reduce travel demand (AVOID), to shift travel to lower-carbon modes (SHIFT) and to improve intensity of transport-oriented emission (IMPROVE). These strategies are suggested to be effective for Asian developing cities (Hayashi et al., 2011). These strategies were originally proposed in a project called CUTE (Comparative study on Urban Transport and the Environment) set by WCTRS (World Conference on Transport Research Society) SIG11 for Transport and Environment. The project classified transport measures according to strategies and instruments as the CUTE matrix (Nakamura, Hayashi and May, 2004). This classification has become popular and been generally used in academic research and policy making.

This study is aimed at identifying the desirable combination of low-carbon strategies for urban passenger transport to achieve the target of CO₂ mitigation in Asian developing cities in 2050 with a backcasting approach. First, measures of land-use transport planning suitable for Asian developing cities are summarised by low-carbon transport strategy. Then, a simplified urban model is developed to analyse the potential effect of each transport strategy on CO₂ mitigation in Asian developing cities, using the data of both Japanese cities and Asian developing cities. Finally, the model is applied to identifying the required levels of contributions of low-carbon strategies to achieving 70% of CO₂ mitigation in Beijing, Shanghai and Delhi from 2005 to 2050.

2. Low-carbon urban passenger transport strategies

A desirable urban low-carbon transport system can be designed with combination of the AVOID, SHIFT and IMPROVE strategies. The representative example of this vision is set with higher technology levels for IMPROVE, better public transport networks for SHIFT and compact urban forms for AVOID (Fig 1). Typical transport measures are reviewed to identify what measures are suitable for Asian developing cities, considering their contexts.

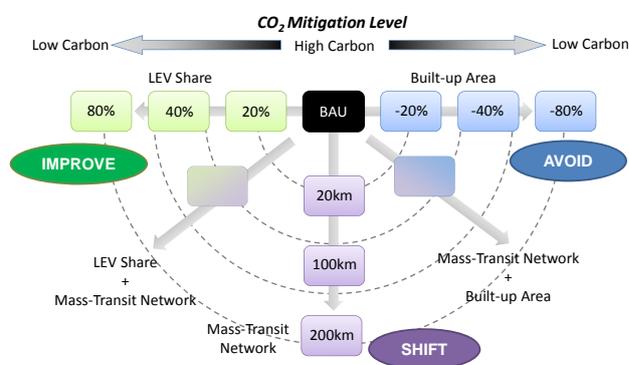


Fig 1 An approach to setting the future vision of a low-carbon urban transport system

2.1 The IMPROVE strategy

The IMPROVE strategy may be the most straightforward approach, as vehicle technologies have kept improved for less CO₂ emission. Conventionally, the regulation of emission standard has been introduced into many Asian countries. However, CO₂ has been unlikely to be covered by the emission standard. In Japan, both of fuel economy and emission intensity have been regulated by a top-runner programme, in which latest technology levels will be set as minimum requirements for future production in 5 years.

These regulations have helped to develop low-emission vehicles, such as EVs and HVs. Asian car industries have been strong, led by Japan and Korea, and have become stronger with rapid growth

in developing countries, particularly China. It reflects the high potential of LEV development, as the Japanese and Korean governments have invested in it. The high level of vehicle technologies may increase their availability for nearby Asian developing countries.

Recently, economic instruments to promote low-emission vehicles have become increasingly popular in combination with regulatory instruments. In Japan, the government has provided subsidies to purchase low-emission vehicles and tax discounts. Thanks to them, the number of HVs was doubled from 2009 to 2010.

2.2 The SHIFT strategy

While mass-transit systems have already been developed in developed cities, they need to be developed in developing cities to provide sufficient levels of mobility to meet their growing demand. This is especially the case of Asian developing cities. They have increased their investment in transport infrastructure development to establish extensive transport networks for trunk lines. However, to reduce traffic congestion caused by growing motorisation, many of transport policies in Asian developing countries have prioritized road development with help of ODA over railway development. This approach would rather induce more car traffic in the long term and consequently more CO₂ emissions.

Since the late 20th century, mega cities in Asian developing countries have started to develop large-scale railway networks. The scale of road construction has been great in Chinese cities. Chinese government has actively supported domestic car industries as their key sector of economic growth. In China, the amount of investments in road development is 4 times larger than the amount in public transport development (Pucher et al, 2007), which enables them to construct highways at an

exceptionally high pace, around 4,000km per year.

While their investments in public transport development are not as much as the investments in road development, the large amount of investments has also been made into railway development. For urban railway, investments in underground have amounted to 1 and 1.7 trillion US\$ per year respectively in Beijing and Shanghai. Shanghai has developed the largest-scale underground network in the world, 420km in total in 2010, to prepare for the expo, which still continues to develop further extension.

However, mega infrastructure development is not always affordable. In South America, some developing cities have introduced Bus Rapid Transit (BRT), which is a bus system with the extensive network of dedicated lanes, giving their priority to the development of low-cost public transport. While the BRT network is as large as a railway network, it does not need extensive infrastructure construction. Thus, it can provide a city-wide transport system with reasonable costs, in which the development cost is around 10-30% of that of normal railway.

BRT was introduced into Curitiba, Brazil, in 1974, as the earliest example, and into Bogota in 2000. Bogota's system is operated without help of public subsidies. Curitiba has successfully increased the ridership of BRT by 2.3% per year in average for the last 20 years (Rabinovitch and Hoehn, 1995), in which 28% of BRT users shifted from cars (Goodman et al, 2006). The modal share of Bogota's BRT has been increased from 6% in 2001 to 18% in 2006, while that of cars has dropped from 15% to 11% (Hidalgo, 2008).

BRT has become popular in Asian developing cities, such as Bangkok and Jakarta. Jakarta's BRT, which was open in 2004, has been developed to the largest-scale network in the world.

2.3 The AVOID strategy

High-density development has strategically been introduced along transit lines. In Japan, urban railway companies have taken initiative to develop new towns around their lines by themselves to secure railway users as their customers since the early 20th century. Singapore implemented a masterplan to expand the city by concentrating development along transit lines in 1970 along with development of mass-transit trunk lines. In South America, Curitiba introduced a zoning system of high-density development along the BRT lines. In this development, less car-dependent areas are designed on 2 street blocks from the BRT lines as the high-density zones, while the density is lower in areas farther from the lines (Goodman et al, 2005). These can be seen as early examples of Transit Oriented Development (TOD).

More recently, strategic spatial development has taken place in Asian developing countries, where urban sprawls have been accelerated due to rapid growth of motorisation. In China, their strongly-centralised planning system allows the government to own land, which makes it easier to strategically implement development plans. Strategic spatial development can generate such a large amount of returns as to be available for further investment in transport infrastructure development. Thanks to the large scale of investment, they have developed railway infrastructure and neighbourhood buildings altogether. In Chinese mega-cities, the extensive development plan of underground networks can bring more development around stations, although their larger investments in road development have caused more overwhelming urban sprawls. In this way, railway infrastructure development can strongly contribute to the AVOID strategy as well as the SHIFT strategy.

While the effects of such compact development on CO₂ mitigation are suggested to be limited in

developed cities (TRB, 2009), they may be more effective in Asian developing cities because of completely different socio-economic trends. Asian developing cities are likely to have exceptionally large amount of new development as motorisation and urban sprawl are accelerated by rapid economic growth. Although some of them might be too motorised and sprawled to develop compact urban forms, there are many Asian cities which are still at the early stage of urban sprawls. Thus, compact development can be much more effective through railway development to concentrate new development around stations in developing cities than in developed cities.

3. Modelling potential effects of low-carbon transport strategies

To identify the potential effect of low-carbon strategies, this study models the mechanism of motorisation and estimates CO₂ emission at a city-wide level, according to economic growth, transport infrastructure development and technology advancement. Traditionally, land-use transport planning has applied urban models and transport models to estimating the probable impacts of transport measures on an existing urban and transport system as a forecasting approach. In a backcasting approach, more effort is required to identify the necessary impacts to design a desirable system. Accordingly, the model is developed to estimate CO₂ emission from passenger cars based on a hypothesised causality.

3.1 The model for motorisation

This model accounts for the mechanism of motorisation in such a way that economic growth and road development would increase car ownership and accelerate urban sprawl, which would lead to increasing car use. On the other hand, it models the impact of urban railway development on calming

motorisation through slowing urban sprawl for AVOID and SHIFT. Urban railway represents mass-transit modes, including BRT.

This model inputs population, income and the levels of roads and railway development to estimate vehicle distance for intra-city trips by mode (Fig 2). While transport models generally input configuration of transport networks, it is simplified with the input of city-wide data by translating transport networks into road length and station density. The advantage of this model is better applicability without detailed input data which are unlikely to be available in Asian developing cities.

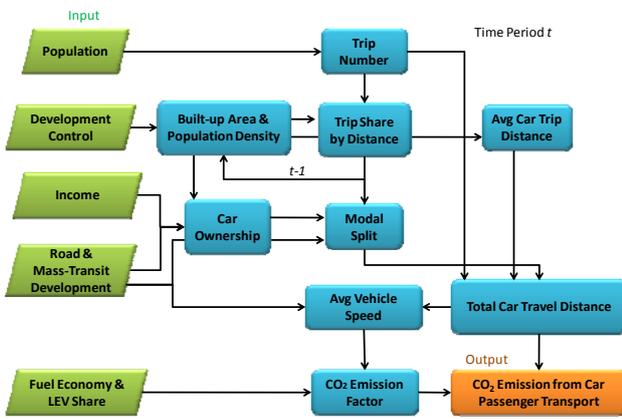


Fig 2 The framework of the models for motorisation, urban sprawl and technological advancement

The parameters of this model are calibrated with panel data of Japanese largest cities from the 1960s and are adjusted to match the estimation with available data of Asian cities (Toga et al., 2010). By using the data of Japanese cities in the period of motorisation, the model is made more applicable to Asian developing cities.

The model estimates modal share at a city-wide level. Modal share is normally estimated with travel time and cost as generalised cost by transport models. This study is focused more on the impact of economic growth and infrastructure development on modal share. Thus, the modal share of car use and

railway use is estimated respectively with car ownership and station density as an indicator of railway development. Car ownership (1000 cars/household) is estimated with population density d (people/km²), road length per person r (m/person) and household income standardised by vehicle price I . In this model, car ownership would be increased by income growth and road development, whilst calmed by high-density development.

$$C_t = \frac{1.99 \cdot 10^4 \cdot r^{0.299} \cdot d^{0.487}}{1 + 10.5 \cdot \exp(-0.791 \cdot I)}$$

Urban sprawl is also modelled by estimating growth in built-up area ΔS_b (km²) according to growth in population ΔPOP (people) and the standardised income ΔI , which leads to lower population density (Nakamura et al., 2011). In this model, urban structure is simply captured with the total built-up area and the average population density in a city, without considering their spatial distribution. The model also introduces station density to habitable area st_h (stations/km²) as a factor negatively affecting growth in built-up area, where railway development can slow sprawl by increasing the number of stations. By modelling the growth, rather than built-up area itself, it can capture a cumulative change in the developed area, which is hardly reduced once developed. Development control can be introduced onto the amount of new development by controlling the percentage of development not allowed to expand built-up area. Considering the growth, this model is run every 5-year periods from 2005 to 2050.

$$\Delta S_b = 0.463 \cdot \Delta POP + 0.0636 \Delta I - 0.0246 st_h + 0.207$$

The impact of urban sprawl on trip distance is modelled by estimating the average distance per car trip l_{car} (km/trip) with built-up area S_b (km²) and road

length per person r . In this model, the number of trips per person per day is set around 2 to be fixed. In Japanese cities, the number of trips per person has not been significantly changed despite economic growth in the period of motorisation.

$$l_{car} = 0.0219 \cdot S_b + 2763 \cdot r + 0.383$$

Using these estimation, modal share is modelled for the ranges of distance per trip. The composition of trip distance is estimated with urban structure measured by built-up area S_b and population density d , where higher density and smaller built-up area increase shorter trips. The types of trip distance contain shortest trips, TS_s , middle-length trips, TS_m , and longest trips TS_l .

$$\begin{aligned} TS_s &= 1 - TS_m - TS_l \\ TS_m &= -0.348 \cdot d + 3.6 \\ TS_l &= 0.131 \cdot S_b - 0.414 \end{aligned}$$

For each range of trip distance, binary logit models are applied to estimating hierarchical choices of modal shares between motorised and non-motorised modes, between private and public modes in motorised ones, between car and motorcycle use in private ones and between bus and railway uses in public ones. Each modal share P_m is estimated with their characteristics chr_m along with their parameters π_m . The shares of motorised and private modes are estimated with car ownership and motor cycle ownership, in which the share of car use is estimated with car ownership. In the choice between railway use and bus use, the share of railway use is estimated with station density to built-up area.

$$P_m = \frac{1}{1 + \exp(\pi_{m1} \cdot chr_m + \pi_{m2})}$$

The overall modal share is calculated by

multiplying the share of trip distance with the modal share of each distance range. As railway use is much lower in Asian developing cities than Japanese cities at the same economic standard, the parameters are adjusted to match the current modal share. For future forecast, the model assumes that railway use would become more popular as the networks are developed more. Accordingly, the parameters are set to be proportionally changed to the relative level of station density to the density of Tokyo in 2005.

In this model, while income growth and road development affect car use through increasing car ownership, railway use is affected by railway development through increasing stations. These changes are reflected by the total distance of car travel which is estimated by multiplying the average vehicle distance with the overall modal share.

3.2 The model for technology advancement

This model estimates CO₂ emission factor with traffic congestion, fuel economy, and LEV spread (Fig 2).

Traffic congestion is modelled in a simple way to estimate the average vehicle speed v (km/h) on roads with the balance between the total vehicle distance L_v (km) and the total road length R (km). The total vehicle distance includes ones of cars, motorcycles and freight vehicles. Distances of car and motor cycle trips are estimated in the model for motorisation as in the previous section. Freight vehicle distance is estimated in proportion to GDP and population.

$$v = 12.3 \cdot \ln\left(\frac{L_v}{R}\right) + 129$$

CO₂ emission factor e (g-CO₂/km) is calculated by dividing emission intensity CF (g-CO₂/l) by fuel economy f (km/l). Fuel economy is estimated with traffic speed and vehicle technologies. For future

levels of vehicle technologies, this model considers the technological improvement of Tank-to-Wheel (TtW) efficiency and vehicle weight.

$$e = \frac{CF}{f}$$

Emission intensity depends on the composition of vehicles by fuel type, where the level of LEV spread can reduce emission intensity. This model classifies passenger cars to gasoline vehicles, HVs and EVs, focusing on emission intensity of gasoline and electricity. While emission intensity of gasoline is fixed in the model, the intensity of electricity is estimated with the intensity of electric power generation, considering the changes in the composition of the power sources over time, such as coals, petrol, natural gas, nuclear, water and biomass.

The total CO₂ emission E (Mt/year) from passenger cars is calculated by multiplying the emission factor e (g-CO₂/km) by car travel length L_{car} (km/year). In this way, this model captures the mechanism that advancement of vehicle technologies and LEV spread would reduce CO₂ emission factor.

$$E = e \cdot L_{car} \cdot 10^{-12}$$

4. Desirable policy packages of low-carbon transport strategies

Models developed in the previous chapter are applied to identifying desirable policy packages of low-carbon transport strategies for Asian developing cities by estimating their potential effects.

4.1 The Case study cities

The case study cities are Beijing, Shanghai and Delhi as Asian mega-cities with rapid economic growth. Population of these cities is more than 10 million people. Despite the recent rapid economic

growth, many Asian developing cities are still high-density and low-carbon cities. In Shanghai and Delhi, population density is more than 20,000 (people/km²), which is higher than the density of Tokyo with around 15,000 (people/km²) in 2005. However, urban sprawl is more serious in Beijing, which is relatively low-density with around 13,000 (people/km²).

Asian developing cities have significant growth in railway development, but have not reached the level of Japanese cities. Beijing and Shanghai has increased the number of stations double from 2005 to 2009 thanks to the international events, such as the Olympics and Expo (Fig 3). Nevertheless, despite the growth, their station density is not as high as Tokyo, 1.26 (stations/km²), and Nagoya, 0.59 (stations/km²).

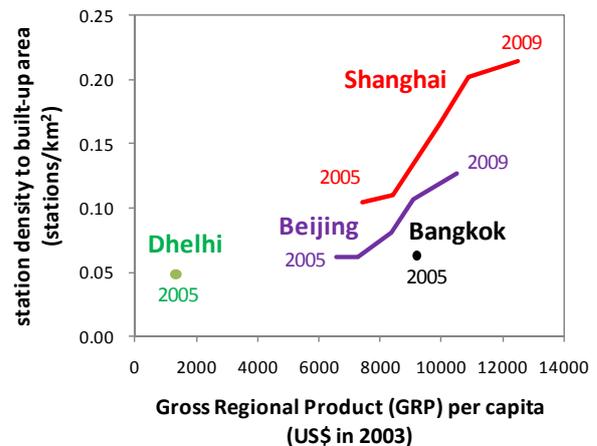


Fig 3 Changes in railway development according to economic growth (Built-up area is fixed to be the level of 2005.)

On the other hand, the level of road development is more comparable between Asian developing cities and Japanese cities (Fig 4). While Shanghai has the lower level of development than Tokyo, those in Delhi and Beijing are higher.

Priority to road development leads to higher car ownership. Fig 5 shows changes in car ownership

according to changes in economic levels. Except Shanghai, Asian developing cities have the higher levels of car ownership than Japanese cities in the period of early motorisation.

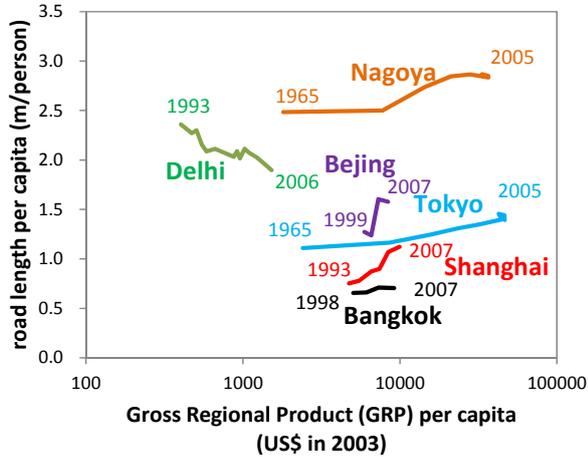


Fig 4 Changes in road development according to economic growth

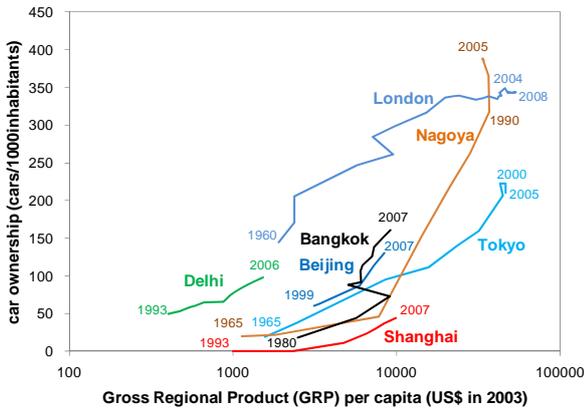


Fig 5 Changes in car ownership according to economic growth

4.2 Policy options and technological scenarios

This study compares a CO₂ mitigation scenario based on low-carbon transport strategies with a Do Nothing Scenario (DN) which is a scenario without any technology advancement, railway development and development control from 2010 (Table 1).

For the IMPROVE strategy, the future levels of technology advancement, such as TtW and vehicle weight, and LEV spread are set based on the existing

forecast for Japan (Yamamoto et al., 2010). In Asian developing cities, although the technology advancement may be less than in developed countries, a leap-frog approach is required for designing low-carbon transport systems by actively applying advanced technologies to developing countries. Accordingly, this study assumes that the same level of technology advancement as Japan would be available in Asian developing countries from 2020. This technological scenario sets TtW efficiency to be improved by 284% and vehicle weight to be lighter by 24% from 2005 to 2050. For LEV spread in 2050, the shares of HVs and EVs in passenger cars are set to be respectively 35% and 65%, while the current share of EVs is quite small.

Table 1 Do Nothing scenario and CO₂ mitigation scenario based on low-carbon transport strategies

<i>Do Nothing Scenario(DN)</i>	
No technological advancement from 2010	
No railway development from 2010	
No development control from 2010	
<i>CO₂ Mitigation Scenario</i>	
IMPROVE	TtW improvement Lighter vehicle weight LEV spread
SHIFT	Low-carbon power generation Urban railway development
AVOID	Development control

The future composition of electric power generation is also set based on the existing forecast for each Asian country (National Institute of Environmental Studies, 2011). In this forecast, the source of electric power generation would be shifted from coal to nuclear and biomass, although nuclear generation is no longer reliable due to the serious incident of Fukushima caused by the Great East Japan Earthquake. This shift would reduce the emission factor of electric power generation by 51%

in China and 47% in India from 2005 to 2050. With these inputs, the model estimates that the single application of the IMPROVE strategy can reduce CO₂ emission by 77% in Beijing, Shanghai and Delhi from DN in 2050 as the highest effect among the strategies.

The SHIFT strategy is designed with urban railway development. As mentioned in the previous section, despite the recent extensive development of railways, the levels of development in Asian developing cities are still lower than those in developed cities. This study assumes that future development would proportionally increase station density to built-up area from 2010 to 2050. If railway would be developed to the equivalent level to Tokyo in 2005 in terms of the station density, it is estimated to reduce CO₂ emission by 35% in Beijing, 30% in Shanghai and 48% in Delhi from DN in 2050.

Urban compaction is designed for the AVOID strategy with land-use development control on new development. This study assumes that development control would reduce the rate of expansion of built-up area from 2010. In DN, built-up areas are estimated to be expanded by 167% in Beijing 182% in Shanghai and 198% in Delhi from 2005 to 2050. According to the model estimation, the strongest development control not to allow any urban expansion from 2010 can reduce CO₂ emission by 61% in Beijing, 72% in Shanghai and 81% in Delhi from DN in 2050.

4.3 Desirable policy packages

The required contribution of each strategy to CO₂ mitigation is identified as a backcasting approach to meet the targeted mitigation. The model estimates growth in CO₂ emission by 524% in Beijing, 714% in Shanghai and 776% in Delhi from 2005 to 2050. This study sets the target of 70% reduction in CO₂ emission in 2050 from the level of year 2005.

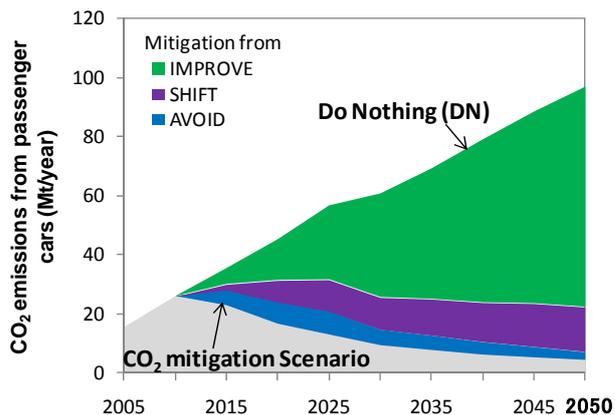


Fig 6 CO₂ mitigation from a package of low-carbon transport strategies in Beijing

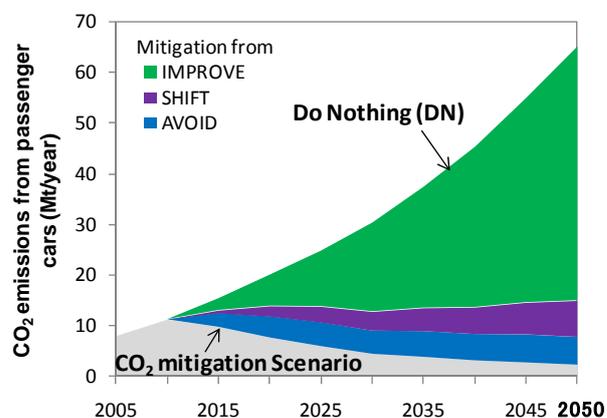


Fig 7 CO₂ mitigation from a package of low-carbon transport strategies in Shanghai

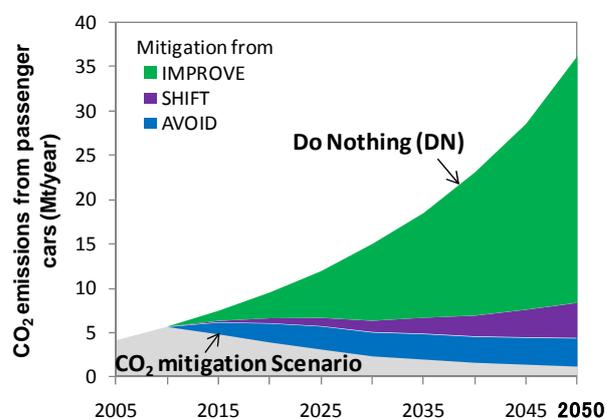


Fig 8 CO₂ mitigation from a package of low-carbon transport strategies in Delhi

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. After the application of the IMPROVE strategy, railway development for SHIFT is applied up to the level of Tokyo in 2005, which follows the application of development control for AVOID up to no urban expansion. If the application of all the strategies is not sufficient, railway development is further increased to meet the target mitigation.

Accordingly, the contributions of low-carbon transport strategies to the 70% mitigation of CO₂ emission are identified for Beijing, Shanghai and Delhi (Fig 6, Fig 7 and Fig 8).

According to the contribution of each strategy to the 70% mitigation, this analysis identifies the necessary levels of transport measures as the policy package to realise the contribution (Table 2). It is revealed that drastic changes both in railway development and spatial development are required to achieve the mitigation target. In all the cities, railways need to be developed at least up to the current level of Tokyo and new development is hardly allowed to expand built-up area.

Table 2 A package of low-carbon transport strategies to achieve the 70% CO₂ mitigation

	<i>SHIFT</i>	<i>AVOID</i>
	Stations / km² of built-up area (times higher than the level of 2010)	% of allowed expansion to the total potentially new built-up area
Beijing	4.33 (42)	0.0
Shanghai	2.66 (10)	0.0
Delhi	1.24 (9)	1.7

Particularly, the largest changes are required for Beijing, where the necessary station density is 3 times higher than Tokyo along with no expansion of

built-up area allowed. This implies that Beijing is already too sprawled to be made compact, which requires much more railway development for low carbonisation than the level of the current extensive development.

5. Conclusions

In this paper, low-carbon transport systems for Beijing, Shanghai and Delhi are designed as policy packages among transport strategies for IMPROVE, SHIFT and AVOID. For each of the strategies, technology advancement of vehicle technologies and LEVs, mass-transit development, such as BRT, and high-density development along mass-transit lines are identified to be suitable for Asian developing cities. To analyse the potential effects of each strategy in Asian developing cities, the mechanism of motorisation is modelled based on hypothesised behavioural changes from the experience of Japanese cities with a city-wide urban model, estimating CO₂ emission from intra-city trips of passenger cars. By estimating the contribution of each strategy to the targeted CO₂ mitigation with the model, a necessary policy package is designed with vehicle technology advancement, LEV spread, urban mass transit development and development control.

These findings suggest that, while the contribution of technology advancement is significant, the AVOID and SHIFT strategies are necessary to achieve the challenging target of CO₂ mitigation. However, the policy package identified in this study may not be realistic with excessive levels of mass-transit development and development control. This implies that more leap-frog measures are required to design the policy package. Furthermore, there is a limitation to methodology by applying the simplified urban model at a city level. By improving the model to capture the impact of urban structure, a wider range of measures can be introduced in the package. This study is expected to contribute to

designing a low-carbon transport system for Asia with a backcasting approach.

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