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**Air Quality Co-benefits of High Volume Low Carbon Transport-
Future in Asia**

(Background Paper for EST Plenary Session-2)

Final Draft

This background paper has been prepared by Mr. Holger Dalkmann, Founder and CEO, Sustain 2030, Berlin, Germany, for the 12th Regional EST Forum in Asia. The views expressed herein are those of the author only and do not necessarily reflect the views of the United Nations.

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Air Quality Co-Benefits of Sustainable and Low-Carbon Transport System: Future in Asia

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Chapter 1: Background

1.1 Introduction: Urbanisation and motorisation trends in Asia and the Pacific

The Asia Pacific region had a population of 4.48 billion in 2017, representing over 60% of the global population (SloCaT, 2018). The growth of the region's population also remains significant, with an addition of 676 million inhabitants between 2000 and 2015. In 2015, Asia's urban population numbered at a staggeringly high 2.38 billion residents, representing 60% of urban population worldwide (UN-Habitat & ESCAP, 2015). Moreover, this population estimated to grow by over 50% by 2050 (UN-DESA, 2018). Additionally, the region also has highest number of megacities (20) with a population of over 10 million (UN-DESA, 2018). The rapid urban expansion in the Asia Pacific region has also resulted in the rise of transport demand and corresponding levels of motorisation. Between 2000 and 2015, the People's Republic of China's of transport activity (in terms of passenger-km travelled) has increased fourfold from 2.6 to 11 trillion passenger-km. For the same period, vehicle ownership has grown tremendously both in the People's Republic of China and India by 1300% and 300%, with the former becoming Asia's largest vehicle market in 2016 with 185 million vehicles sold (SloCaT, 2018).

City	Car ownership per 1000 persons		Modal share of public transport (% of all motorised trips)	
	1995	Most recent data	1995	Most recent data
Mumbai	21	44	81	67
Shanghai	15	42	68	62
Beijing	43	142	53	48
Tehran	95	170	28	28
Jakarta	91	203	48	56
Kuala Lumpur	209	314	32	19
Hong Kong	46	55	72	88
Singapore	116	112	37	57
Seoul	160	227	42	71
Taipei	175	253	24	40
Melbourne	594	649	9	8

Table 1: Rising car-ownership and decreasing public transport use in Asia-Pacific cities between (Source: Barter, 2015, based on analysis conducted by the author using multiple sources from 1995 to 2014)

A similar trend has been observed in ASEAN countries, whereby between 2000 and 2010, average vehicle ownership increased sharply by 54%, from 26 vehicles per 1000 residents to 40 vehicles (Mo, Kwon, & Park, 2014). According to OECD (2019), private vehicle ownership for Asia's 6 emerging economies, namely, India, Indonesia, Myanmar, Philippines and Cambodia, increased by an average of 13.2% annually between 2005-2015. Concurrently, rising motorisation was also recorded in 10 major capital cities in Asia Pacific as illustrated by Table 1. Although car ownership in these cities significantly vary between 42 to 314 per 1000 persons, several cities demonstrates a doubling of private vehicular ownership, along with a decline in the modal share of public transport. Consequently, cities such as Jakarta, Mumbai, Beijing, and Kuala Lumpur are already traffic-saturated and on the

pathway towards even greater automobile dependence (Barter, 2015). Lastly, a significant proportion of the motorisation in Asian countries is comprised of motorised two- and three-wheelers, accounting for 50-80% of all vehicles (WHO, 2011). For instance, in 2013, the number of motorcycles in Hanoi (Vietnam) and Phnom Penh (Cambodia), far exceeded that of automobiles – by 10 and 5 times respectively (Mo, Kwon and Park, 2014). Between 2000 and 2015, the global freight mobility increased from 64 to 108 trillion tonne-km. For this increase, the highest growth of per-capita freight transport demand was recorded in the People’s Republic of China (457%) and India (239%) (SloCaT, 2018).

1.2 Relevance of sustainable transport for achieving air quality improvement and SDG targets

Due to the complexities of both air pollution and transport sector issues, they cannot be addressed in isolation, and without considering their multi-faceted interrelations within the global sustainable development agenda. The 2030 Agenda for Sustainable Development agreed by 191 countries worldwide came into force in September 2015, comprising of 17 Sustainable Development Goals (SDGs) and 169 targets. Although measures focussed on both sustainable transport and air pollution are not exclusively represented as one of these 17 SDGs, they are mainstreamed through direct and indirect actions corresponding to several other goals (SloCaT, 2018a). Some of these include SDGs related to health (3), energy (7), infrastructure (9), reducing inequality (10), cities and human settlements (11), and climate action (13). As highlighted by SloCaT (2018), Sustainable Transport also contributes directly to five targets for road safety (Target 3.6); energy efficiency (Target 7.3); sustainable infrastructure (Target 9.1), urban access (Target 11.2), and fossil fuel subsidies (Target 12.c). Transport also indirectly contributes to eight SDG targets. These particularly include two targets on air pollution –

(a) Target 3.9, which intends to “by 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination”, by lowering the mortality rate attributed to ambient air pollution, and

(b) Target 11.6, which aims to “by 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.” (UNSD, n.d.).

Other transport related targets consist of – agricultural productivity (Target 2.3), access to safe drinking water (Target 6.1), sustainable cities (Target 11.6), reduction of food loss (Target 12.3), climate change adaptation (Target 13.1), and climate change mitigation (Target 13.2). These linkages are illustrated in Figure 2.

Such high degree of interrelatedness indicates that planning and implementing sustainable transport measures not only meets basic mobility demands, but also helps advance the achievement of a range of other SDGs, including air pollution. The progress of SDGs related targets is reported by member countries annually at the High-level Political Forum (HLPF) through Voluntary National Reports (VNRs). However, an analysis of the 47 VNRs submitted in HLPF 2018 reveals two issues (SloCaT, 2018). Firstly, only 26% of the VNRs articulate policy measures and concrete evidence related to actions on sustainable transport. Secondly, the explicit linkage between transport development and air pollution reduction remains weak, with only 15% VNRs articulating it (see Figure 3). Therefore, to achieve air quality management through sustainable transport, Asian countries should proactively seek strategies to maximise synergies and minimise trade-offs between the aforementioned SDGs. An essential first step towards this is the systematic identification of the cumulative impacts transport and air pollution

on cities, regions and communities. These impacts and the SDGs they correspond to are outlined the following sub-sections.

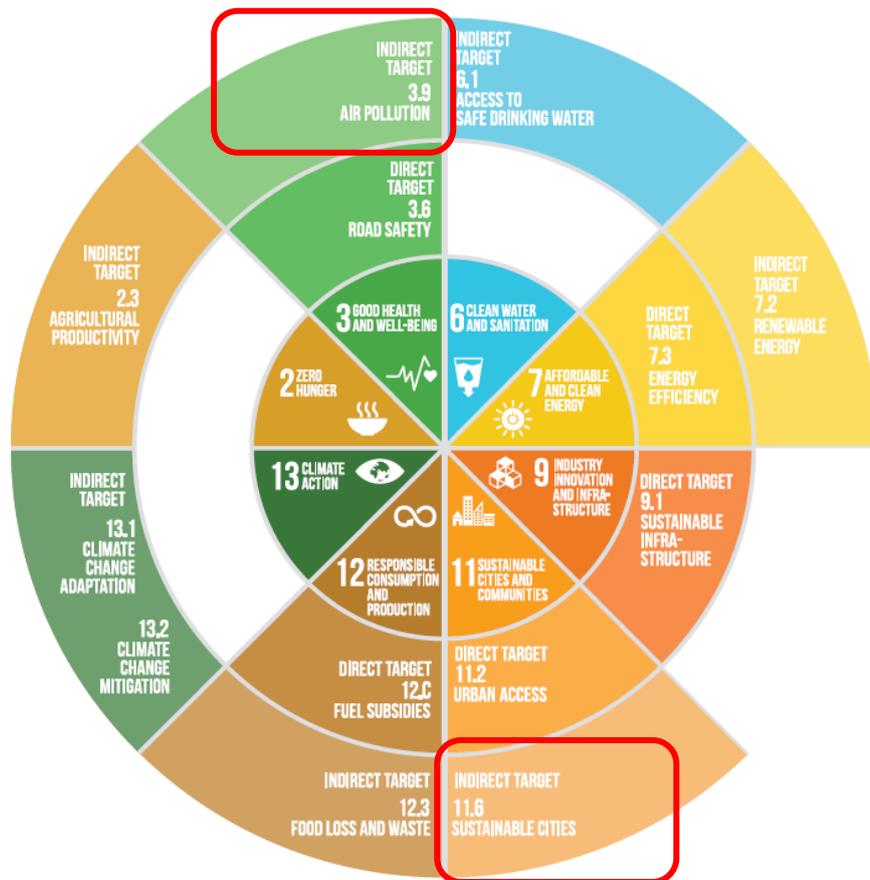


Figure 2: Sustainable transport linked to direct and indirect SDGs targets (Source: SloCaT, 2018)

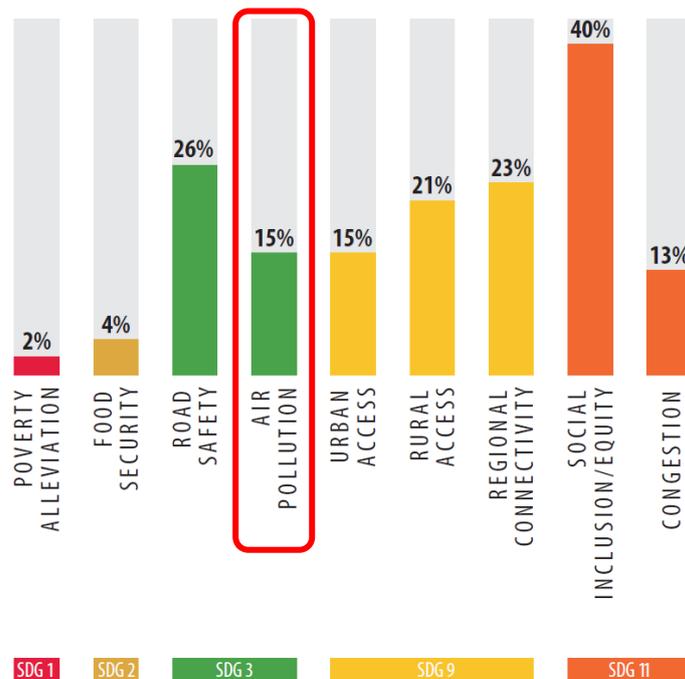


Figure 3: Low reporting on sustainable transport and air pollution linkages in VNRs (Source: SloCaT, 2018)

1.3 Impacts of transport on urban air quality and GHG emissions (SDGs 3,7,11,13)

According to the World Health Organisation (WHO) estimates, exposure to hazardous air pollution causes 7 million premature deaths annually (WHO, 2018b). It is also critical to differentiate between ambient (or outdoor) and indoor air pollution caused by cooking with polluting fuels or technologies – the former category being the primary focus of this paper. In 2016, deaths from ambient and indoor pollution amounted to 4.2 million and 3.8 million respectively (WHO, 2018b). Approximately 90% of these deaths occur in low and middle-income countries, with about one-third of these, i.e. 2.2 million deaths occurring in Asia-Pacific region (WHO, 2016). Further, WHO Guidelines also indicate that only 8% of the total population in Asia-Pacific live in conditions where the air quality does not pose significant health risks. Furthermore, WHO database documenting 4300 cities and settlements worldwide suggests that 97% of the cities with more than 100,000 inhabitants in low and middle-income countries fail to meet WHO air quality guidelines, thereby positioning air quality management as primarily an urban challenge.

Particulate matter type		PM ₁₀		PM _{2.5}	
City	Country	Annual mean, µg/m ³	Year	Annual mean, µg/m ³	Year
Delhi	India	286	2010	153	2013
Kabul	Afghanistan	260	2009	86	2009
Dhaka	Bangladesh	180	2013	86	2013
Ulaanbaatar	Mongolia	148	2010	68	2013
Beijing	China	121	2010	56	2013
Kathmandu	Nepal	114	2008	50	2013
Tehran	Iran	91	2010	30	2013
Hà Nội	Viet Nam	86	2009	39	2013
Colombo	Sri Lanka	64	2010	28	2013
Seoul	Republic of Korea	49	2010	22	2013
Metro Manila	Philippines	49	2010	22	2013
Jakarta	Indonesia	48	2010	21	2013
Bangkok	Thailand	38	2012	20	2013
Singapore	Singapore	27	2011	17	2011
Wellington	New Zealand	13	2012	6	2011
Canberra	Australia	12	2012	7	2012

Note: Recommended WHO standards for PM₁₀ and PM_{2.5} are 50 and 25 µg/m³ respectively.

Table 4: Annual mean PM10 and PM2.5 levels in selected capital cities in Asia-Pacific (Source: UN-Habitat & ESCAP, based on WHO Ambient Pollution in Cities Database, 2014)

The most deteriorated air quality conditions are observed in the megacities in Asia, as highlighted by Table 4. In these cities, the levels of pollutants, especially Particulate Matter (PM), exceeds 4 to 6 times the safe standards recommended by WHO (UN-Habitat and ESCAP). While the origins of ambient (outdoor) air pollution in Asian cities are numerous and vary seasonally, evidence suggests that the highest primary emissions come from road-based transport, along with power-generation and industrial activities. Other secondary sources also include agriculture, waste burning, and cookstoves burning coal and biomass fuels (UNEP, 2018). Diesel vehicles have the potential to reduce transport sector CO₂ emission. However, they also emit the highest proportion of particulate matter (PM1.0 and PM2.5) and black carbon, and cause the highest health-related impacts (WHO, 2011). Concurrently,

the international shipping sector is also one of highest emitters of pollutants. According to an estimate in 2005, shipping in seas surrounding Europe contributed 1.7 million tonnes of sulphur dioxide (SO₂), 2.8 million tonnes of nitrogen dioxide (NO_x), and 195,000 tonnes of particulate matter (PM_{2.5}) emissions (Transport & Environment, n.d.).

Along with air pollution, the transport sector is also the leading contributor of greenhouse gases (GHG) emissions, and therefore, one of the direct causes of climate change and global warming. Transport accounts for 23% of energy-related GHG emissions worldwide, as well as responsible for the highest energy use than any other end-use sector. About 80% of these emissions originate from land transport (mostly by cars) and freight, far exceeding those from shipping and air travel combined. Under business-as-usual scenario, global transport energy use is projected to grow by 80% until 2030, and consequently becoming the single-largest GHG emitter accounting for 46% of global emissions by 2035 (ADB, n.d.; WHO, 2011). In 2016, Asia accounted for 2.3 gigatons of transport CO₂ emissions, while were 39% of the global total. Between 2000 and 2016, rising motorisation and freight activity led to an absolute transport emission increase by 92%, while per capita transport emissions grew the fastest by 61% compared to all other regions (SloCaT, 2018).

1.4 Impacts of air pollution on cities and communities

The effects of air pollution in large Asian cities are not limited to the urban or metropolitan scales alone, but transmitted over hundreds of kilometres across regional and sometimes international boundaries. Moreover, this not only exacerbates the risk for human health and disease burden within communities, but also results in far-reaching impacts in terms in the social, economic, environmental, climate change-related spheres. These wide-ranging impacts are explained as follows.

1.4.1 Health and social impacts (SDGs 3 & 8)

Ambient air pollution is composed of multiple health-harming pollutants. The most injurious transport-related pollutant is the Particulate Matter (PM), due to their small size of 10 microns (PM₁₀) and 2.5 microns (PM_{2.5}) in diameter – primarily emitted from road dust, vehicular tail-pipe exhausts, tyre wearing and braking. These particles are able to surpass the biological defences against dust and enter deep into the respiratory system. PM_{2.5} includes pollutants such as black carbon, heavy metals, sulphur dioxide (SO₂), nitrates, and even carcinogenic substances, such as benzene derivatives (WHO, 2015). A study conducted in four Indian megacities indicated that 20-50% PM_{2.5} emissions are generated from gasoline and diesel vehicles traffic (WHO, 2011). Road-based transport with internal combustion engines (ICE) also emits other pollutants such as carbon monoxide (CO), and nitrogen oxide (NO_x) from diesel exhausts and two-stroke engines, as well as lead emissions from using leaded-fuels. Particularly in Asian cities, road transport is estimated to be responsible for up to 98% of CO and 85% of NO_x emissions (WHO, 2011).

The health impacts of these air pollutants include heightened risk of respiratory and cardiovascular diseases, cancer, reduced lung function, adverse birth outcomes and higher mortality. For instance, during 2005-2015, Beijing's chronic air pollution has led to lung cancer rates increasing by 60%, while smoking rates remained steady for the same period (UN-Habitat and ESCAP). Further, the 2.2 million deaths air pollution-related deaths, which occurred in Asia in 2016, were attributed to heart disease (29%), stroke (27%), chronic obstructive pulmonary disease (22%), lung cancer (14%) and pneumonia (8%) (WHO, 2018c). Furthermore, air pollution emergencies during extreme spike in pollutant levels, can disrupt regular social functions, as citizens are advised to stay indoors and institution and workplaces to remain closed. For example, in 2017 in Delhi, the Indian Medical Association and the

capital city's Chief Minister issued such a warning, when air pollution reached 25 times the WHO recommended levels (The Guardian, 2017).

1.4.2 Economic impacts (SDGs 8 & 10)

The market costs of air pollution on the economy comprise of loss of agricultural productivity, additional health-related expenditures due to illness, and loss of working days which affects labour productivity. According to OECD estimates (2016), global air pollution-related costs are projected to increase from 21 billion in 2015 to 176 billion in 2060. Additionally, these estimates also suggest a surge in the lost working days amounting to 6 million people missing work on a daily basis in 2060. The economic consequences of air pollution also include the increase of welfare costs associated with risks of premature deaths and calculated from the willingness to pay to avoid them. According to an estimate from 2013, air pollution exposure costs the global economy about 5.11 trillion USD in welfare losses alone. This cost for South and East Asia is equivalent to 7.4% and 7.5% of GDP respectively (UNEP, 2018). Moreover, global welfare costs associated with premature deaths due to air pollution are projected to rise to 18-25 trillion by 2060 (OECD, 2016).

1.4.3 Environmental impacts (SDGs 2, 6, 11, 15)

Land transport is a major emitter of ground-level ozone, which has damaging effects on vegetation. Exposure to even relatively low levels of ozone causes significant damages to crops and natural systems. This is subsequently detrimental to the agricultural output and food security, as well as ecosystem services, such as provision of water, food, fibre, medicines and timber (UNEP, 2018). Moreover, this damage is enhanced in developing countries with high mixed land-use in Asia, where agricultural activities are undertaken in close proximity to urban areas. Two other pollutants emitted by the transport sector – SO₂ and NO_x – also have harmful ecological effects. These include acidification, which degrades soil and water quality, and eutrophication, which entails excessive enrichment of soil nutrients and reduces plant biodiversity (EPI, 2018). Lastly, high levels of PM_{2.5} are also observed to interfere with precipitation and lead to unpredictable rainfall patterns. This is especially critical for the monsoon seasonal rains in South Asia, which is the primary source of water.

1.4.4 Climate change impacts (SDGs 7 & 13)

Along with carbon dioxide (CO₂), two other transport-related emissions from burning fossil fuels – namely, ozone and methane – are highly potent greenhouse gases. The latter traps 84 times more heat compared to CO₂, and has contributed to about 25% of the global warming so far (EDF, n.d.). Black carbon, a transport-related pollutant emitted primarily from diesel, is the second largest contributor to global warming after CO₂ (WHO, n.d.). When deposited on snow or ice surfaces, black carbon substantially increases radiation absorption. This phenomenon is attributed to the rapid retreat of Himalayan glaciers, and therefore increase the risks of disasters related to glacial lake outbursts and flooding of the Asia's major rivers downstream and the cities surrounding them (UNEP, 2018). Rapidly urbanising and highly dense Asian cities are also highly exposed and vulnerable to other natural and climate change-induced disasters, such as cyclones and droughts. Between 1970-2011, Asia-Pacific recorded 1.9 million fatalities associated to natural disasters, which was about 75% of the global total. Additionally, the economic losses from these disasters in the region amounted to 720 billion between 2000 and 2011 (UN-Habitat and ESCAP, 2015, based on UNISDR data).

Chapter 2: Major Issues, Challenges and Opportunities for Sustainable and Low-Carbon Transport Development in Asia

2.1 Introduction: What is a sustainable and low-carbon transport system?

In 2010, twenty goals were adopted under the Bangkok Declaration for achieving an environmentally-sustainable transportation system across Asian countries by 2020 (EST, 2010). Towards this, EST member countries aimed at “avoiding unnecessary motorised transport, shifting to more sustainable transport modes and, Improving transport practices and technologies.” Furthermore, a sustainable transport system is also characterised as one which satisfies the following criteria –

- “It allows individuals, companies and societies to meet their basic mobility needs in a way that preserves human and ecosystem health, and promotes equity within and between successive generations,
- It is affordable, efficient, offers a choice of transport mode, and supports a competitive economy, as well as balanced regional development, and
- It limits emissions and waste within the planet’s ability to absorb them, uses renewable resources at or below their rates of generation, and uses non-renewable resources at or below the rates of development of renewable substitutes, while minimising the impact on the use of land and the generation of noise” (Dalkmann & Brannigan, 2007; ECMT, 2004).

2.2 Opportunities to address sustainable transport issues through the EASI framework

To facilitate the development of sustainable transport which adheres to the Bangkok Declaration goals, a strategic framework widely adopted in research and practice is a combination of four policy responses – Enable, Avoid, Shift, Improve (or EASI). The EASI approach and the solutions covered by the four categories are explained as follows (Dalkmann & Brannigan, 2007; Stucki et al., 2015; SUTP, 2004). Moreover, each of these categories also serves as a solution to the specific sustainable transport issues outlined later in this chapter (See Figure 5).

Enable: This category consists of measures which are not necessarily technical in their nature, as compared to those covered in the other three ASI categories. They aim at the improvement of overall transport governance and create enabling conditions for the technical solutions to be planned and implemented. These actions comprise of governance efficiency, administrative reforms, including the establishment of lead agencies to overcome the constraints of fragmented decision-making. These measures also include financial mechanisms to access to sources of international, national, and subnational funding. Additionally, this category includes capacity building initiatives for improving the technical competencies of public agencies – essential for evidence-based policymaking, strategic and long-term planning of public transport systems, as well as effective regulation of mobility services.

Avoid: These solutions aim at improving the efficiency of transport system and reducing the need for motorised travel, length of trips and total vehicle kilometre travelled (VKT). This is achieved through Travel Demand Management (TDM), and better land-use and transport integration through urban development and regional policies – like Transit Oriented Development (TOD) along high-volume public transport corridors. Additionally, the goal of these measure is also disincentivising the use of private motorised modes, through higher taxes, congestion pricing, or lesser parking provision.

Shift: These solutions imply shifting travel patterns from modes that consume highest energy (such as private cars) to more sustainable, low-carbon and collective modes, such as public transport, last-mile connectivity and shared mobility. Additionally, they are also aimed at the greater adoption of non-motorised transport (like walking and cycling), and a shift of road-based freight transport to railways and inland waterways. These modes have a lower energy consumption, a higher occupancy, and lower GHG emissions per kilometre travelled compared to private automobiles.

Improve: These solutions entail improving the technology of existing vehicles, fuel efficiency and optimisation of transport infrastructure. These measures aim at downsizing or phasing out of older vehicular fleets based on high-emissions technology reliant on high-carbon and polluting fossil-fuels, such as diesel and standards for better fuel economy. Towards this, electrification, along with a greater uptake of renewable energy, for freight and passenger transport as well as private vehicles is intended.

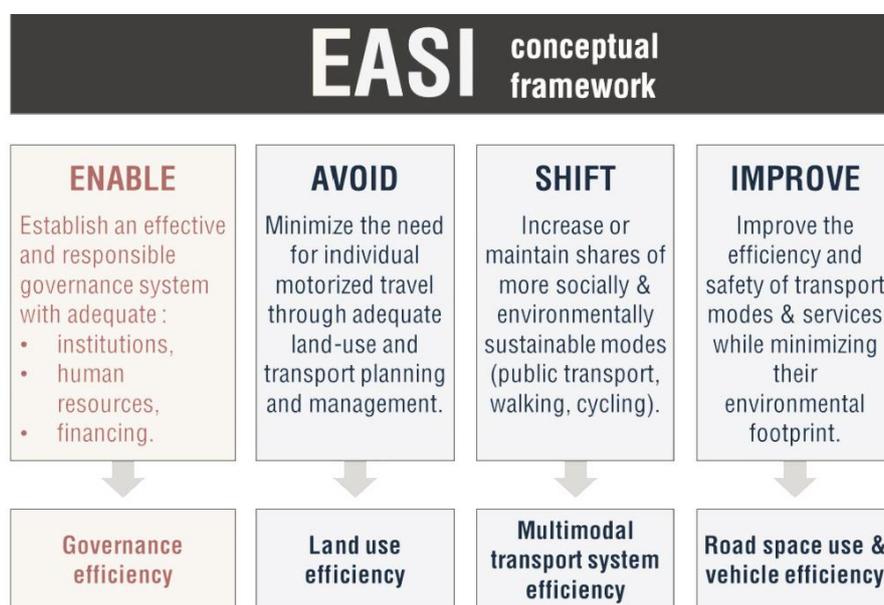


Figure 5: EASI framework and its strategic objectives (Source: SSATP, 2015)

2.3 Scope and recent trends in sustainable transport development in Asia

As explained in the previous chapter, a large number of traffic-saturated cities in Asia have seen investments and rapid construction of a wide range of public transport systems over the last two decades. By the end of 2016, the People’s Republic of China had fully-functioning metro systems in 30 cities measuring over 3,500 km, while India currently has metro systems functional or in various stages of implementation in 15 cities and measuring over 1,110 kms (Economic Times, 2018; Xinhuanet, 2017). In 2014, both the People’s Republic of China and India recorded a high modal share in railway passenger transport – 14% and 27% respectively, as compared with the global average of 8%. Further, the People’s Republic of China also demonstrates extensive development of High-speed Speed Rail since 2000, measuring 25,000 km with 464 billion passenger km in 2016 (SloCat, 2018). Furthermore, the People’s Republic of China also utilises one of the highest railway freight mode shares with 40% in 2014, as opposed to the world average of 28% (SloCat, 2018).

At the same time, in the ASEAN countries, 5 cities have operational rapid transit systems measuring over 600 km, with an additional 8 interregional high-speed corridors being implemented (Global Mass Transit, 2015; Smart Rail World, 2015). Lastly, there exists a strong preference for the BRT in Asia as a flexible, cost-effective and quick-to-implement system with physically segregated and high-priority bus lanes, often with enclosed stations. BRT systems in 43 Asian cities measuring over 1,500 km presently transport close to 1 million passengers daily (Global BRT Data, n.d.). In terms of freight transport, the modal share in tonne-km of surface freight by rail for both India and the People's Republic of China was high at 35% in 2014. Notably, the modal share of rail freight only accounted for 1% for the Association of Southeast Asian Nations (ASEAN) countries (SloCaT, 2018).

2.4 Challenges for sustainable transport development in Asia

Despite of the positive trends described above, the development of sustainable transport in Asia is still primarily concentrated in larger metropolitan cities or regions with high economic growth (Mo et al., 2014). Moreover, as highlighted in the previous chapter, these efforts have not been able to restrict the trend of rising motorisation and increased reliance on private cars and motorcycles even in large metropolitan areas. Hence, there is a critical need to adopt the Enable-Avoid-Shift-Improve (EASI) sustainable transport paradigm a nation-wide scale – especially in smaller cities and town that comprise a majority of Asia's urban network. This can potentially minimise the air quality impacts from the transport sector (as explained in the previous chapter), and maximise the co-benefits of the uptake of new public transport services, already significantly underway across the Asian region. However, towards achieving this, one of the most crucial challenges is the conventionally supply-driven and automobile-oriented policy approach predominant in many Asian cities. Such a detrimental approach has led to a range of interrelated constraints in scaling up of sustainable transport practices. These are outlined in the following sections.

2.4.1 Land-use and transport planning

Along with extremely high rates of motorisation and urbanisation, cities in Asia's developing countries suffer from unstructured territorial expansion and insufficient regional planning measures, which creates barriers in integrating the development of both land-use and transportation systems (Mo, Kwon and Park, 2014). There are multiple interdependent factors which has led to this situation – Firstly, Asian cities have some of the highest densities in the world – around 35 denser than Latin American cities, and between 2.5 to 10 times denser than European and North American cities. Moreover, between 2000 and 2010, 42 Asian cities featured in the 100 densest cities worldwide. Some of these include – Dhaka (Bangladesh), Mumbai and Surat (India), Macau (The People's Republic of China) and Hong Kong Special Administrative Region of China (Cervero, 2013).

Secondly, along with high density, these Asian cities also exhibit significantly less road space – less than 10%, as compared with 20 to 35% percent in European and North American cities respectively (Cervero, 2013). As a result, the existing capacity of road networks fall short of accommodating the ever-increasing traffic demand. For instance, for large metropolitan cities in India, the annual growth rate in 1990s was 5 to 10%, while the increase in road capacity was under 1% (Pucher, Korattyswaropam, Mittal, & Ittyerah, 2005). Such conditions ultimately result in severe congestion along limited road networks, which lower the average traffic speed of the city. For instance, in Manila, it was recorded that traffic speeds fall rapidly when volume exceeds 50% capacity, resulting in average

speeds as low as 10 kmph and below 20 kmph for 75 to 92% of all trips (Mo, Kwon and Park, 2014). Moreover, the high economic costs traffic congestion for Asian countries are equivalent to the loss of GDP by 2 to 4.4% (UN ESCAP, 2007).

Thirdly, to address the rising traffic saturation, city authorities have a tendency to adopt car-oriented transport policies, which comprise of supply-side measures for increasing the available road space – most commonly through widening existing roadways, along with the construction of more highways and flyovers (Jain, 2011). New road construction creates an ‘induced demand’ which results in further increasing the vehicle kilometres travelled (VKT) by private modes, thereby making it unattractive for both citizens to use public transport systems and for public authorities to effortfully develop them. Such underutilisation systematically weakens the capacity of existing public transport agencies to operate high quality services and ensure their accessibility, intermodal integration and network management. This leads to a ‘vicious cycle’ of poor mobility options, deteriorating liveability and even greater reliance on private modes under congested traffic conditions (Petersen, 2004).

Finally, high economic growth coupled with the absence of strong regional planning mechanisms has also resulted in decentralised and unorganised geographical expansion at the peripheral areas of Asian cities (Jain, 2011). This phenomenon, termed as ‘urban sprawl’, primarily comprises of land-uses such as – low-cost housing, informal settlements, and real-estate construction spurred by land-value speculation. However, in most cases, such development is not balanced with proportionate job-creation at the urban peripheries and necessitates longer commuting distances (Cervero, 2013). Therefore, this pattern of growth results in a lack of mixed-use, and consequently leads to higher VKT along the already congested corridors which connect the suburbs and the city centre. Moreover, such a spatial structure emulates that of cities in advanced economies, which are highly-motorised and resource-intensive. For Asian cities, this contributes to higher fossil fuel consumption, as well as higher air pollutant and GHG emissions within a dense urban environment (Petersen, 2004).

2.4.2 Road network and design

The negative impacts of a car-oriented transport policy are not only limited to the emissions-intensity of mobility at the macro city-wide scale, but also affect the road design at the micro neighbourhood scale. These issues can be classified into two categories – (a) Structure of the road network in relation to the overall traffic movement, and (b) Road engineering of streets, which includes physical elements, such as the sidewalks, lane widths, road pavement, curbs, traffic islands, utilities etc.

Firstly, in order to facilitate an efficient flow of high-volume traffic, the city’s road network must be essentially designed for a range of functions, such as – community-level local streets to provide access to properties, the collector roads which distribute traffic among local streets, and finally the arterial roads or urban highways which act as major city-wide thoroughfares. A large number of Asian cities which have rapidly grown in last few decades lack such a functional hierarchy in terms of its traffic network, and lead to many of the transport-related emissions and air quality issues previously described. For instance, in cities like Jakarta and Bangkok, the absence of intermediate distributor roads has resulted in extensive use of narrow alleys within communities as thoroughfares and has worsened the traffic saturation of major arterials (Cervero, 1991). At the same time, such conditions also result in the neighbourhoods that are unconnected from the rest of the traffic network or a disjointed network structure network with missing links. This increases the trip distances between locations, results in less route options and further directs a majority of traffic onto busy arterials (Litman, 2015).

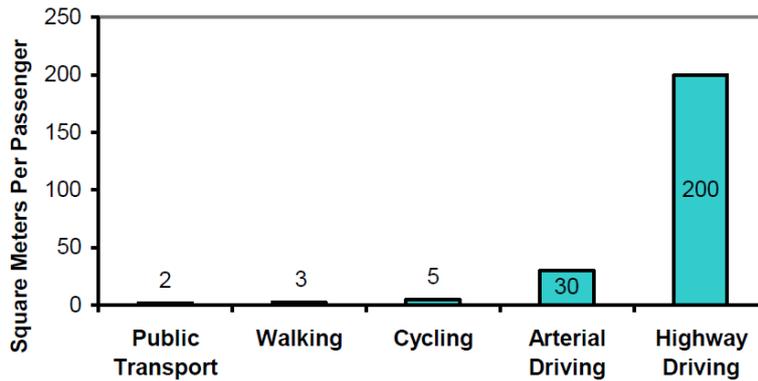


Figure 6: Road space required for various transport modes (Source: Litman, 2015)

Secondly, car-oriented transport planning also influences the space allocation and engineering of the road infrastructure. Conventional road-based planning prioritises minimising the congestion and maximising travel speeds of motorised traffic and volumes and, therefore, governs the design decisions regarding the level-of-service (LOS) assigned to traffic lanes. However, motorised traffic also requires the highest area of space allocation (as indicated in Figure 6). Therefore, where the Right-of-Way is limited, especially in dense Asian cities, maximum LOS is provided for motorised traffic functions (like automobiles, parking, freight vehicles), and negligence of other mobility modes, such as BRT, conventional bus lanes or walking and cycling (Litman, 2015). Such a lack of prioritisation for all modes is especially detrimental for Asian cities where car-usage is very low and a majority of population depends on other mobility options. For instance, in Mumbai (with a population of over 22 million), private cars only account for 14% of the mode share of the total trips (Deloitte, 2018a). Additionally, the lack of infrastructure for walking and cycling also creates physical barriers in terms of accessibility for last-mile connectivity and public transport systems, thereby reducing their usage within the mobility mix.

2.4.3 Governmental/Public service capacity: Vehicle technology, inspection and maintenance

Because of the extremely high demand for transport and the supply of high-quality public transport options by local governments unable to match it, these deficits in mobility services in developing countries are often met by the private sector. As a result, city authorities face significant challenges of effective regulation and enforcement of environmental laws for the transport sector. Firstly, faced with less manpower and resources, administrative capacities of city agencies fall substantially short for managing the vehicular standards and performance for a very large number of loosely organised small-scale operators and industry associations. As a result, a management culture of ‘muddling through’ governs the quality of these services, and left at the discretion of individual public officials or departments and their unofficial negotiations with operators (Meakin, 2004). Although these services address critical last-mile connectivity, operators also tend to choose profitable routes with high ridership – thereby leaving gaps in the coverage and availability of public transport (CDIA, 2011).

Secondly, a large proportion of transport services in Asia are delivered through the informal economy, at times even operating without a licence. For instance, in India, for an urban network that comprises of over 5000 cities and towns, only 100 have formalised public transport systems (Jain, 2011). These

mobility options include vehicle types such as – motorcycle taxis, three-wheelers (auto-rickshaws, tuk-tuks, motorised tricycles), mini-buses, Jeepneys etc. Often, national regulatory frameworks addressing the specific needs of the informal sector are either absent, or, where do exist, their implementation within highly-localised policy environments remain inadequate (Cervero, 2013).

Thirdly, deficient regulation leads to a lack of enforcement of vehicle technology, emission standards and fuel types for informal transport, and has significantly contributed to deteriorating air quality in Asian cities. For reducing operating cost and increase revenues, informal operators resort to cutting corners by not adequately investing in the maintenance of their vehicles (TERI and UN-Habitat, 2012). This results in high emissions of air pollutants and the fuel-run offs on roads harm the local ecological conditions related to soil and water quality (CDIA, 2011). For instance, in Manila, the informal transport is dominated by over 60,000 Jeepneys which primarily run on second-hand diesel-fuelled engines. These vehicles have significantly contributed to the proportions of PM, NOx and SOx in the total mobile source emissions (Mo, Kwon and Park, 2014). Lastly, there is an extremely high prevalence of three-wheelers powered by petrol-fuelled two-stroke engines for informal transport throughout Asian cities. These engines emit a high volume of unburnt hydrocarbons, CO, CO₂, along with Particulate Matter that is 13 times higher than regular engines (TERI and UN-Habitat, 2012). Despite of national regulatory efforts and policy direction for phasing out of such high-emission vehicles toward cleaner fuels – such as Compressed Natural Gas (CNG) or Liquefied Petroleum Gas (LPG) – and low-emission technology (like electric vehicles) remains a critical challenge.

2.4.4 Road safety

A car-centric approach to road design leads to adverse impacts in terms of road safety. For a road network that is designed to accommodate the rising volume of vehicular traffic with wider lanes and maximise their speeds, the risk of deaths and serious injuries in a crash also rises exponentially. Further, this risk is borne by the most vulnerable and physically exposed groups of road users, which primarily includes pedestrians, bicyclists and motorcyclists. For instance, according to a WHO survey, vulnerable road users comprise of 46% of the road traffic deaths worldwide (WHO, 2011). Research also indicates that the risk of a pedestrian dying in a traffic crash is 8 times higher when struck by a vehicle traveling at the speed of 50 kmph, as compared to that at 30 kmph (See Figure 7).

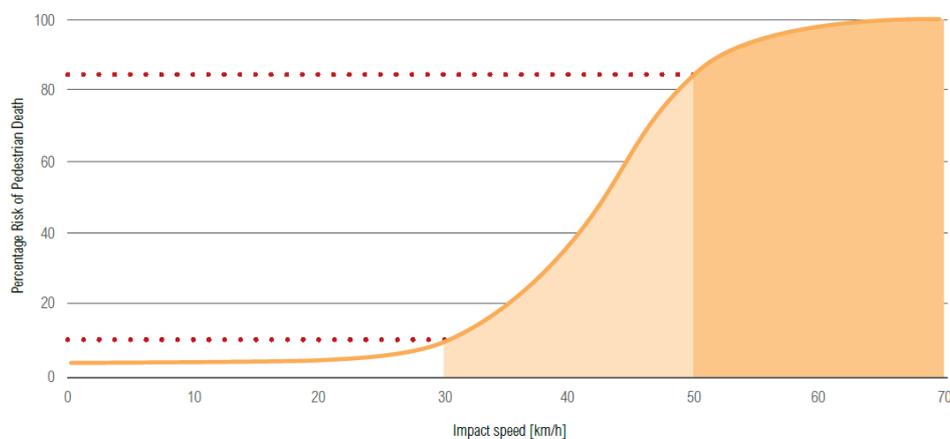


Figure 7: Relationship between pedestrian safety and impact of vehicular speeds (Source: WRI, 2015)

Asian countries have some of the highest traffic accident fatalities globally. Southeast Asia recorded the second highest regional rate for road traffic deaths at 20.7 deaths per 100,000 population and account for 25% of the fatalities globally (WHO, 2018a). As per country-wise data, India has the second highest annual number of fatalities at 146,000 in 2015 (BBC, 2016). Moreover, a landmark survey which examined the conditions of walkability in 13 Asian cities revealed that 41% of the respondents rated the pedestrian facilities in their cities as “bad” to “worst”, and a tendency of 67% of the respondents to shift to motorised transport modes should their walking environments fail to improve (Leather, Fabian, Gota, & Mejia, 2011). Therefore, preventing the consequences of unsafe and inconvenient road conditions for non-motorised modes is especially critical for Asian cities, where walking and cycling have historically accounted for a large percentage of modal shares (WRI, 2015).

A major reason for the lack of such facilities is also the perception of pedestrians and bicyclists as being ‘less important’ than automobiles by public authorities within the transport planning and design processes (Mo et al., 2014). The resultant paucity of space and resources for the construction, operation and maintenance of infrastructure dedicated to vulnerable road users forces them to use high-speed vehicular traffic lanes, thereby significantly increasing both their risk and exposure to crashes. Concurrently, where such infrastructure does exist – in the form of sidewalks, bicycle lanes etc. – it is often poorly designed and lacks the basic understanding of the specific needs of vulnerable road-users that results in an unsafe built environment (WRI, 2015). Some of these design flaws include – discontinuous or extremely narrow sidewalks with frequent obstructions, poorly paved surfaces, lack of pedestrian ramps, absence of crossing opportunities with dedicated pedestrian signals or safe distances, poor visibility of oncoming traffic, lack of connectivity to transit stations etc.

2.4.5 Transport governance

Considering the complexity and multidimensional nature of the transport sector, its effective governance is a challenging prospect. For establishing and operating an efficient, high quality and sustainable transport system, it is essential that several actions are simultaneously undertaken and implemented that combine both supply-side and demand-side measures. However, concerned public authorities in developing countries, often deal with transport issues in a piecemeal manner, instead of adopting a comprehensive planning approach that is integrated spatially, functionally, sectorally and hierarchically (Agarwal & Kumar, 2013).

In the absence of a holistic approach, transport governance in developing countries in Asia is often highly fragmented (Meakin, 2004). This is highly relevant for metropolitan cities with high population and vast regional extent. For these cities, travel needs extend beyond the jurisdictional boundaries of a single municipality, which is primary unit of for transport-related investments and decision-making. Therefore, a high degree of coordination is required between adjacent municipalities to ensure policy coherence across the entire metropolitan area. There is an essential requirement of a singular ‘lead agency’, which is legally, financially, and technically capable for managing the strategic functions of policymaking, planning and construction of public transport facilities, as well as operating various modes. Most megacities in the ASEAN region suffer from the lack of such an empowered lead agency (Mo, Kwon and Park, 2014).

The provision of seamless multimodal connectivity across all available transport modes – such as BRT, MRT, LRT, conventional buses, last-mile connectivity – also remains a significant barrier for increasing the wide-scale adoption of sustainable transport in Asia. A critical factor which prevents such systemic integration is that the decision-making for transport services is distributed across a large number of

public agencies at various levels within the prevalent administrative hierarchy. At the same time, the political conditions and the state of governance decentralisation also heavily influence local government's autonomy. These factors also define the range of a municipality's service-delivery responsibilities, as devolved from higher governmental levels.

In many Asian countries, public transport services in large cities – being the primary engines of economic growth – are managed by the central agencies, parastatal bodies or 'special purpose vehicles' (SPVs). For example, Bangkok's metropolitan issues are dealt with exclusively by the central government ministries and cabinet, especially due to the political sensitivity of the transport-related issues (Meakin, 2004). These organisations usually have a high degree of autonomy and their own sources of earmarked funding for transport-related projects. Weak urban governance stemming from poor devolution of functions at the city level – as evidenced in India – also allows national and state governments to bypass the agenda and mandates of municipalities and other local authorities (G. Bhat, Rajasekar, & Karanth, 2013).

As a result, there exists an unhealthy competition or 'turf wars' amongst various transport agencies, which hampers the overall efficiency of transport systems and the preference of commuters to use them. This is illustrated by evidence from several Asian cities. In Bangkok, the absence of fare and transfer integration between the several public transport services (like the MRT, BRT, Skytrain, airport rail link) is known to cause severe inconvenience for the city's transit users (Mo, Kwon and Park, 2014). In both Seoul and Singapore, despite of high-quality transport infrastructure, commuters are required to walk long distances to transfers between regional trains or MRTs or between bus-stops and MRT lines (Sim, 2019; Mo, Kwon and Park, 2014). Lastly, lack of a strategic planning framework and, as a result, the missing cooperation between urban development and transport departments is also the key barrier in the integration between land-use planning and transport policies, as is experienced in Chinese cities (Diaz & Bongardt, 2013). The inefficiencies of transport governance described herein also have far-reaching effects on interrelated issues in terms of finance, technical capacities and regulation, as explained in the next sections.

2.4.6 Funding and financing issues

Despite of the recent efforts to promote public transport, walking and cycling, the automobile-oriented transport policy predominant in Asia also influences the manner in which available public funds are expended on projects supporting unsustainable modes. This poses enormous financial constraints, since the current political and institutional setups in the transport sector – including investors, donors, and decisionmakers – tend to favour investments in large-scale road infrastructure, such as urban highways and flyovers (Bhatt, 2018; Diaz & Bongardt, 2013; Dalkmann & Sakamoto). It is therefore essential for cities and policymakers to identify the specific sources of funding, as well as financial mechanisms that support their sustainable transport initiatives. At the same time, it is also important for cities to differentiate the financial requirements in terms of initial capital investment (for the construction and development of transport infrastructure), and the recurring expenditure (for maintenance and operations purposes).

Generally, these funding sources comprise of governmental transfers from state or national ministries, local taxes – like fuel surcharges, vehicle taxes, congestion charges, parking fees, land-value capture or property taxes, advertising revenues etc., and international sources, such as – bilateral or multilateral funding (Official Development Assistance or ODA and climate finance) from donor countries, and loans or grants from development banks. Despite of the existence of numerous funding

sources, a major challenge is that the disbursement of most of these funds are administered by national or state government agencies (Dalkmann & Sakamoto, 2012). This also relates to the previously mentioned issue of limited governance decentralisation in Asia, which leads to decreased fiscal autonomy for municipal authorities. It is therefore essential to enable an institutional setup that removes the barriers in the flow of these national and supranational sources towards increased local-level investments.

As noted by Diaz and Bongardt (2013), the institutional mechanisms to access finance for sustainable transport could be further classified into two categories – (a) Centralised funding programmes, and (b) Decentralised financing policies. In the centralised model, the most of the decision-making powers regarding funding, planning and implementation are retained by the national government, while local governments have limited responsibilities, financial risks and scope in types of expenditure (mostly capital). On the other hand, a decentralised model consists of a mix of central and local funding (co-financing), as well as a greater role of local governments to implement projects and greater flexibility in allocating funds for a range of expenditures (both capital and operations functions).

Although there is no absolute adherence to each of the two models and each country follows a mix of both, many large Asian cities in emerging economies (especially in India) could be classified into the centralised funding category – with the exception of those in the People’s Republic of China, which lean towards the decentralised process. Nevertheless, both the types of mechanism are associated with barriers in the implementation of sustainable transport (Diaz & Bongardt, 2013). The centralised model risks excessive standardisation of planning for all cities, lack of opportunities in developing municipal capacity, and excluding local innovative solutions. As also, the decentralised model suffers from municipal debt accumulation due to credit from commercial loans and unsustainable funding for covering operational and maintenance costs, as observed in the People’s Republic of China. Lastly, private sector financing through Public-Private Partnership (PPP) features in both the types of mechanisms. Although private sources can potentially fill the public funding gaps for sustainable transport, this mode also associated with drawbacks related to substandard implementation (to maximise profits), and a significant financial risk should the contractor go bankrupt (Dalkmann & Sakamoto, 2012).

2.4.7 Technical expertise and institutional capacity

There exist multiple constraints for governmental organisations at all levels in terms of transport-focussed technical knowledge and manpower, and robust capacity building programmes are necessary to address them. Firstly, the strategic planning and implementation of environmentally sustainable urban transport systems is a complex and multidisciplinary area, requiring a skillset that encompasses civil engineering, transport economics, traffic engineering, environmental and urban planning etc. Since this is a relatively recent practice in developing countries, with a limited pool of specialised professionals, the hiring of technically competent and qualified staff by public agencies remains a challenge (Kumar and Agarwal, 2013).

Secondly, in most ASEAN countries, there is a severe lack of transport databases that are up-to-date and available in a digitised and easy-to-use format (Mo, Kwon and Park, 2014). This hampers the process of future travel demand forecasting, as well as the monitoring and evaluation of the existing state of urban transport services. Outdated data also results in errors in demand estimation or cost-benefit analyses, and officials tend to favour ad-hoc decisions instead of evidence-based and informed

policymaking. This further minimises the need to invest in developing the technical capacity for public servants.

Thirdly, high-quality data that aggregates detailed information from all transport and public utilities departments (such as the layouts of underground sewage, electricity, gas, water supply lines, and elements such as street-lights, traffic signals and trees etc. above ground) is either insufficient or non-existent. As a result, there is a lack of inter-organisational coordination over repairs and maintenance operations and unforeseen on-site challenges emerge during the execution stages of a project. Moreover, in the absence of streamlined project management practices, the frequent digging up of road space for construction purposes not only worsens traffic congestion, but also affects the walkability and accessibility for public transport users.

Lastly, high level of technical capabilities at the local level are also needed for accessing global funding such as Official Development Assistance (ODA) and various multilateral climate funds. Although the benefits of the availability of these funds for sustainable transport are numerous, there exists a systematic and often lengthy process to apply for them (Binsted, Bongardt, Dalkmann and Sakamoto, 2013). This requires the submission of extensive technical details pertaining to budgets estimates, project formulation, various types of impacts (environmental, social, economic etc.) and so on. Local authorities often lack the knowledge regarding the fulfilment of these prerequisites, or extensively rely on consultants to undertake these processes. Furthermore, because of this knowledge and skills deficit by public officials, the utilisation of ODA in ASEAN countries remains low (Mo, Kwon and Park, 2014).

Chapter 3: Comprehensive Analysis of Air Quality Co-Benefits of Sustainable and Low-Carbon Transport

3.1 Introduction: Defining 'co-benefits'

The notion of co-benefits implies the benefits which are accrued as the collateral impacts or side-effects of a specific policy measure. These co-benefits are usually generated in areas other than the explicit target of the original policy measure, whether it is climate or sustainable development. The Intergovernmental Panel on Climate Change (IPCC) defines co-benefits or “ancillary benefits” as “the positive effects that a policy measures might have on other objectives, irrespective of the net effects on the overall social welfare.” These effects are often subject to uncertainty and depend on local or regional circumstances and implementation practices, as well as the pace and scale of deployment of various mitigation measures (IPCC, 2014a). Moreover, based on the positive extent of these effects, they are termed as either co-benefits, or in case these effects are adverse or uncertain, they imply risks.

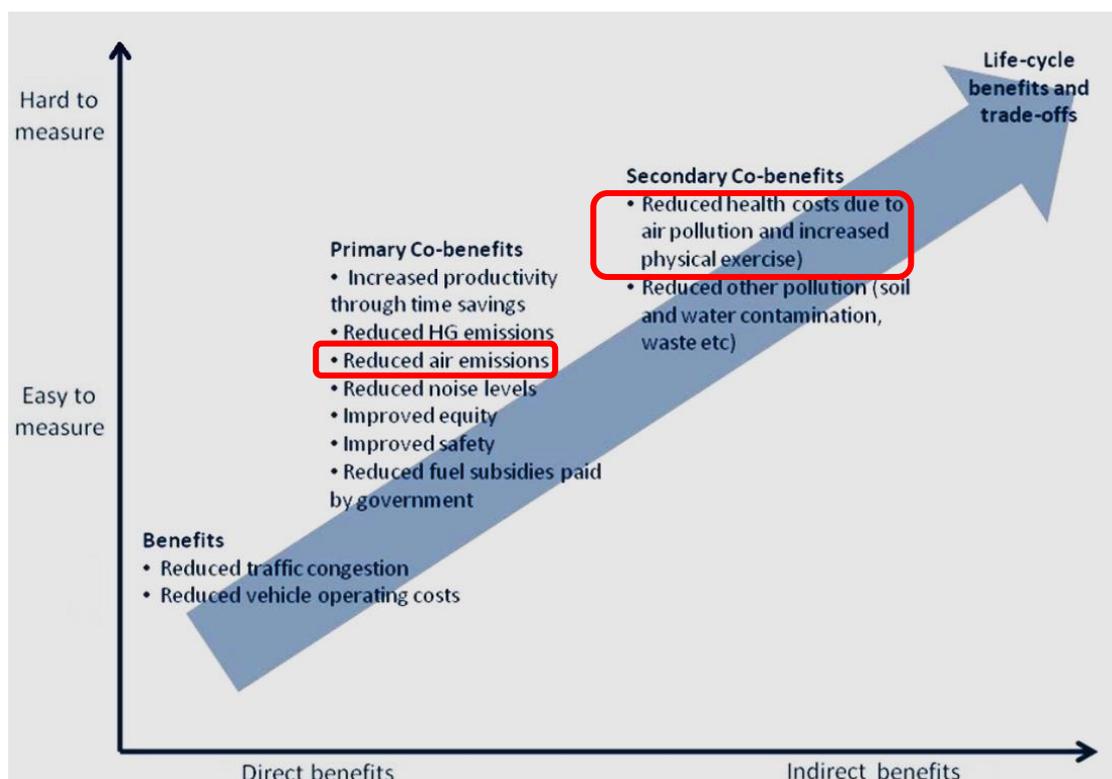


Figure 8: Air quality-related co-benefits of sustainable transport (Source: ADB & CAI-Asia, 2009)

The concept of co-benefits also varies from the perspective of global perspective or Asian (local or regional one). From a global climate change perspective, co-benefits are the additional benefits of policies specifically directed at climate mitigation, i.e. reducing GHG emission. On the other hand, co-benefits for developing countries in Asia implies the climate mitigation benefits of policies that focus on sustainable development issues, which are often a higher priority than GHG emissions reduction (Fabian, 2009). Nevertheless, sustainable and low-carbon transport being a critical climate mitigation strategy, has the potential to generate synergies and trade-offs for a range of sectors, and result in

co-benefits with other social, health, economic, and environmental objectives associated with air quality management. Towards this, a co-benefits-led approach intentionally internalises co-benefits at the conception of a policy or project to maximise the co-benefits, while taking into consideration short term impacts and long-term GHG reductions (Fabian, 2009). Additionally, the IPCC also states that “integrating air pollution abatement and climate change mitigation policies offers potentially large cost reductions compared to treating those policies in isolation” (IPCC, 2007). In order to adopt such an approach, it is essential to systematically identify both the direct and indirect air quality-related co-benefits resulting from sustainable transport strategies (as illustrated in Figure 8). These multi-dimensional categories of co-benefits are discussed in the following sections.

3.2 Health and social co-benefits

The health and social co-benefits of sustainable transport primarily arise from the reduced exposure to harmful pollutants for passengers, as opposed to those using relying on private vehicles within a microenvironment. Additionally, a larger mode share of public transport, walking and bicycling also has the potential to reduce the cumulative levels of pollutants at the city or regional scales. There exists ample evidence which highlights how emissions from collective transit systems like Metrorail are substantially less compared with private modes. Analysis of transport-related GHG emissions from developing countries suggests that while diesel and gasoline cars emit between 85 to 170 gm of CO₂ per passenger per kilometre, buses and rail transit emit between 20 and 70 gm of CO₂ respectively (Sperling & Salon, 2002). Moreover, a study conducted in Bogota indicates that cars and motorcycles also emit significantly higher amounts of pollutants like CO, NO_x and PM_{2.5} per passenger compared with buses (Cuellar et al., 2016) (See Figure 9).

Tests related to air quality monitoring and the effects of exposure to pollutants for road-users are highly localised, and subject to a high degree of variation in land-use, weather, wind and seasonal characteristics for a specific microenvironment. Furthermore, these variations are also affected by the tropical and humid climate of most temperate Asian countries. Additionally, such climactic conditions have a higher potential for secondary formation of particulate matter (Narita et al., 2019). At the same time, hotter climate may also lead to a higher rate of breathing and more inhalation of pollutants (S. H. Tan, Roth, & Velasco, 2017). Therefore, to assess the air quality-related comparison between various private and public transport modes, we consider the air-quality monitoring tests conducted particularly in Asian cities in India, Hong Kong SAR of China, Singapore and Thailand (Goel, Gani, Guttikunda, Wilson, & Tiwari, 2015; Li, Che, Frey, & Lau, 2018; Narita et al., 2019; S. H. Tan et al., 2017).

These sources corroborate highly relevant findings, summarised as follows – (a) A commuter’s trip involves passing through several microenvironments, and the degree of pollutant exposure depends on the openness of the mode used. Accordingly, motorcyclists and active modes such as walking or cycling carry the highest risk of exposure, followed by passive modes like open non-air-conditioned (AC) buses and cars or taxis; (b) Lowest exposures were observed in underground metro cabins, MRT stations, and AC cars in that order; (c) Very high degree of seasonal variation was recorded between summer and winter conditions, the latter recording higher pollution; and (d) Air pollution in several Asian cities was observed to be a multi-sectoral problem. Thus, road-users are also exposed to emissions originating from crop-burning and industrial activities, in addition to those from traffic. Under such conditions, segregated public transportation systems emerge as one of the most protective modes, since a dedicated corridor with enclosed cabins and stations physically separates

passengers from general traffic exposure while waiting to board or during the journey. Concurrently, increased adoption of public transport also results in substantial health gains, primarily through reduced air pollution and lower risks of associated with cardiovascular, respiratory and pulmonary diseases, as explained in Chapter 1 (WHO, 2011).

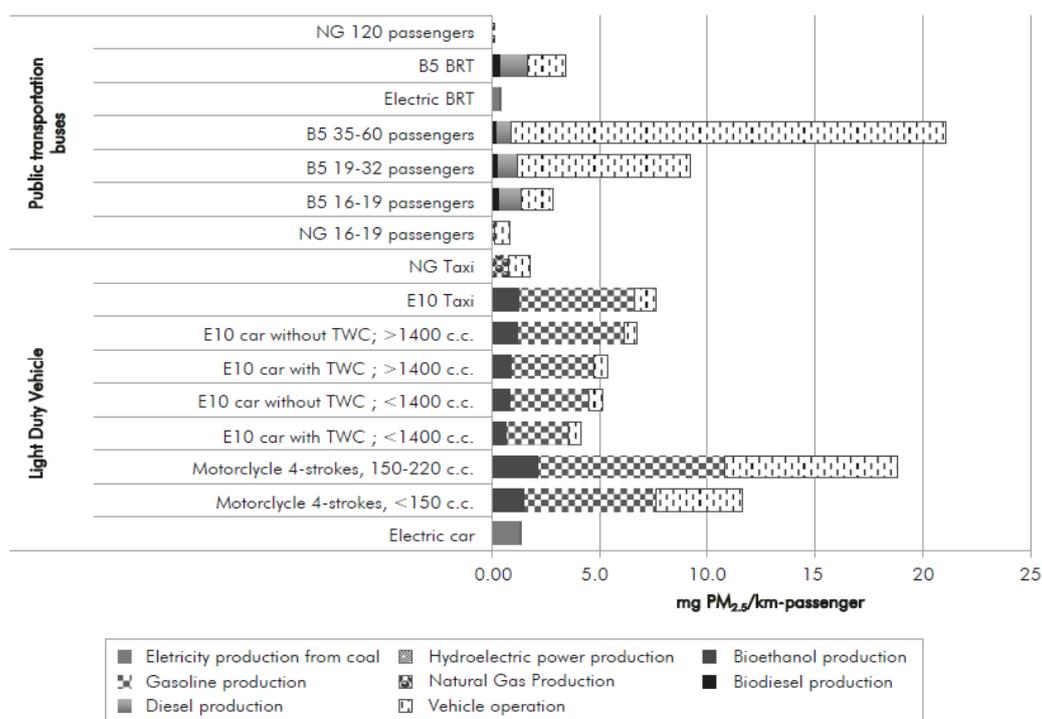


Figure 9: Comparison of emissions in developing countries from various transport modes in terms of $PM_{2.5}$ (above) and CO_2 (below). Public transit modes indicate lowest per passenger-km emissions, while cars and motorcycles indicate the highest equivalent units (Sources: Sperling & Salon, 2002; Cuellar et al., 2016)

As highlighted in the previous chapter, the unstructured geographical growth characteristic of Asian cities also has a tremendous impact on air quality. Evidence indicates that between 2000 and 2010, unplanned urban sprawl in East Asia has led to an increase in pollutants at the metropolitan regional scale – primarily in NO_2 levels and to a lesser extent of $PM_{2.5}$ levels which are influenced by more localised sources (Larkin et al., 2016). In Shanghai, increasing levels of $PM_{2.5}$ were recorded with an equivalent rise in travel distances especially in peri-urban areas, due to – unstructured urban expansion and the lack of a contiguous transport network in terms of density, mix of land-use and

accessibility to transit, which leads to added congestion (See Figure 10) (Han & Sun, 2019; Zhou, Li, & Wang, 2018).

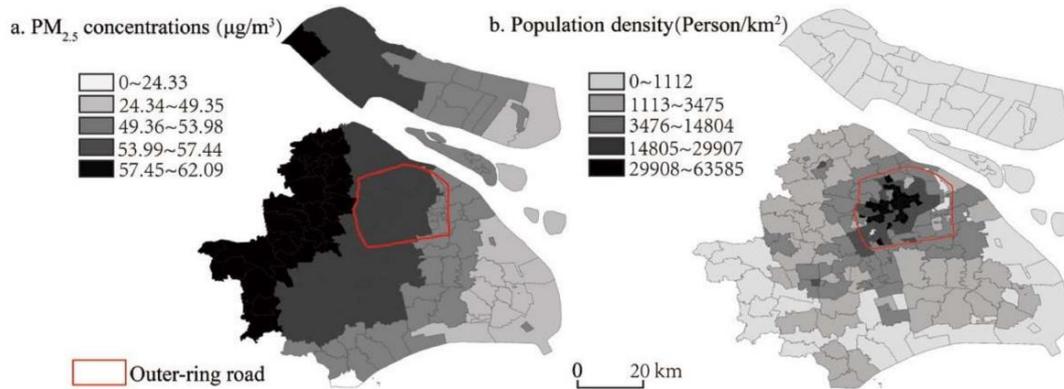


Figure 10: Spatial distribution of PM_{2.5} concentrations and population density in Shanghai (Source: Han & Sun, 2019)

Such a land-use pattern also has severely negative health consequences along busy roads with high traffic density, where air pollution is most concentrated (WHO, 2011). Under such conditions, the integration of land-use and public transport systems not only contains urban sprawl, but also generates significant health benefits by lowering hazardous pollutant exposure through shorter trips and increased modal shift to low-emissions transport modes. In particular, mobility planning through Transit Oriented Development (TOD) process (as elaborated in Chapter 4) is a globally demonstrated tool to spatially organise urban development along high-quality mass transit corridors.

The health-related co-benefits of TOD also include reduction of excessive noise pollution in the vicinity of traffic corridors, which is known to cause exacerbated stress levels, increased blood pressure and sleep disturbance (WHO 2011). As modes that emit zero pollutants and induce an active lifestyle, bicycling and walking are also critical measures which maximise the health co-benefits of sustainable transport. Lack of physical activity is responsible for over 3 million deaths annually worldwide, and a major cause of death and illness from noncommunicable diseases such as type 2 diabetes, obesity and some types of cancer. Towards this, a higher modal share of walking and bicycling in the transport mix and the resulting physical activity leads to lower risks of cardiovascular diseases and lesser average obesity rates, along with other multi-dimensional health benefits (as illustrated by Table 11).

Additionally, a wider adoption of walking and cycling with multi-modal TOD improves the transport choices for last mile connectivity and potentially increases the public transport usage, as well as a generates a range of social co-benefits. These includes increased access to social infrastructure, such as schools, hospitals, markets and work opportunities. This is especially relevant from the perspective of social equity. This is especially relevant for implementing both the SDGs and the UN's New Urban Agenda which respectively aim at "equitable and affordable access to sustainable basic physical and social infrastructure for all, without discrimination" and ensuring that "no one is left behind".

Literature indicates that the citizens that regularly use public transport, walking and bicycling comprise of a significantly higher percentage of users such as – lower-income groups, women, children, teenagers and older citizens. However, in doing so, these vulnerable groups also face multiple issues. Firstly, in developing countries where the cost of purchasing private vehicles and fuel prices remain high, lower-income groups exceedingly rely on cheaper public transport options and non-motorised

modes such as walking and bicycling. As noted earlier in this chapter, walking and cycling activities are also associated with higher air pollution exposure.

Lower all-cause mortality**	Less coronary heart disease**
Less high blood pressure**	Less stroke**
Less type 2 diabetes**	Less metabolic syndrome**
Less colon cancer**	Less breast cancer**
Less depression**	Better fitness**
Better body mass index and body composition**	More favourable biomarker profile for bone health and for preventing cardiovascular disease and type 2 diabetes**
Better functional health in older adults**	Better-quality sleep*
Less risk of falls in older adults**	Better health-related quality of life*
Better cognitive function**	

*Table 11: Summary of health co-benefits associated with increased physical activity - Key: ** Strong Evidence; * Modest Evidence (Source: WHO, 2011 based on data from US Dept of Health and Human Services, 2008)*

Secondly, evidence also suggests that the poorer neighbourhoods are also prone to higher air and noise pollution due to their proximity to urban highways, as well as their location away from city-centres where most jobs are located (WHO, 2011). Formal and informal transport services like affordable bus services, intermediate public transport (like rickshaws, tuk-tuks), walkable sidewalks and cycling infrastructure significantly foster social inclusion for the poor and vulnerable members of the society. At the same time, greater investments in sustainable transport also results in higher productivity gains, due to the large number of people employed in the informal and formal public transport sector (IPCC, 2014b).

Thirdly, as elaborated in Chapter 2, developing countries also suffer from a lack of well-designed street infrastructure which facilitates safe and comfortable walking and bicycling conditions. This especially poses safety risks and hinders access for older citizens, children and persons with physical disabilities. In the absence of accessible public transport and street infrastructure, older citizens and disabled persons are also susceptible to facing social exclusion, isolation and also result in deteriorated mental health conditions. At the same time, children in automobile-dependent cities are solely dependent on their parents for their mobility needs. Limited mobility for this group can result in hampered development of cognitive and motor skills and also contribute to increased obesity (WHO, 2011). Therefore, sustainable transport strategies that provides affordable and convenient accessibility to public and non-motorised transport can potentially yield multiple social and health co-benefits for the vulnerable road users in Asia.

3.3 Morbidity and mortality co-benefits

While the previous sub-section dealt with the indirect impacts of air pollution, the most striking and direct impact of air pollution is the resulting number of premature deaths. Globally, the number of premature deaths due to outdoor air pollution are projected to increase from 3 million in 2010 to a global total of 6 to 9 million people in 2060 (OECD, 2016; WHO, 2016). This substantial increase is attributed to higher concentrations of PM2.5 and ozone and the rate of urbanisation, leading to higher

levels of exposure. According to these estimates, the highest premature deaths in 2060 are projected to occur in India and the People’s Republic of China – each over 2000 deaths per million people – along with smaller increases in Japan and Korea, particularly due to ageing populations. To address this threat, WHO estimates indicate that reducing the PM1.0 levels from 75 micrograms per cubic meter of air, which are common in several developing cities, to 20 micrograms can lead to a 15% reduction in mortality (WHO, 2011).

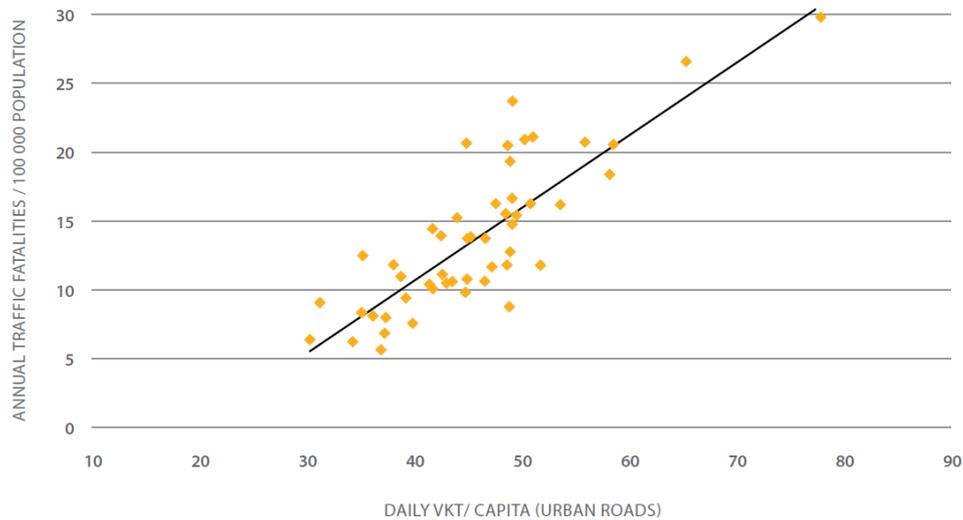


Figure 12: Positive correlation between VKT on urban roads and traffic fatality rates in the US states (WRI, 2013, based on US Federal Highway Administration (FHWA) Highway Statistics 2008)

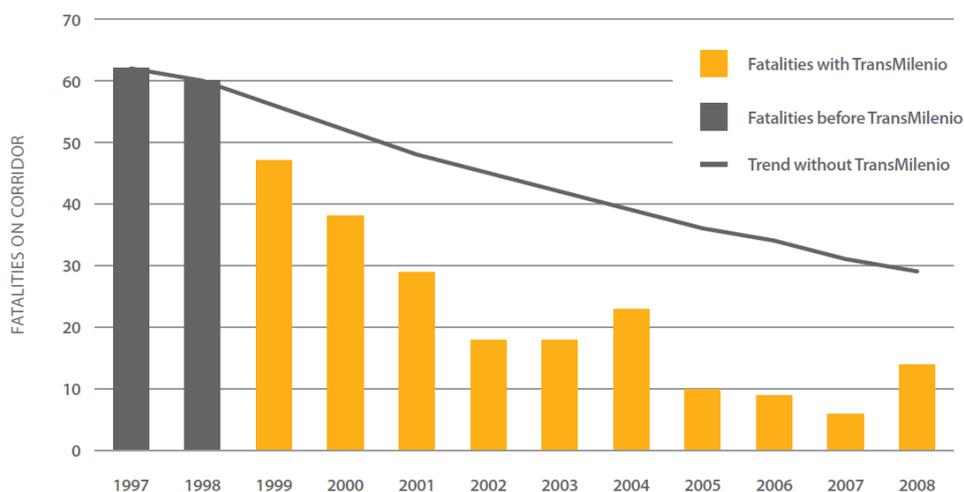


Figure 13: Reduction of reported traffic fatalities after the implementation of Transmilenio BRT corridor in Bogota (Source: WRI, 2013)

As mentioned in the previous chapter, Asia also has some of the world’s highest mortality rates associated traffic fatalities due to motorised traffic crashes. Road traffic injuries currently kill approximately 316,000 people annually in Southeast Asian region, and estimated to become the fifth leading cause of death by 2030 globally (WHO, 2018a). Two major factors that directly influence mortality from traffic accidents are – the number of vehicle kilometres travelled (VKT) and traffic speed. VKT is widely recognised in the research and practice discourse as a strong predictor of crashes

for both urban and rural roads (See Figure 12) (WRI, 2013). Sustainable transport and compact urban development policies aim at shorter trip distances and shifting travel to modes with higher occupancy – thereby simultaneously reducing VKT, the physical exposure to traffic crashes and road safety risks. Evidence from successful cases, such as the Transmilenio BRT in Bogota, indicate a reduction in the number of reported fatalities after implementation (See Figure 13). At the same time, regulation and enforcement of lower traffic speeds result in minimising the probability traffic crashes and the mortality risk posed to vulnerable road users. Evidence suggests that the risk of a pedestrian dying in a traffic crash rises 3 times between speeds ranging from 50 kmph and 80 kmph (Chan, 2017).

Reducing traffic speeds and increased public transport usage also generate a critical co-benefit of improving the air quality in the vicinity of busy traffic corridors. Maintaining uniform and lower speeds for a steady traffic flow minimises the tendency of vehicles to constantly start and stop and, hence, the unnecessary need to frequently accelerate and decelerate while driving (Quarmby, Santos, & Mathias, 2019). Further, such a traffic pattern not only decreases tail-pipe emissions, but also prevents the release of particulate matter from braking and tyre friction. Studies show that braking at 30 mph releases twice the volume of braking particles as compared to that at 20 mph (Font & Fuller, 2016). Furthermore, lower speeds also lead decrease in fuel consumption. Every 15 kmph increase in speed results in 20-25% rise in fuel consumed along with proportionate emissions.

Lower speeds also affect GHG emissions, as evidence in Ahmedabad's BRT system in India. After its implementation, the GHG emissions along the corridor reduced by 35%, while traffic fatalities decreased by 66% by the second year (Welle et al., 2018). Therefore, although most speed management policies are focussed on improving road safety, their co-benefits of air quality improvement and climate mitigation must also be taken into consideration. Another highly effective approach to tackle road safety, while yielding other allied co-benefits is the 'Vision Zero' approach to road safety. This strategy comprises of a comprehensive set of 'safe systems' solutions to minimise crashes and traffic fatalities (further explained in Chapter 4). These strategies coupled with public transport initiatives have resulted in remarkable outcomes. The fatality rate in Sweden reduced by 55% between 1994 and 2015 after the implementation of Vision Zero programme. Moreover, similar strategies in Spain resulted in a decline in fatalities by over 60% since 1994, while in the Netherlands it fell by 50% between 1998 and 2007 and saved 1700 lives (Welle et al., 2018).

3.4 Economic co-benefits

According to the OECD, there are two major direct market impacts of air pollution on a country's GDP – reduced labour productivity, increased health expenditures and reduced agricultural yields. As per these estimates, the total annual market costs of outdoor air pollution are projected to increase annually from 0.3% in 2015 to 1.0% in 2060 (OECD, 2016). However, because of the concentration of air pollution and high rate of related mortality, this economic impact for the Asian region is the range of 1.25% to 2.5%. The most severe economic consequences within this range are projected to be faced in the People's Republic of China, where the problem of air pollution would also be coupled with that of an ageing population in the coming decades, and therefore result in significantly higher medical expenditures. These estimates also indicate that air pollution-related market costs for the Indian economy are projected to rise eightfold to over USD 280 billion – more than 7% of the current GDP.

The non-market costs of air pollution also include welfare costs related to premature deaths, the costs of suffering pain and illness, and the willingness to pay for the avoidance. Accordingly, the regions with the highest projected welfare costs are the People's Republic of China, which recorded the

highest number of cases of illness associated with air pollution, particularly for bronchitis (OECD, 2016). Nevertheless, these large Asian countries are also currently undergoing both rapid urbanisation and motorisation. Therefore, countering transport emissions through sustainable transport policies is essential to minimise the aforementioned economic impacts of air pollution. The social costs of public health due to outdoor pollution is also calculated as disability-adjusted life years (DALY). Accordingly, a study conducted in Delhi highlighted that the health benefits from measures that reduce CO₂ emissions by a modal shift from LDVs to public transport and active travel resulted in an increase of 12,516 DALY per million capita per year (Woodcock et al., 2008 quoted in IPCC, 2014b).

The economic co-benefits of sustainable transport measures also arise from its effect on traffic congestion which negatively affects journey times and results in substantial economic losses. For instance, in Asia, the value of time lost due to traffic congestion in terms of the city's GDP was equated at 4% for Manila (Philippines), 3.3% to 5.3% in Beijing (People's Republic of China), and 1% to 6% in Bangkok (Thailand) (IPCC, 2014b). Lastly, there are multiple economic co-benefits from sustainable transport which arise from lesser reliance on fossil-fuels. Compared with other energy-intensive sectors, transport depends mostly on oil, with 94% of fuels for transport being petroleum products (IPCC, 2014b). Countries rely heavily on oil-imports to meet the transport sector's needs and are susceptible to fluctuations of international oil prices. Therefore, sustainable transport policies that induce a shift away from conventional fossil fuel-intensive modes (such as private cars) and larger adoption of collective and hence less energy-intensive modes (like public transport) result in significant economic co-benefits in terms of reduced fuel spending and oil-imports. At the same time, reduced overall transport demand (through TOD and demand management policies) leads to lesser exposure to oil price shocks and enhanced energy security (IPCC, 2014b).

3.5 Environmental co-benefits

While sustainable transport results in air and pollution noise pollution-related co-benefits, it also has favourable effects on other environmental and natural systems – such as, vegetation, water and biodiversity. In particular, integrating transport planning and urban design to prioritise moving people over vehicular traffic can significantly enhance the urban liveability and climate-resilience, particularly at the scale of microenvironments along streets. The primary reason for this is that mass transit and non-motorised modes such as walking and cycling occupy far less space compared with traffic that majorly comprises of private automobiles. For instance, the per capita space requirement for transit is 0.75 to 2.5 square meters, while that for automobiles is 21-28 square meters (IPCC, 2014). Therefore, high-volume sustainable transport measures allow the inclusion of environmental design features, particularly in congested and dense neighbourhoods, without compromising on the number of passengers travelling through them. These strategies are termed as 'complete streets', further elaborated in Chapter 4.

Evidence suggests that natural features such as urban greening and increased vegetation (also termed as 'green infrastructure') within microenvironments result in the mitigation of smog conditions due to the evaporation-transpiration process of trees and the dry deposition of pollutant particles (such as PM₁₀, NO_x, Ozone) on vegetation surfaces (Akbari, Pomerantz, & Taha, 2001). This is especially critical for Indian and Chinese cities, where seasonal spikes in air pollutant levels regularly result in smog conditions. For example, in December 2018, Delhi in India and 79 cities in the People's Republic of China (including Beijing) were blanketed in thick smog, affecting visibility and resulting in cancellations of flights and closure of major highways (Lau, 2018; The Guardian, 2018).

Complete Streets solutions also result in several other environmental co-benefits (IPCC, 2014b, 2014a). These include – (a) Mitigation urban heat-island effect and reduction of ambient temperature due to the shade from trees and open spaces; (b) Reduction of noise pollution and increased road safety due to lower speeds and lesser lane-widths (also referred to as ‘road diet’); (c) Economic benefits for businesses due to improved urban environments and liveability of the neighbourhood; (d) Increased flood mitigation capacity of the available street space due to higher permeable surface areas; and (e) Increased ground-water percolation and harvesting rainwater for greater climate resilience. Additionally, the reduction of ozone levels due to sustainable transport modes also results in the avoidance of their detrimental effects on vegetation, as explained in Chapter 1.

3.6 Climate change co-benefits

In 2015, passenger transport was responsible for 5.5 gigatons of CO₂ emissions and accounted for 59% of the global transport emissions (SloCaT, 2018b). Further, Asia’s share of global transport which was 39% in 2016, is projected to rise to 31% by 2030 (ADB, n.d.). Such an enormously rising emissions trend also needs to be seen from the perspective of the Nationally Determined Contributions (NDCs) submitted by the Asian countries under the Paris Agreement. Accordingly, the NDCs of several Asian countries (including India and Vietnam) have upheld their need for continued industrialisation in favour of rapid economic growth. To achieve this, these countries have yet to commit to a deadline for peak GHG emissions similar to advanced economies. Instead, their NDCs indicate a strong emphasis towards achieving climate mitigation as a co-benefit of their existing and forthcoming policies for sustainable transport and urban development (Govt of India INDC, 2015). This is also pertinent in terms of air quality management, since evidence suggests that transport modes with high GHG emissions also generally emit more hazardous air pollutants per passenger-kilometre of travel (WHO, 2011). For instance, Indian cities of diverse sizes, with populations ranging from 250,000 to 20 million, indicate a strong correlation between both air pollutants and GHG emissions (CAI-Asia, 2009).

There exist multiple co-benefits of sustainable transport policies which simultaneously lead to GHG reduction and long-term development of low-emissions technology for urban mobility. These include – avoidance of unnecessary trips, the reduction of overall traffic volume and trip distances, the adoption of low emission vehicles or LEVs (such as electric or hybrid vehicles, and electric-bikes), the gradual replacement of older vehicular fleets using highly-polluting fuel like diesel with compressed natural gas (CNG), liquified natural gas (LNG) or biofuels, and a modal shift towards collective forms of transport, such as public transit or shared mobility. Additionally, sustainable transport measures also aim at the uptake of pollution-mitigating technologies – such as retrofitting internal combustion engine (ICE)-based vehicles with ‘catalytic converters’ to filter tailpipe emissions. Simultaneously, these initiatives also result in co-benefits such as a reduction in noise pollution, since EVs and non-motorised transport modes are significantly quieter compared with regular ICE-based vehicles. Moreover, with a potential downsizing of vehicular fleets and traffic volumes, these measures also aid in the decreasing both fossil fuel consumption and transport-sector-related GHG emissions for a city, region or country.

The adoption of LEVs, and particularly electric or hybrid vehicles, also has positive impacts on air-quality improvement, since they emit zero to substantially lower tail-pipe emissions compared to conventional ICE-based and fossil-fuel reliant vehicles. For instance, one estimate for the city of Tel Aviv-Jaffa (Israel) which high concentrations of PM_{1.0} indicated that electrification of all diesel buses could result in saving 140 air pollution-related deaths annually (WHO, 2011). However, it must also be

considered that the final impact and total co-benefits of LEVs also depends on the local sources of electricity generation. Additionally, moderate amounts of particulate emissions are still emitted by LEVs due to braking and tyre friction, as with other modes of road-based transport.

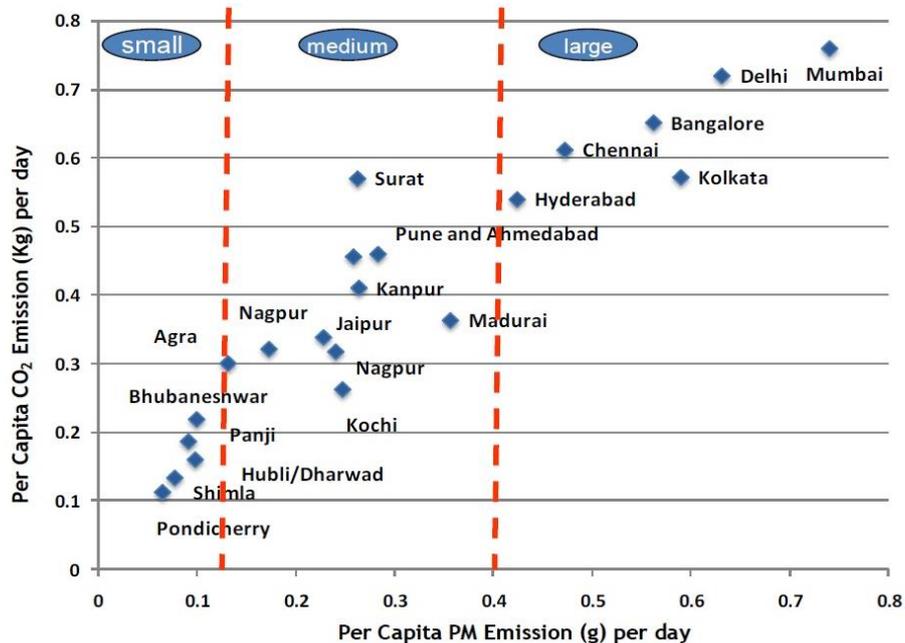


Figure 14: Strong correlation between air pollutants and GHG emissions in India cities (Source: CAI-Asia, 2009, based on data from Ministry of Urban Development of India, 2008)

The technological improvement of LEVs, along with greater modal share of walking and cycling also has the potential to yield multiple co-benefits, albeit under best-case scenarios (IPCC, 2014b). These include – (a) GHG emission reduction and energy security for cities and regions due to decreased fossil fuel usage; (b) Positive effects on economic growth due to less reliance on oil-imports; (c) Promotion of local industries and businesses involved in innovative LEV technologies; (d) Reduced carbon intensity of fuels by replacing oil-based products with natural gas or biofuels; and (e) Reduced energy intensity of economic growth due to greater uptake of renewable energy, like solar and wind. With the cost of these sources decreasing rapidly in the last decade, their utilisation to fuel mobility is also increasingly becoming an economical choice instead of being an environmental one. A study from Germany indicates that electrifying road freight transport could result in the fuel saving of 16,000 EUR per 100,000 km driven. Additionally, this would also result in cutting CO₂ emissions by 7 million tonnes, if one-third of Germany’s truck traffic were electrified and supplied with renewable energy (Siemens, n.d.).

Lastly, the rise of shared-mobility use in the form ride-hailing apps, dockless bike-sharing and micro-mobility (collectively referred to as ‘new mobility’) also potentially impacts GHG emission reduction. Evidence from the People’s Republic of China highlights that bike-sharing in Shanghai alone in 2016 led to reduced fuel consumption by 8,400 litres, and a decline in CO₂ and NO₂ emissions by 25,000 tonnes and 64 tonnes respectively (Zhang & Mi, 2016 quoted by Hormick, 2019). Additionally, studies

in the US suggest that car-sharing services have led to a reduction of average individual transport energy and GHG emissions of their users by approximately 51% (Jung & Koo, 2018).

3.7 Agriculture co-benefits

As mentioned in Chapter 1, ground-level ozone emitted from land transport is highly detrimental to vegetation. It penetrates deep within leaves and hinders plant growth, thereby negatively affects agricultural productivity. Additionally, higher ambient temperatures due to ICE-based transport emissions also causes increased evaporative emissions of volatile organic compounds (VOCs) and lead to higher ozone levels (IPCC, 2014). Evidence also suggests that in NDC scenarios whereby ozone reductions have been achieved also overlap with higher production values for ozone-sensitive crops, such as maize, soybeans, oilseeds and wheat (Vandyck et al., 2018). In 2017, the top 10 wheat-producing countries worldwide included the People's Republic of China, India and Pakistan (FAO, 2017). Therefore, sustainable transport could result in significant improvement in crop yields by reducing ozone emissions. This is especially relevant for Asia where agricultural activity still constitutes a substantial percentage of GDP, if not one of the highest. This share was 18% for South Asia, 8% for east Asia, and 12% for Southeast Asia in 2015 (FAO, 2018).

Chapter 4: Sustainable and Low-Carbon Transport Solutions for Improving Air Quality

4.1 Introduction: A typology of solutions

As elaborated in Chapter 2, a guiding strategy widely adopted in the research and practice discourse to structure policy measures for sustainable transport is the Enable-Avoid-Shift-Improve (EASI) strategy. This conceptual framework is summarised as – ‘**Enable**’ solutions set up an efficient and responsible governance system with funding and technical capacity; ‘**Avoid**’ solutions minimise individual motorised trips and travel demand; ‘**Shift**’ solutions increase the modal share of public transport, walking, cycling and shared mobility; and ‘**Improve**’ solutions aim at optimising infrastructure, and upgrading to low-carbon and energy efficient technologies (Dalkmann & Brannigan, 2007; Stucki et al., 2015). The inventory of solutions explained in this chapter also follows this framework. Additionally, the broad EASI categories also include numerous policy measures which could be further classified based on their objectives (Dalkmann & Brannigan, 2007). These five types are explained as follows.

- a) **Planning measures:** Infrastructure measures that reduce travel needs or optimise trip efficiency
- b) **Regulatory measures:** Governmental policies, legislations or regulations that discourage travel, and restrict certain motorised private modes
- c) **Economic measures:** Instruments that generate revenue through taxation or penalisation, and influence public behaviour
- d) **Informational measures:** Initiatives that raise awareness, disseminate information and induce behavioural change
- e) **Technology measures:** Solutions aimed at phasing out older high-emissions technology and transitioning to efficient and low-carbon vehicle or fuel types

Simultaneously adopting a mix of these instruments from each of EASI categories can potentially address not only the supply of high-quality sustainable mobility options, but also curb air pollution and GHG emissions from the transport sector. These individual measures are outlined in the following sub-sections along with their classification as per EASI categories and a combination of policy measure types.

4.2 Low Emission Zones and Congestion Charging

Solution type: ‘Avoid’ – Regulatory and Economic measures

Low Emissions Zones (LEZ) consist of establishing dedicated emission control areas to restrict motorised traffic within specific regions or corridors prone to poor air quality due to traffic congestion. Additionally, LEZ initiatives are specifically directed towards minimising the usage of polluting vehicles based on stringent emission standards. These types include heavy duty vehicles, older vehicles which comply with outdated emission standards, or those fuelled by diesel. Diverting such traffic away from dense neighbourhoods and on corridors with fewer residents living in their vicinity results in substantial health co-benefits. In some cases, the usage of restricted vehicles within LEZs is allowed only after the payment of toll. Congestion charging (CC) is a similar policy measure, albeit implemented as a key driver to improve traffic flows to minimise congestion, and only secondary to reduce negative environmental impact. CC solutions comprise of enforcement mechanisms to charge

motorists to ply certain corridors or areas (for e.g. city-centres prone to traffic saturation) and penalise them for non-compliance. The alleviation of traffic congestion also has significant impacts on local air-quality owing to the reduction in the time of engine idling and the resultant tail-pipe emissions within a microenvironment.

Cities where LEZ or CC solutions have been successfully implemented include London, Stockholm, Berlin, Beijing, and Singapore. Particularly in Europe, 200 cities in 12 countries have created LEZs as a localised air pollution measure. (Quarmby et al., 2019). This is primarily driven by a legislation by the European Commission which aims at limiting the exposure to pollutants such as PM2.5, PM10, NO2 and benzene. Moreover, there exist two unique LEZ enforcement initiatives in London, to be operational from 2019 and 2021 respectively. These include – **(a) Zero Emission Zones** which only permit vehicles with no tailpipe emission, such as electric vehicles, and **(b) Ultra Low Emission Zones** which only permit vehicular models like hybrid vehicles, which comply with the most stringent emission standards. London’s LEZ and CC policies have so far resulted in the lowering of PM2.5 levels by over 3%, a 30% reduction of congestion, and 95% vehicles driving through the LEZ adhering to strictest emission standards (Wang et al., 2017).

A highly effective variant of CC measures is Singapore’s policy of Electronic Road Pricing (ERP), operational since 1998 (further explained in Chapter 5). This method deploys an advanced system with cameras, dashboard units, overhead road gantries, cashless payment, radio communication technology, to automate the toll-collection along selected corridors and zones across the network. In the US, congestion pricing policies were legislated in 2019 for the first time after decades of failed attempts in New York. Lastly, a new form of CC policy specifically levies a surcharge on vehicles provided through ride-hailing apps. In the US, such initiatives have been considered in Seattle, and already implemented for Uber and Lyft-operated cars entering the Manhattan area of New York.

4.3 Speed management

Solution type: ‘Avoid’ – Regulatory and Planning measures

Speed management is achieved through a mix of actions related to regulatory, awareness and technological improvements. These include – stricter enforcement by the traffic police to follow traffic rules (including seat-belts and helmet usage), higher fines, better surveillance and monitoring by deploying camera technology, behavioural change or awareness campaigns to expose to risks of speeding, as well as national, local or regional laws that regulate speeds based on the function and hierarchy of road infrastructure. Although laws addressing these solutions are already present in most Asian countries, their implementation and management remains a crucial issue (Shah et al., 2018). For better speed control, especially in residential areas with vulnerable road users, cities worldwide are witnessing a steady increase in community-level advocacy for stricter regulation focussed on creating Low Speed Zones with 30 kmph speed limits. Such laws have been successfully enacted in cities like Sao Paulo in Brazil, Edinburg, Portsmouth, London in the UK and Oregon in the US. However, research also indicates that in most countries, 40-50% of the motorists drive above mandated speed-limits (Chan, 2017).

To address non-compliance and tackle road safety in a comprehensive manner, the ‘Vision Zero’ approach is being increasingly adopted by transport authorities. The Vision Zero approach originated primarily in European countries in the 1990s and has since been adopted by several advanced and developing countries alike. At the core of this approach lies the ‘safe systems’ strategies which, as

opposed to conventional approaches, shift the focus from the errors of the persons involved in traffic crashes to comprehensively designing built environments which lead to fewer collisions. This approach combines regulatory measures with planning measures, such as road engineering and urban design features which deter speeding, thereby resulting in safer built environments. With the precedence of successful implementation in Sweden, the Netherlands and Spain, London's new Vision Zero plan also proposes similar engineering and planning initiatives and lowering speed limits to 20 kmph within all of the city's Congestion Charging zones (TfL, 2018). Lastly, lower speeds also result in noise-pollution related co-benefits. Evidence suggests that a 30 kmph speed limit results in 40% (3 decibels) decrease in noise levels originating from urban traffic flows, thereby also resulting in additional health co-benefits (VanderBerg, Penalosa, Sooley, O'Rourke, & O'Connor, 2015).

4.4 Parking management

Solution type: 'Avoid' – Regulatory and Economic measures

The management and pricing of parking provision in the targeted urban areas has the potential to affect the travel behaviour. Estimates from the US indicate that higher parking charges lead to less use of single-occupant cars, and higher rates of carpooling and uptake of public transport, walking and cycling. Another study indicates that charging for parking facilities which reflects the true cost of its provision results in reducing travel by 10-30% (WHO, 2011). Parking restriction solutions comprise of raising the prices for paid parking, imposing pricing for free parking, and minimising on-street parking by reforms in urban planning or building construction laws. A notable example of parking reforms, currently being implemented in several cities globally, is the abolishment of a minimum number of mandatory parking spots per building. Addressing parking at the scale of a neighbourhood rather than individual properties works in the favour of decreasing the overall volume of traffic within polluted zones or corridors. Additionally, it is also important to consider the role of digitally-enhanced or 'smart' technologies to manage parking more efficiently. Some of these include – parking sensors, real-time license-plate tracking, automated valet parking, car-siloes for automated stacking, solar power canopies etc.

4.5 Public transport systems

Solution type: 'Shift' – Planning, Technology and Regulatory measures

Planning and implementing new public transport systems, as well as improving the existing ones is a critical solution in reducing pollutants and GHG emissions. These include Bus Rapid Transit (BRT), Metrorail or Mass Rapid Transit (MRT), light-rail (LRT), and suburban or high-speed rail systems, as well as improvements in conventional bus services. These high-capacity public transport measures aggregate a significantly higher number of passengers into an equivalent space occupied by private cars and are, therefore, grossly economical in terms of GHG emissions and air pollution.

An increased supply of high-quality public transit services also potentially results in modal shift from cars or motorcycles and lowers the total vehicle kilometres travelled (VKT) by private modes. This is also attributed to the increase in the geographical coverage of mobility services, particularly for suburbs or peri-urban areas within the metropolitan region. At the same time, the well-planned and operated network of mass transit system also integrates a discontinuous patchwork of existing formal or informal transport services, thereby ensuring better accessibility through seamless transfers and

last-mile connectivity. Towards this, a planning tool increasingly being adopted is Sustainable Urban Mobility Plans (SUMP) at the city-level or National Urban Mobility Policies (NUMP). According to the European Commission, “the SUMP concept considers the functional urban area and foresees that plans are developed in cooperation across different policy areas and sectors, across different levels of government and administration and in cooperation with citizens and other stakeholders” (Wefering, Rupprecht, Buhrmann, & Bohler-Baedecker, 2013).

The positive impacts of public transport-related measures can be maximised by a range of complementary solutions. These include – (a) Technological measures to integrate diverse modes into a singular network, synchronised through transport management systems and standardised via fare collection services like smart cards; (b) Economic measures such as subsidising public transport fares to increase modal shifts. Several cities worldwide have begun to consider experimentation of free public transport to combat seasonal spikes in air pollution – for e.g., Berlin’s latest decision to make public transport free for school children and Delhi’s recent proposal aimed at female commuters; and (c) Facilitate intermodal transfers with the inclusion of last-mile connectivity modes in the transport planning process – shared mobility services (ride-hailing, bike-sharing etc.), intermediate public transport (rickshaws, tuk-tuks etc.) and walking and cycling.

4.6 Walking and cycling

Solution type: ‘Shift’ – Planning and Informational measures

To raise the modal shares of walking and cycling, cities worldwide are designing and implementing high-quality street infrastructure, with features such as – unobstructed and continuous networks of bicycle tracks and parking spots, public or private bike sharing schemes, priority signalling and waiting areas to turn at intersections, physical segregation between bike-lanes and general traffic or parking lanes for safety, as well as informative signage to highlight the presence of vulnerable bicyclists for motorists. At the same time, road network in many low and middle-income Asian cities – having rapidly expanded in a haphazard manner – lack sufficiently wide and uninterrupted sidewalks which are comfortable and safe for walkability. Moreover, since these roadways are already traffic-saturated, public authorities are often wary of taking away space from motorised traffic lanes for the fear of worsening congestion. In such situations, pedestrians are invariably forced to walk on traffic lanes – at the cost of increased risk of accidents and a higher exposure to pollutants. It is therefore essential that continuous sidewalks of at least 2 to 3 meters wide with an even surface be pre-emptively planned for, to channelize pedestrian movement separated from vehicular traffic.

However, as indicated in the air quality tests referenced in Chapter 3, pedestrians and bicyclists are also more exposed harmful pollutants. Further, these users also tend to inhale higher doses pollutants due to heavy breathing and the unevenness of terrain that requires greater physical effort. It is therefore essential that NMT users be prevented from sharing the same road space or travel within very close proximity of vehicular traffic. Additionally, their routes must be planned as afar as possible from congested zones – through solutions such as pathways dedicated only to walking and cycling, and passing through existing open spaces (VanderBerg et al., 2015).

Despite of a multitude of environmental and health benefits, walking and cycling also suffer from a negative public perception, partly owing to harsh weather conditions. In several of Asia’s emerging economies a personal car is seen as a status symbol by an aspirational populace. To counter this, few metropolitan cities are witnessing policy advocacy in favour of higher walking and cycling, and led

primarily by communities and civil society organisations. A prime example of such social movements is the 'Raahgiri' initiative in India which began in the city of Gurugram in 2013, and inspired from the successfully implemented 'Ciclovía' programme in Bogota. The weekly 'car-free day' or 'open-streets' event – which creates temporary walking/cycling-only streets for a range of civic activities for raising awareness about sustainable mobility – has since been adopted by over 70 urban communities and led to infrastructure improvement in several others (Bhatt, 2018). Concurrently, such campaigns demonstrate and generate air-quality-related evidence by monitoring variations within microenvironments. These complementary informational measures also lead to an increased public engagement about air-quality issues and resultant health hazards. Lastly, this measure also informs citizens about the availability of a range of modal choices (public transport, walking and bicycling etc.), thereby shifting the public behaviour and perceptions around them.

4.7 Complete Streets

Solution type: 'Avoid'/'Shift' – Planning measures

While the previous sub-sections outlined individual modes, it is also critical that these elements are coherently planned in conjunction with each other to maximise their collective co-benefits. Towards this, the intermodal concept of 'complete streets' is useful to structure the urban design that integrates diverse sustainable transport modes together. The 'complete street' concept implies the efficient design of the available Right-of-Way (ROW) to equitably include diverse modes such as bicycles, walking, public transport, in addition to the dominant usage by automobiles. The process of designing such streets involves a setting modal hierarchies and priorities which allows higher space utilisations for walking and cycling and public transport modes, and often taking away road spaces currently used for vehicular traffic lanes and parking. Such a shift of spatial allocation reduces the exposure to harmful pollutants within a micro-environment, and potentially leads to a reduction in traffic volume due to improved public transit accessibility and reduced on-street parking.

A critical component of Complete Streets measures which is highly relevant for air-quality management is the inclusion of ecological features and urban greening within the ROW. These include the plantation of trees or hedges, installation of bio-swales or plantation or pits for stormwater collection and natural treatment. A prominent example of road redesigning and reconstruction towards a 'complete streets' transformation is the Tender S.U.R.E. (Specifications for Urban Road Execution) project being successfully implemented along 12 corridors in the city of Bangalore in India since 2015. Along with the standardisation of design elements and a mandatory ROW allocation for NMT modes, the project also completely restructured the layout and management of underground utilities and legacy systems to accommodate the new design and environmental features. Additionally, it also reformed the procurement and bidding process for construction, thereby allowing the entry of architectural firms experienced in executing high-quality public space projects (Deccan Herald, 2019).

4.8 Transit Oriented Development

Solution type: 'Shift'/'Improve' – Planning and Regulatory measures

Transit Oriented Development or TOD mechanisms comprise of developing areas around transit stations with a priority for high density or compactness of built form, a mix of complementary land-

uses and a creating a network of multiple last-mile connectivity which support the main public transport spine. Additionally, the concept of TOD could be applied to a range of spatial scales. This includes macro-level solutions for transport networks or corridors and neighbourhoods around station areas, to micro-scale solutions, like complete streets and green open spaces adjacent to transit infrastructure. In the context of this paper, TOD translates as those strategies that determine the spatial urban form at both macro and micro scales in the vicinity of public transport facilities and which lead to short-term or long-term reduction of air pollutants from traffic in these areas. In successful cases in Asia – such as Hong Kong SAR of China and Singapore – such measures have led to a higher usage of walking, cycling and shared mobility, capture of land-value from the real-estate development and therefore, increase profitability for transport authorities, and enhanced accessibility and modal share of public transport (Huang & Mehiratta, 2014).

In addition to reducing the private vehicular VKT and restricting urban sprawl, these solutions also have tangible air-quality advantages for commuters within the microenvironments surrounding transit station. This is particularly due to their physical separation from general traffic via elevated walkways and a direct access to surrounding built environment. Additionally, since the creation of high-quality open spaces within TOD zones, there is an improved infrastructure resilience to combat climate-induced disasters such as flooding. Lastly, density coupled with climatologically-sensitive urban design can potentially induce faster wind circulation and thereby, quicker dispersion of pollutants along traffic corridors. Evidence in terms of air quality improvement as a result of TOD strategies has been recorded along the Cheong Gye Cheon (CGC) Greenway project in Seoul. Along this corridor, the removal of a six-km elevated highway and replacing it with pedestrian pathways and landscape features led to a reduction of PM10 by 13%, and NO₂ emissions declined by 17% compared to the regional average (Suzuki, Cervero, & Iuchi, 2013)

4.9 New Mobility

Solution type: 'Shift'/'Improve' – Regulatory and Technology measures

With the ubiquity of internet connectivity and smart-phone technology across Asian cities, the role of app-based shared mobility (or new mobility) in addressing air quality challenges is critical. This category encompasses a wide variety of mobility services, such as – bike sharing, carpooling, on-demand ride-hailing and 'micro-mobility' which includes dockless bicycles, electric bikes and electric scooters. These services offer an increased modal choice for commuters other than conventional public transport, as well as an access to a range of low-emission vehicles (such as EVs and e-scooters) without the requirement of individual ownership. The systematic inclusion of these modes in a city's mobility mix could significantly improve last-mile connectivity, while potentially reduce VKT of personal vehicles and the overall rate of motorisation. Moreover, due to the decentralised nature of service-provision, new mobility has the potential to cover a larger geographical coverage compared to public transport, depending of the market-potential.

At the same time, regulatory support to new mobility can lead to the acceleration of technological innovation through the involvement of private sector in service-delivery. Such a business model brings in new sources of funding in the form of private equity or venture capitalism and economic growth through the creation of a city's start-up ecosystem. Additionally, there is also the possibility of aggregating all the diverse services onto a common platform that offers 'Mobility as a Service' (MaaS) for greater adoption and convenience. With rapid advancement in technology and coupled with heavy private investment, these new mobility service providers often operate in a grey regulatory

environment. To maximise their potential co-benefits for the city's air quality improvement, it is essential that outdated laws and regulations be updated through a collaborative effort between city authorities, existing taxi associations and technology companies.

Lastly, the adoption and implementation of new mobility services still being relatively recent, evidence around their potential downsides is now emerging. In the US, two prominent ride-hailing companies – Uber and Lyft – have been found to be responsible for rise in VKT in six major cities (Bliss, 2019). Another study into the life-cycle assessment of electric scooters concluded that for two-thirds of the trips, e-scooters generate more GHG emissions compared to alternatives like walking, cycling and public transport (Hollingsworth, Copeland, & Johnson, 2019). These impacts also include a very short life-cycle with embodied GHG emissions of the mechanical components, and those emitted by freight fleets transporting them around the city. Additionally, a lack of regulations for this new mode have also been widely reported to cause crashes and obstructing pedestrian movement on sidewalks.

4.10 Renewable energy and Low Emission Vehicles

Solution type: 'Shift'/'Improve' – Regulatory and Technology measures

The adoption of renewable energy is achieved through diverse measures, such as – blending conventional fossil fuels with biofuels (like ethanol or bio-diesel), conversion of natural gas vehicles to upgraded biomethane fuels, increasing the uptake of Low Emission Vehicles (LEVs), and the electrification of public transport (REN21, 2019). The category of LEVs includes a wide range of vehicular types or technologies, such as battery-electric vehicles (EVs), hybrid vehicles and those fuelled by hydrogen, electro-fuels and synthetic fuels. Moreover, these types span both private (cars, scooters, taxis, freight trucks) as well as the public sector (buses and cargo fleets, trams, trains etc.).

However, there also exist multiple challenges towards mainstreaming renewable energy in transport because of the heterogeneity of these technologies, differing market penetration and costs, project cycles, and sustainability potential. As a result, the share of renewable energy in the transport sector (including road-based transport, shipping and aviation) was estimated at a lowly 3.1% in 2015, thereby further necessitating the implementation of these policy measures (SloCat, 2018b). The adoption of LEVs, and particularly EVs, also remains extremely low across global markets – with less than 1% of new registrations worldwide (Mckinsey & Company, 2014; REN21, 2019). To address the aforementioned challenges, there are several solutions being adopted at the local, national and international levels. For instance, a major policy instrument is the biofuel blending mandate legislated in at least 70 countries worldwide. In Asia, India has emerged as one of the foremost promoters for incentivising biofuel production, distribution and consumption, with blending mandate requirements of over 20% for biofuel shares (SloCat, 2018b).

Current policies focussed towards mainstreaming electric mobility face major infrastructural and technological barriers. Such measures for increasing the purchasing and driving of EVs essentially requires setting up wide-scale charging infrastructure across the city. In the absence of this infrastructure, EVs can induced a 'range anxiety' which prevents conventional car users to switch to them. This shortcoming can be countered by technologies, such as battery swapping. However, the cost of batteries still remains exorbitantly high for all types of consumers to afford them. This especially applies to heavy-duty EVs such as electric buses and freight modes. To address this challenge for the road freight transport, advanced countries are now investing in the electrification of their logistic systems and highway infrastructure. These e-Highways comprise of overhead catenary

wires which power electric trucks. Additionally, several innovative technologies focussed on long-haul trucks and urban freight and are being pioneered and tested by private companies (like TESLA in the United States), and public agencies (such as Deutsche Post in Germany). Alternatively, vehicular electrification is also being led by new mobility companies operating electric-cars and electric scooters. For instance, Ola – one of India’s largest shared-mobility providers – aims at operating 1 million EVs in Indian cities by 2022 (Banerji, 2019).

To alleviate issues around EV uptake, cities and national governments in Asia have effectively provided regulatory solutions, such as – subsidies and tax-breaks for manufacturing and purchasing EVs, and reforms in urban planning and building regulations to accommodate more EV parking spots and charging infrastructure. Additional incentives comprise of lower electricity cost for charging points and free public parking. Lastly, an effective economic instrument is using public procurement policies for greater EV uptake. Government programmes like the China New Energy Vehicles Program (2009) and India’s flagship FAME or Faster Adoption and Manufacture of (Hybrid and) Electric Vehicles Scheme (2015) have managed to successfully incentivise both public as well as private sector purchase. Further, People’s Republic of China’s domestic EV market share is estimated to grow to 50% by 2025 (Holland, 2019). Additionally, these initiatives also support the electrification of public transportation, which has resulted in enormous air quality improvements in cities like Shenzhen – which reached 100% electrification of its fleet of 16,500 buses in 2017 (SloCaT, 2018b).

4.11 Vehicle technology and emission standards

Solution type: Improve – Technology and Regulatory measures

To reduce GHG emissions and air pollution from dirtier types of fossil fuels (like Diesel) and the vehicle technology that consumes them, governments have been effectively using regulatory and economic instruments in order to phase them out. These measures provide a clear policy direction to facilitate pathways for the uptake of newer technologies, and thereby also enable the transition of manufacturing processes. Such innovative low-carbon technologies not only benefit domestic markets, but also potentially result in economic development through their export. This also leads to the creation of newer business models and unlock private-sector investments. For instance, India announced an objective of phasing out all diesel vehicles sales by 2030, which has led to substantial investments by the domestic automobile manufacturers in electric vehicle technology (Business Today, 2017).

Stricter Emission Standards and Labelling Schemes are also effective solutions to inform better consumer choice towards low-emission vehicles and regulate automobile companies to manufacture them. The ‘Euro’ emissions standard which applies to all vehicles sold in the European markets covers pollutants such as PM10 and NOx (Weinmann, 2014). Moreover, these standards have also been successively adopted by 14 Asian countries (See Figure 15) (European Environment Agency, 2015). Finally, economic reforms such as higher taxes or lesser subsidies on highly polluting fossil fuels can aid in phasing them and result in an increased use of renewable energy.

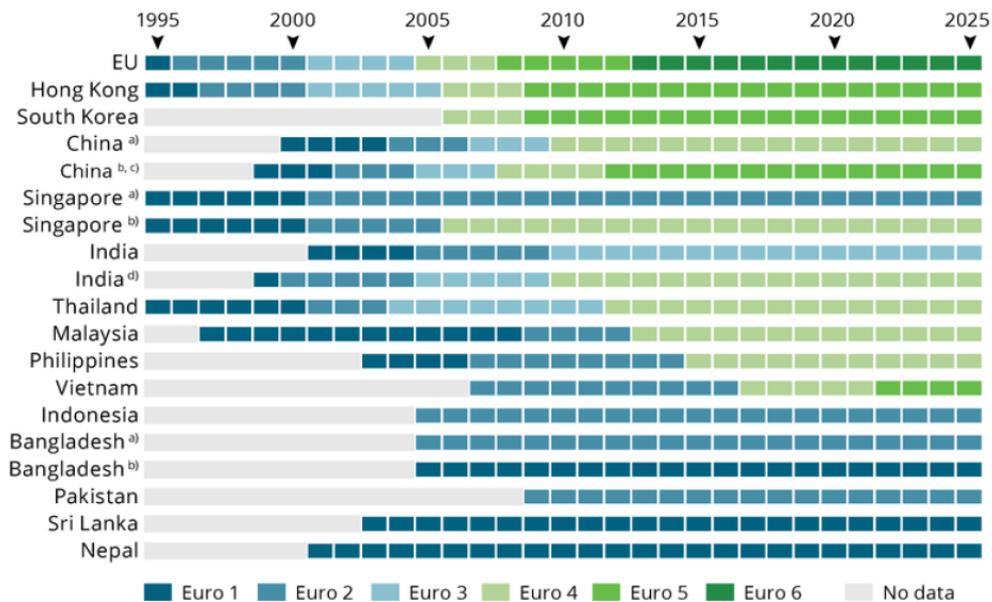


Figure 15: Successive adoption of the Euro standards for fuel economy in 14 Asian countries (Source: EEA, 2015)

4.12 Inspection and maintenance programmes

Solution type: 'Improve' – Technology and Regulatory measures

As mentioned in the previous Chapter 2, the transport governance and regulatory issues lead to the lack of enforcement mechanisms to ensure vehicular maintenance of private and public transport. Additionally, such a non-compliance of standards established for safe, clean and fuel-efficient vehicle fleets also results in severe impacts on air quality and GHG emissions. An effective measure to counter such a situation is the design and implementation of an Inspection and Maintenance (I/M) scheme. An I/M system comprises of periodical checking and repairing of tail-pipe emissions and pollution-control devices (such as, catalytic converters) for all vehicles under operation in a city. I/M initiatives also significantly complement other policy measures, such as fuel quality standards, as well as the retrofitting and replacement of older vehicles by LEVs. I/M programmes also ensure that automobile owners regularly maintain their vehicles, which in turn results in them complying with emission limits. Further, the systematic maintenance of vehicle fleets has the potential to reduce fossil fuel consumption by upto 7%, depending on the emission standards (Kolke, 2011). Furthermore, there is ample evidence which indicates the air quality improvement through I/M measures, due to the reduction of pollutants, such as CO, Hydrocarbons, and NO_x (See Figure 16).

The implementation of I/M schemes also needs to be supported by legal and regulatory frameworks at the national level to establish emissions limits, and define inspection requirements and procedures. At the same time, local and regional authorities need to ensure adequate supervision of the technical services of performing emission checks, and that the private sector agencies offering these services are selected through unbiased, independent and open tenders (Kolke, 2011). Another good practice also comprises of centralising the I/M system, whereby the inspection function is separated from maintenance function – in order to produce efficient results, without any fraud or corruption. In this mode of implementation, vehicular checking is performed in 'test-only' stations under stringent governmental oversight, while remedial maintenance or repair works are undertaken by private sector garages or car-dealers. Lastly, to maximise air quality improvement, I/M schemes also need to

strategically prioritise the targeted vehicular types (like motorcycles or heavy-duty vehicles), based on their share of total pollutant emissions in a city.

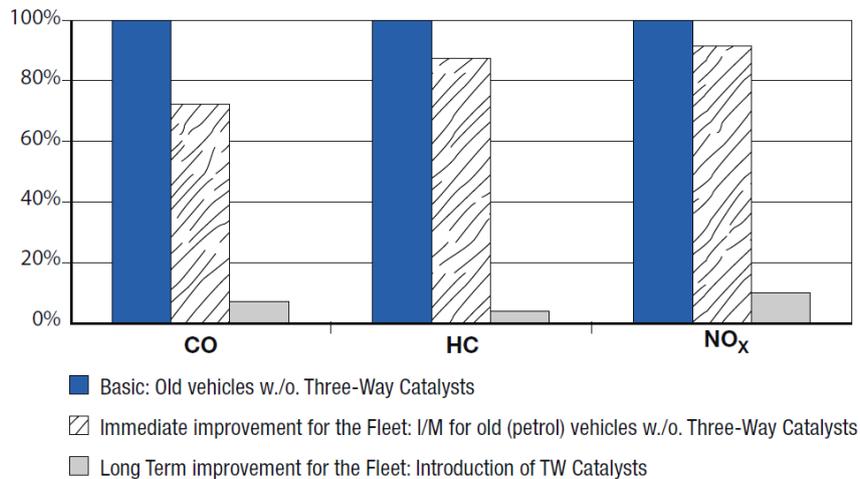


Figure 16: Emissions reduction by installing of 3-Way Catalytic Converter and the resultant air quality improvement for vehicular fleets (Source: Kolke, 2011)

Chapter 5: Case Studies and Good Practices

As summarised in previous chapters, addressing sustainable transport issues is a complex intervention, with multiple entry-points and without a universally-applicable solution. Therefore, there is a critical need to assess the feasibility of various demand and supply-side solutions within the EASI framework. The case-studies outlined in this chapter demonstrate how innovative policy measures while primarily tackling the challenges of both urban mobility and air pollution, also yield multiple co-benefits in terms of GHG emissions, public health, social inclusion etc. Additionally, these cases also indicate how coordinated implementation of multiple policy instruments, taking into consideration their synergies and trade-offs, has resulted in air quality improvements under drastic conditions. The three cities selected for investigation are selected on the basis of income-level categories of respective countries, as classified by the World Bank in 2019 – Singapore (high-income), Beijing in People’s Republic of China (upper middle-income), and Delhi in India (lower middle-income) (World Bank, 2019). With the unique governance systems and air pollution challenges in these countries, it is crucial to also consider how generic solutions have been localised to suit the context of each of the cases.

5.1 Case study: Singapore

The Republic of Singapore (population: 5.6 million) is an exceptional city-state in Asia that has achieved very rapid economic growth since its independence in 1965, and despite the constraints of limited geographical area and availability of natural resources. Concurrently, the development and implementation of sustainable transport measures has also been undertaken in parallel with the industrialisation and economic policies. The traffic congestion problem in Singapore reached its peak in 1975 with growing motorisation, and a package of effective Transport Demand Management (TDM)

policies, environmental regulations, and multiple public transport projects were successively undertaken to address it. As a result of these measures, Singapore now has a cost-effective, multi-modal and highly efficient public transport system, which had a considerably high modal share of 67% during peak hours in 2016, and current plans aim at reaching 75% by 2030 (LTA, 2018).

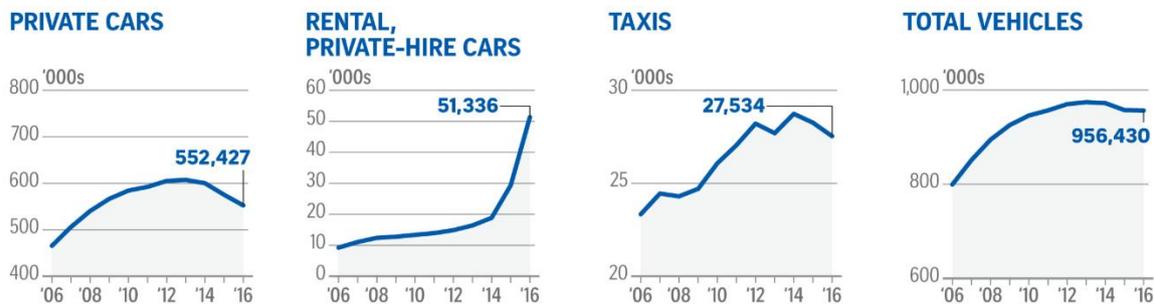


Figure 17: Shrinkage of vehicular fleet in Singapore as a result of TDM (Source: Straits Times, 2017, based on Land Transport Authority (LTA) data)

The policies aimed at stabilising car ownership keeping its growth minimal has also been highly effective in the last decade. As a result, car population in the city-state fell by 4% in 2017, the lowest recorded in previous eight years and a shrinkage for three consecutive years between 2014 and 2016 (See Figure 15) (C. Tan, 2017). Notably, a rise of rental car fleet by three times was also recorded for the same period, attributed to the increased reliance on ride-hailing services, such as Uber and Grab since 2013. At the same time, Singapore has also managed to decouple its economic growth from the transport emissions. Between 1991 and 2014 the GDP grew by 91%, while CO₂ emissions per capita from the transport sector fell by 21%, as illustrated by Figure 16 (SloCaT, 2018b). Concurrently, Singapore’s air-pollutant emissions, particularly those for SO₂ and PM_{2.5}, have remained considerably lower than other large cities in developing countries in Asia and Latin America (Velasco & Roth, 2012). These exemplary policy measures are explained in the following sub-sections.

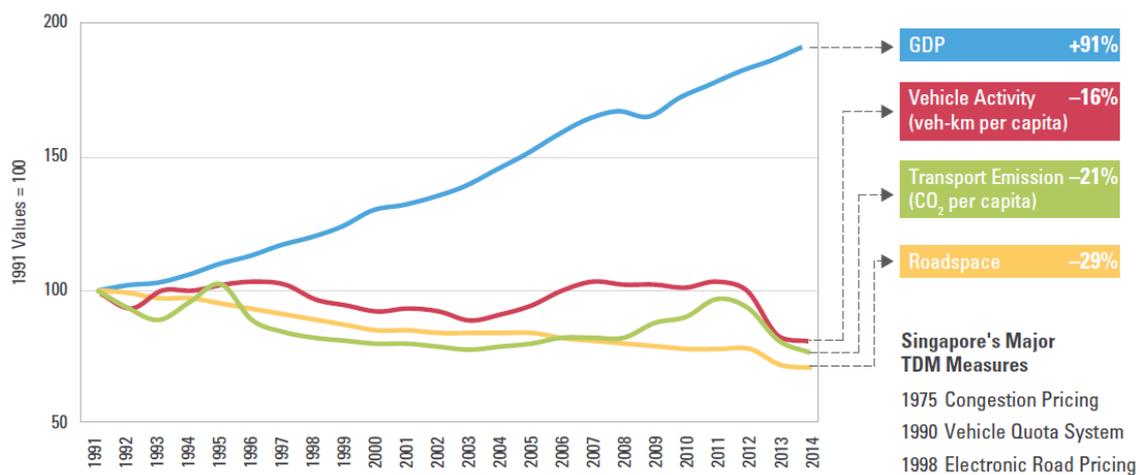


Figure 18: Decoupling of transport and economic growth and other co-benefits due to TDM policies in Singapore (Source: SloCaT, 2018)

5.1.1 Area Licensing Scheme and Electronic Road Pricing

Singapore was the first city in the world to implement congestion pricing in its Central Business District (CBD) through the Area Licensing Scheme (ALS) in 1975. The programme comprised of designating a restricted zone (RZ) with 31 control points. ALS also entailed the use of day-long licenses for private vehicles (including taxis, motorcycles and freight trucks) plying in the RZ during morning and evening peak hours. The RZ was subsequently enlarged beyond the CBD to congested corridors and waterfront roads. The scheme ran for 23 years primarily through manual enforcement, and was gradually replaced by the technologically-advanced Electronic Road Pricing (ERP) Scheme in 1998 (Lam & Toan, 2006).

ERP is a method for traffic congestion management which relies on a set of overhead gantries (or toll gates) and vehicles equipped with in-vehicle units with multifunctional smart cards. As a result, the toll collection system is completely automated and cashless, as the ERP charge is deducted every time a vehicle opts to enter the RZ and passes an ERP gantry. This also eliminated the need to slow down traffic for enforcement, thereby reducing congestion at toll-collection points (Wang et al., 2017). This next phase of the ERP system – to be operational by 2020 – aims at making congestion charging based on distances travelled per vehicle, by utilising a mix of cellular network and GPS-based monitoring technology to alert and charge motorists based on real-time traffic conditions (C. Tan, 2016).

5.1.2 Vehicle Quota System and Certificate of Entitlement

Since 1990, Singapore policy to restrain car ownership has been enforced using the Vehicle Quota Scheme (VQS). Under this scheme, potential car-buyers bid through a public auction every month to obtain a Certificate of Entitlement (COE) valid for a period of ten years. After the end of the ten years, the CoE can be further renewed for 5 or 10 years, and subject to the auction prices at the time of renewal. The quota of new license released every year is regulated by the public authorities. As a result, the COE has served as a highly effective tool for tightening the annual allowable growth of Singapore's car fleet. This growth rate has been lowered systematically – from 3% to 1.5% in 2009, 1% in 2012, 0.5 in 2013, and 0.25 since 2015 (C. Tan, 2017). In October 2017, it was announced that this rate would be further reduced to zero, along with the investment of 20 billion USD in rail infrastructure and bus contracting subsidies (SloCaT, 2018). Moreover, these TDM measures are also complemented by Singapore's current policy push to become 'car-lite' by the means of – enhanced public transport connectivity, improved infrastructure to increase walking and cycling by four times the current modal share of 14% in 5-10 years, and substantial technological developments (like ride-hailing apps, micro-mobility and testing autonomous mobility) (Cheong, 2017).

5.1.3 Governance reforms and multimodal integration

Along with the aforementioned TDM measures, Singapore has also implemented successive administrative reforms to deliver efficient transport governance. In the post-independence 1970s period, Singapore's public transport was low-quality and managed by numerous operators in a fragmented market (Bin & Ching, 2013). As a response, the privatised Singapore Bus Services (SBS) was established in 1980s to regulate the operators, along with the implementation of the Mass Rapid Transit (MRT) system. In the next phase of reforms, the Land Transport Authority (LTA) was established in 1995 to address the prevalent issues around profitability, affordability and multi-modal integration. The formation of LTA marked the creation of a lead agency by merging of four public authorities, and consolidated the functions of network planning and strategic management. Additionally, LTA has also extensively engaged in public participation through well-designed communications and knowledge products, in order to disseminate information and gather feedback regarding their policy proposals (Wang et al., 2017).

The LTA has been leading the preparation and implementation of the Land Transport Masterplans (2008, 2013 and 2018), towards integrating all MRT, light rail transit (LRT) and SBS bus operations into seamless travel experience. As noted by Lam and Toan (2006), these multimodal integration efforts could be classified into three categories – **(a) Physical integration** by constructing vertical interchanges and transfers between MRT and bus systems, covered walkways that link surrounding communities, and integrating stations and commercial and office developments through land-use planning; **(b) Fare integration** to speed up payment and fare collection through the TransitLink fare card (1986), and subsequently the EZ link cashless card (2002 onward); and **(c) Network integration** through continuous investment into expanding the MRT network (currently measuring 200 km), and subsidies and route rationalisation for SBS buses to increase their financial viability.

5.1.4 Electric vehicles, fuel economy standards and feebate schemes

Singapore has also implemented stringent fuel economy standards, which are critical for addressing air pollution not only from light-duty vehicles (LDVs), but also heavy-duty vehicles (HDVs) for freight transport, shipping and aviation sectors. Two such programmes were the Carbon Emission-based Vehicle Scheme (CEVS) launched in 2013 and later replaced by the Vehicular Emissions Scheme (VES) in 2018. These offered feebates, i.e., financing through fees and rebates, aimed at incentivising consumers to purchase low emission vehicles (LEVs) and maximise compliance with the latest Euro-6 fuel standards. Moreover, VES also expanded the scope of major pollutants covered to five types of emissions, along with CO₂. These included – hydrocarbons, carbon monoxide, nitrogen oxides, and particulate matter (ASEAN, 2018). At the same time, LTA’s current Transport Masterplan also aims at progressively electrifying its public bus-fleet – with 60 buses to be rolled out by 2020 and 100% transition by 2040 (Tan, 2019). Singapore is also set to trail high-speed charging infrastructure with automated rooftop connection systems – which can fully charge electric buses in 10 minutes to run for 35 km.

5.2 Case study: Beijing

As the capital of People’s Republic of China, Beijing has undergone tremendous urbanisation and economic development – with a GDP growth of 1078% (6.6% each year) and a population increase of 74% between 1997 and 2017 (currently at 21.5 million) (UNEP, 2019). For the same period, the rapid rise of the number of vehicles by three times, along with congestion, has resulted in persistent air quality issues. The air pollution across the country turned chronic especially in the winters of 2012 and 2013. During this period, emissions from vehicles accounted for a high percentage of pollutants – 31% for PM_{2.5}, 33% of VOCs, and 50% of NO_x (WRI China, 2018). Moreover, regional transport still accounts for one-third of Beijing’s air pollutant concentrations – 26 to 42% and 55% to 75% on heavily polluted days. Additionally, the transport sector alone also accounted for 28.5% of the total CO₂ emissions in 2014 (Wang et al., 2017; UNEP, 2019). To address this challenge, both the national and local governments have since adopted multiple policies that have now started to yield favourable outcomes.

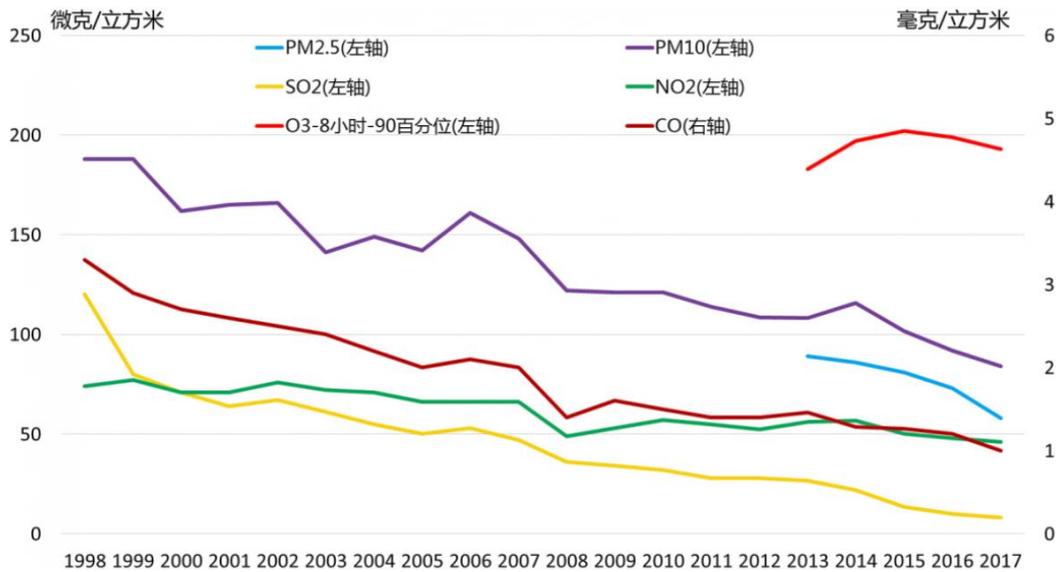


Figure 19: Reduction in annual average concentration of major air pollutants in Beijing between 1998-2017 (Source: UNEP, 2019, based on Beijing Environmental Protection Bureau data)

In Beijing, air pollution has been high on the agenda of the four consecutive five-year plans for 20 years between 1997 and 2017, and the city adopted its systematic ‘Clean Air Action Plan’ with specific clean air targets for the period of 2013-2017. Concurrently, to tackle air pollution goals through regional cooperation, the national government also released the ‘Plan for Coordinated Development of Beijing-Tianjin-Hebei Region’, which started being implemented during the 2008 Olympic games. These air quality management systems have led to significant improvements in the last 20 years, specifically the last five years which targeted PM2.5 levels (See Figure 17). The reduction of ambient levels of pollutants for duration of 2013-2017 has been 35% for PM2.5, 70% for SO₂, 38% for CO and 18% for NO₂ (UNEP, 2019). Some of these effective policy measures for sustainable transport are outlined in the following sub-sections.

5.2.1 Low Emissions Zones and TDM policies

Beijing has been heavily targeting older vehicles which do not comply with Euro I standards, termed as ‘yellow-labelled vehicles’ and consisting mostly of heavy-duty trucks. Despite being 10% of the total fleet, these vehicles were responsible for over half of the vehicular emissions (Weinmann, 2014). Low Emissions Zones with restrictions on these older vehicles were successively introduced along the city’s Second Ring Road in 2003, for the Fifth Ring Road in 2008, Sixth Ring Road in 2010, and finally for the entire city in 2015 (UNEP, 2019; Weinmann, 2014). The city’s most recent LEZ policy for the entire urban area within the Fifth Ring Road was implemented in 2017. These LEZ measures are estimated to reduce 11 metric tonnes of NO₂ and PM emissions per day and 2.5 million metric tonnes of CO₂ emissions by 2020 (WRI China, 2018). Additionally, government subsidies were introduced since 2009 to offer incentives for trading in and phasing out older high emission vehicles. This policy eliminated 1.7 million older vehicles during 2013-2017. Furthermore, starting in 2013, Beijing began imposing car ownership restrictions by instituting a total quota of 20,000 newly registered license plates per month, which was then reduced to 150,000 in 2014 (UNEP, 2019). These TDM policies have managed to stem the rising rate of motorisation and helped alleviate the intensity of traffic congestion issues. At the same time, there have also been efforts to introduce congestion charging in Beijing. Draft proposals were formulated in 2016 by the authorities to tackle peak-hour traffic gridlocks. However, the

proposal was postponed indefinitely the following year, due to a lack of consensus within the government (Qiu, 2019).

5.2.2 Public transport development and shared mobility

In 2004, Beijing implemented the country's first full-featured Bus Rapid Transit (BRT) system with a dedicated busway, 17 median stations, offboard fare collection, traffic signal priority, and intelligent transport systems (ITS) features. The BRT resulted in 40% travel time reduction, a high ridership of 120,000 average daily passengers, and only costed 1/15 of a metro line (Deng & Nelson, 2013). The model also led to development of similar systems in 32 cities in People's Republic of China. Further, in addition to the current suburban train network, a proposal to implement 1,000 km of regional rail network was also declared in 2015 to connect the city with neighbouring Tianjin and Hebei (Gan, 2015). At present, Beijing also relies extensively on shared electric bikes. Data from Mobike – a prominent new mobility company – indicates that 81% of bike-trips are used for last mile connectivity around transit stations (Shoakun, 2018). Another key ride-hailing provider is Didi, headquartered in Beijing. With their services available in 400 Chinese cities, the company clocks a daily average of 30 million rides, which resulted in the saving of 43 million litres of fuel and 97,000 tons of CO₂ emissions in 2018 (Zhang, 2019). Lastly, the city is also rapidly electrifying the public bus fleets, and it is estimated that electric buses would exceed 11,000 by the end of 2020 – comprising over 50% of the total fleet (NewsChina, 2019).

5.2.3 Emission standards and vehicle retrofitting

Beijing has also been leading on imposing stricter emission standards, with the local government formulating and revising more than 30 of them since 1998 and being the first to implement Euro V standards in 2013. Additionally, the renovation and retrofitting of 200,000 gasoline vehicles to reduce CO, hydrocarbons and NO_x emissions has been carried out in 4 phases since 1999. This initiative also covers diesel buses and other heavy-duty public service vehicles such as – airport and school buses, postal shuttles and garbage trucks. Between 2015 and 2017, a total of 17,000 such vehicles were installed with Diesel Particulate Filters to reduce harmful emissions (UNEP, 2019).

5.3 Case study: Delhi

Delhi – the national capital of India with a population of 19 million – has also been widely documented as one of the most polluted cities worldwide. The city has a high rate of motorisation with over 1,500 new vehicles registered daily, and one of the highest vehicle densities nationwide at 93 cars per km of roads (Deloitte, 2018b). The resulting congestion has led Delhi to have the highest concentration of PM_{1.0} globally when compared with other megacities with over 14 million habitants, according to a WHO assessment for the period of 2011-2015 (WHO, 2016). Due to the city's geographical location and topographical characteristics, it also experiences severe seasonal spikes in air pollutant levels in winters (November to January), often leading to the local authorities declaring public health emergencies. Delhi's air pollution is largely attributed to the industrial activity and crop-residue burning within the larger metropolitan region and surrounding states. Moreover, the transport sector is also responsible for majority of NO_x and 30-50% of PM emissions (Bhavnani, Himanshu, & Sharma, 2018). Nevertheless, there have been modest improvements in the last decade, in part due to sustainable transport policy measures. According to data from the Delhi Pollution Control Committee (DPCC), the average annual PM_{1.0} and PM_{2.5} levels have reduced by 21% and 20% respectively between 2012 and 2018 (Indian Express, 2019). Some of these prominent measures are as follows.

5.3.1 CNG conversion programme

The CNG (Compressed Natural Gas) conversion programme implemented between 1996 and 2005 in Delhi was an ambitious policy thrust to phase out older polluting vehicles and fuel technology. The package of measures therein comprised of retiring all old commercial vehicles, converting of all passenger vehicles – including buses, taxis and rickshaws – to CNG, tightening of emission standards, reducing sulphur-content of diesel and petrol, and the installation of catalytic converters. The advantages of using CNG include cutting down emissions of CO and hydrocarbons by 80-90% compared to gasoline, improved fuel efficiency, and lower maintenance costs and lesser running costs. Evidence suggests that implementing these solutions has resulted in the gradual reduction of NO_x, CO, PM₁₀ and SO₂ concentrations in Delhi (Goyal & Sidhartha, 2003; Narain & Krupnick, 2007).

5.3.2 Odd-even license plate restriction

Delhi was also India's first city to enforce a vehicular restriction scheme based on the license plate number of vehicles allowed to ply in the entire city for the duration of the programme. The odd-even rationing policy was trialled for four weeks during Delhi's air quality-related emergencies of 2016 and 2017, when the PM₁₀ and PM_{2.5} levels exceeded over 10 times the safe levels recommended by WHO. Although the policy was not entirely effective in significantly reducing PM_{2.5} levels, it resulted in positive changes in the amount of harmful air-borne chemicals, such as arsenic and lead (Altaf, 2018). Moreover, the odd-even scheme also features as one of the seven strategies within the Clean Air Action Plan recently released by the local government (Indian Express, 2019). Another critical measure was banning the entry of heavy-duty trucks and other freight transport in the city, whenever severe pollution levels persisted for more than 48 hours.

5.3.3 Public transport development and mainstreaming of e-rickshaws

Operational since 2002, the continuous expansion of the Delhi Metro system has resulted in high-quality public transport network now measuring over 350 km. In 2019, the system recorded one of its highest monthly average ridership at over 4.7 million trips (Parveen, 2019). The Metro has not only addressed the rising transport demand in the city, but has also led to several co-benefits. According to one estimate, the monetary value of the air pollution reduction due to the Metro (from reduced fuel consumption, vehicle purchases and congestion) was the equivalent of 96 million USD in 2011-12 (Murty, Dhavala, Singh, & Ghosh, 2006). Moreover, the city also has a high modal share of 31% for public transport and 39% for walking and cycling (Deloitte, 2018b). Another prime feature of Delhi's intermediate public transport (IPT) is the proliferation of battery-operated electric rickshaws for last mile connectivity. The rapid adoption of this low-emission mode is attributed to India's favourable electric vehicle-related national policies which provide purchase subsidies and lower electricity tariffs for operators. At the same time, this trend has also led to a growth of domestic industries manufacturing e-rickshaws, with 340 of them being based in Delhi alone (Bhavnani et al., 2018).

5.4 Lessons learnt and challenges ahead

To summarise the analysis of the three case-studies, transport governance emerges as one of the key drivers for some improvement of the transport system leading to air quality management benefits. Singapore has greatly benefitted from the establishment of the LTA, empowered through a special legislation. This case indicates the presence of several all the good governance practices in terms of a highly-capable lead agency model with consolidated authority over all transport-related function. While the LTA retains the ownership and operations of the interchanges and intermodal terminals, the public transport services themselves are operated by private companies. As a result, LTA is able to

focus on strategic management functions and formulate comprehensive plans that are hierarchically and spatially integrates (Agarwal & Kumar, 2013). This is reflected the merits of the latest Land-use Transport Masterplan 2040, building on the remarkable sustainable transport and air quality improvements in the last few decades. At the same time, Singapore also benefitted from being ahead-of-the-curve on implementing many progressive transport policies. The prime examples are the congestion pricing policies in effect since 1975, which are only now being considered in other advanced economies globally and in Asia. Such a prolonged head-start has allowed Singapore to fine-tune their policy implementation and making it technologically-advanced with every iteration over the decades.

In both Beijing and Delhi, many of the effective policy measures were reactive instead of proactive, and in response to the chronic issues of air pollution and traffic saturation. In terms of transport governance, local governments both in India and People's Republic of China face barriers in implementing sustainable transport initiatives, such as – fragmented responsibilities, devolution of authority, technical capacity, knowledge and overall manpower (Bhat et al., 2013; Diaz & Bongardt, 2013). Despite of these challenges, Beijing's policy measures have been exceptional being a provincial capital with higher institutional capacities. In Delhi, the city has continually suffered since decades from administrative conflicts between the national and local governmental agencies, both of whom vie for authority over the National Capital Region. There have been several cases whereby progressive policies have been overly contested between opposite political parties ruling at the national and regional levels – only to result in inaction (Hindustan Times, 2018) the face of such challenges, implementing successful programmes (such as the CNG conversion) has been made possible through strong judicial interventions and a close supervision of the Indian Supreme Court (Narain & Krupnick, 2007). Additionally, the Metro system's implementation was spearheaded by an independent and technically-competent parastatal agency – the Delhi Metro Rail Corporation (DMRC).

All three cases indicate a strong policy push by the national government for a wide-scale transition to cleaner fuels and low-carbon mobility. Especially, the People's Republic of China and India have launched a series of national plans to boost the adoption of solar energy and the sale and manufacturing of electric vehicles – in line with their Paris Agreement commitments. Presently, some policy measures are being debated and await a full-scale roll out – such as, the odd-even scheme in Delhi, congestion pricing in Beijing, and GPS-enabled ERP in Singapore. The long-term impacts of these policies remain yet to be seen. Lastly, the regulation of new mobility and ride-hailing companies remains a challenge for all three cities, as their ridership and business models mature. Singapore is set to test its Mobility-as-a-Service (MaaS) initiative to integrate ride-hailing and micro-mobility it within the city's 'car-lite' strategies. As newer modes (self-driving cars) and disruptive technologies (like Internet of Things) enter the market, their integration through a common platform and their complementarity with public transport, walking and cycling will decide if they are truly beneficial in terms of reducing VKT, climate change and air pollution.

Chapter 6: Conclusions

As climate science is telling us, the pressure to take action on climate change is very urgent. As transport is the sector with the largest increase of GHG emissions, it requires particular attention by national and local governments. In parallel, air pollution is becoming one of the largest health threats in Asia with the transport sector as a main source. As the paper showed, with strong links between air pollution and climate change as well as other co-benefits of sustainable transport, a comprehensive approach to tackle the issue is needed. Experience in Europe and in countries like Singapore, People's Republic of China, Japan and South Korea show, that a wider range of strategies and actions is needed to create a pathway towards sustainable mobility. When creating strategies in Asian countries and cities, the specific issues such as the enormous increase in motorcycle transport and urban freight delivery need to be taken into account. The E-A-S-I Framework shows that there are a wide range of options to implement whilst it is important to ensure that the strategies supplement each other. In other words, it is important to ensure that a sustainable transport supply through walking, cycling, public transport, as well as shared vehicle infrastructure is accompanied by managing the demand through restricting car travel through regulatory measures as well as pricing.

To ensure such a comprehensive strategy, a vertical integration of transport related policies between local as well as national government is crucial. National government can enable cities to act by providing national financial resources for local government to invest in local infrastructure and at the same time empowering local decisionmaker through strengthening their city/metropolitan planning. At the same time, the paper shows that sustainable transport also has a strong impact on health, the economy and even the agriculture sector. Therefore, there is a need for a cross-ministerial collaboration to tackle the biggest challenges.

In addition, national government can set the right incentives by increasing taxation on car ownership and fuel consumption. Finally, national governments are required under the Paris Accord to submit their new climate action plan by the end of 2020. This is an opportunity to set national targets and create a comprehensive action plan for the transport sector.

With such a national framework in place, cities should be enabled to act and decrease the pollution, as well as the other negative impacts of increasing individual motorisation. The case studies have shown the importance of a comprehensive plan aligned with substantial investment in public transport and walking/cycling infrastructure. In many Asian cities, there is still limited knowledge on the current environmental impacts like air quality. Effective air quality monitoring combined with better collection of transport data, can improve the understanding of the most adequate solutions.

At the same time, new mobility solutions like ride hailing and bike sharing require better integration to ensure that they contribute to ensure reduced environmental and health impacts. As the systems are often provided by the private sector, regulations need to be in place to ensure these mobility solutions support accessibility, in particular in sub-urban less dense areas, rather than competing with the public transport system in the most congested areas. Cities like Singapore and Seoul have shown that charging and restricting individual car transport aligned with a better integrated transport system for all citizens can lead to substantial improvements reducing air pollution and improving the quality of life.

Finally, regional collaboration, outlined in the following final chapter, can help the countries and cities to improve their policies and actions enabling sustainable mobility by: developing a regional reporting

framework on the SDGs and Nationally Determined Contributions (NDCs) under the Paris Agreement; facilitating a peer-to-peer learning and coordinated capacity building program; and identifying improved and increased international support in terms of financing and capacity building.

Chapter 7: Recommendations for the EST Forum

The paper has shown the need for a comprehensive strategy for local and national government to take action on transport to fulfil the SDG and Paris agreement objectives. While the global framework and its global reporting is an important part of the implementation, it lacks a regional perspective as well as a sectoral one. As there is neither a separate SDG on transport, nor a requirement for a dedicated transport plan as part of the NDC under the Paris Agreement, a regional framework like the EST could help to fill that gap and help countries to enhance their climate and sustainable action. The following six recommendations could be considered as part of a future design of the EST Forum.

1) Creating a SDG/NDC national reporting framework

Currently, national governments are required every five years to share their efforts as part of the voluntary SDG reporting (VNR) to the UN. However, as the paper has shown, there are a broad variety of gaps in the documents. Secondly, as transport has no separate SDG, the references to transport are spread across the different chapters and therefore lack integration when it comes to reported actions. To an extent, the same can be observed in the climate action plans. For example, while there is a requirement to report on co-benefits, there is so far no country that has looked in detail at the complete range of specific co-benefits of transport as described in this paper. Therefore, one single comprehensive national SDG/NDC report on transport could help to better combine in one document. This would encourage the cross-ministerial collaboration on transport, as well as simplifying the reporting towards the different international agendas.

The EST Forum could play a vital role to help countries with the set-up of such a system. First of all, it could create a regional reporting framework, which includes a key indicator framework, as well as guidance for national strategies and policy actions.

2) Support national action through EST Partners

One of the strengths of the EST Forum is that it not only brings national and local governments from the region together, but also the international development partners who are active in the region. While many of them already collaborate and coordinate on the national level, it could also facilitate a dialogue on the regional level between the key international stakeholders. An outcome could be an Asian roadmap, wherein different partners would describe their commitment and leadership in certain specific actions (e.g. finance or capacity building) or transport thematic areas (e.g. urban freight, motorcycles). Such a partner roadmap could help the countries to better understand the offer from the international partners. Annual reporting on the activities of the international partners could allow also monitoring of their commitment and identify where there might be gaps in international support.

3) Enable a peer-to-peer learning platform on EST for the Asian countries and cities

While establishing national reporting on sustainable transport could benefit from international support, learning from other countries could also be of value. The EST Forum could facilitate peer-to-peer learning not only during its annual meeting, but also through co-hosting with international partners specific trainings and workshops – thereby allowing country partners to share their knowledge and challenges. Another element to consider might be to create a virtual platform for knowledge exchange including hosting webinars and sharing relevant documents online.

4) Capacity Building for EST

Many international partners already provide capacity building as part of their programmes and countries aiming to improve local capacity to tackle the challenges caused by transport. However, there is no comprehensive review of the current knowledge gaps within the institutions as well as a clear understanding as to whether the current educational system provides students with the appropriate knowledge on sustainable mobility. The EST Forum could help to create regional guidance for a capacity development needs assessment, which could, once applied, help the national government to take action and the international partners to better target their future programmes.

5) Financing EST

According to the ADB, there is an annual financial gap on transport infrastructure investment of more than 2 trillion US Dollar a year in Asia. While there is a continuous discussion at a country level around how to raise more money and how to invest more funding, there is a gap on finding solutions at the regional level. Linking the future of finance debate with the need for enhancing action on transport and climate could encourage a new perspective to find solutions for the region. This discussion could include, in particular, private investors as well as pension funds together with the international development partners from the bilateral and multilateral banks.

6) Include Local Stakeholders

Finally, as the paper has documented, most impacts of the transport systems are local and require local solutions. In the last years, the EST Forum established a Mayor Forum to facilitate not only national government actors, but also local leadership to take action on sustainable transport. It is important to ensure that all the suggestions above are supported by as well as enable local government to act. Therefore, keeping those stakeholders engaged as an important part of the forum should be considered.

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