THE SUSTAINABLE MOBILITY- CONGESTION NEXUS: A CO-BENEFITS APPROACH TO FINDING WIN-WIN SOLUTIONS

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ABSTRACT

This study aims to qualitatively assess the global and local environmental co-benefits from implementing sustainable mobility policy strategies to tackle environmental externalities of the road transport sector, in New Delhi (India) and Toyama (Japan). To this end, policy packages to pursue congestion reduction have been evaluated, including promotion of public transport infrastructure and soft-mode programs. The analysis suggests that implementing a co-benefit approach to simultaneously reduce global (GHG) and local air pollutant emissions can tackle urban congestion and simultaneously promote social equity and economic prosperity. The co-benefits approach is flexible to many different contexts as the nature of co-benefits can vary according to local priorities. The implication of this is that integration of climate concerns can be mainstreamed into transport policy across many levels of development.

Key Words: road transport paradigm shift; win-win policies; environmental sustainability; congestion.

INTRODUCTION

In fast growing cities, motorization goes hand in hand with economic development and travel demand. This is due in part to rising incomes making personal motorised transport more affordable but also due to inadequate provision of public transport to meet rising travel demand. Between 2000 and 2020, the global motor vehicle fleet is foreseen to increase by twofold to up to 2 billion vehicles, mainly in emerging economies in Asia and Latin America (Sperling and Gordon, 2009). This rapid growth has led to chronic traffic congestion, which results in longer commuting times, lower productivity and reduced accessibility in urban areas. Furthermore, nearly 3,400 people die daily on the world's roads, mainly in rapidly developing countries. If following a *business-as-usual* trend, road traffic accidents will become the fifth leading cause of global deaths (WHO, 2013). Road transport is also one of the main sources of air pollutants and GHG emissions in urban areas. As vehicle fleets in developing countries tend to be older and less efficient than in developed countries, they consume more fuel per kilometre and put a greater load on the environment.

In mature cities, financial problems and declining population are putting further pressure on already stressed urban environments. For instance, Japan has one of the oldest populations in the world as well as one of the lowest birth rates. According to the National Institute of Population and Social Security of Japan (IPSS, 2012), the Japanese population is projected to decline to 86.7 million inhabitants by 2060, meaning a decrease of 30% compared with 2010 levels. Ironically, energy consumption per capita tends to increase in developed cities, especially due to the road transport sector. Because public transportation costs have a scale effect, irregular demand results in unreliable and costly services. Consequently, passengers may shift from public to individual motorised modes. This increases fossil fuel consumption and intensifies emissions of local air pollutants and greenhouse gases. Furthermore, a shift to innovative low-carbon infrastructure is more costly in low intensity passenger infrastructures than high intensity ones, which can support extra costs. Low

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carbon infrastructure, such as plug-in electric rechargers in cites, implies significant investment and is only feasible in densely populated urban centres.

It is, therefore, imperative to design new patterns of urban mobility in both expanding and mature cities, in order to cope simultaneously with economic development, social inclusion and global and local environmental protection. Among a wide portfolio of options, it is essential to consider local conditions and implementation costs, and to evaluate their full impact. How will mobility patterns drive cities towards sustainable development? Which sustainable mobility policies will optimize environmental co-benefits at least cost? To clarify these questions, this paper examines strategy packages to address congestion through the reduction of private vehicle ownership and travel demand in cities. Different sustainable mobility frameworks have been analysed, including the promotion of public transport infrastructure and soft-mode programs. Through this analysis, this paper seeks to contribute to sustainable development at the city level.

Two contrasting examples of transport projects from cities at opposite ends of the spectrum were assessed: New Delhi, India, and Toyama City, Japan. While New Delhi is a rapidly growing mega-city, with a rising car ridership, Toyama City is struggling with rapid depopulation and declining use of public transportation. To reduce transport-related emissions, both cities have implemented innovative sustainable mobility packages. By comparing the different strategies, the analysis suggests that taking a co-benefit approach to simultaneously reduce greenhouse gas and local air pollutant emissions can help rationalize policy options to solve urban congestion. Furthermore, by taking environmental considerations as central criteria, multiple benefits pertaining to sustainable mobility may be achieved.

I. ANALYTICAL FRAMEWORK

In order to evaluate the potential local and global environmental co-benefits of sustainable mobility paradigms in urban areas, the present study relies on a qualitative analysis, which includes three stages: (i) literature review, (ii) case study analysis, and (iii) qualitative assessment of co-benefits.

At first, a review of previous studies available in literature is presented. This includes selected journal papers and relevant reports in order to examine key backbones related to urban mobility in cities and potential mitigation strategies to tackle the current unsustainable paradigm of mobility. Selected factors driving congestion and rising motorisation, including increasing urban population, rising private vehicle ownership, and insufficient ineffective public transportation infrastructure, are assessed. A comparative analysis between cities in emerging and developed economies was conducted, highlighting their common bottlenecks regarding urban mobility. Further, mitigation strategies to tackle congestion and travel demand, as well as foster low-carbon energy and technological shifts, were analysed.

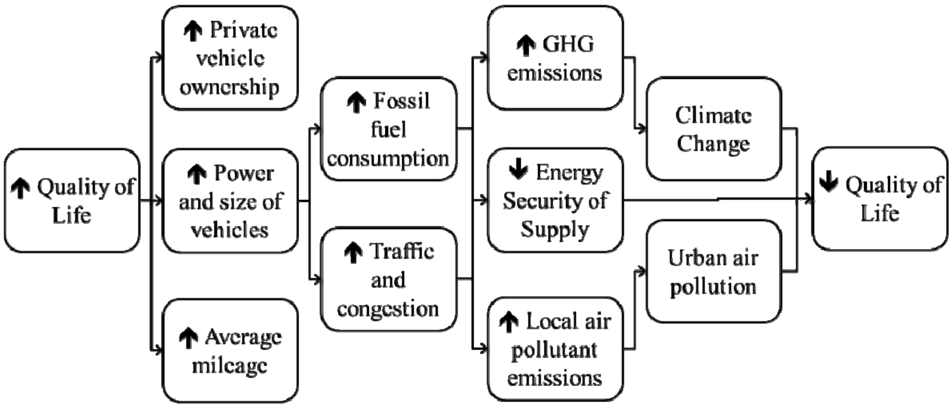
At a second stage, best practice strategy packages were selected and are presented in the form of case studies, which looked at two contrasting sustainable mobility frameworks from New Delhi, India and Toyama City, Japan. Through a comparative assessment, the analysis highlights key strategies implemented as part of their innovative sustainable mobility packages, as well as their goals and outcomes. Finally, using the case studies as a starting point, a co-benefit assessment is described which considers both global and local environmental impacts.

II. THE VICIOUS CIRCLE OF TRANSPORTATION

Transportation is an inherent prerequisite for a sustainable high quality of life in urban areas. People require fast, affordable, comfortable and safe accessibility to bridge the gap between different functional layers within the cities. Rising income results in higher motorisation rates and travel demand both in developed and developing countries. High income citizens tend to drive longer distances and shift to private motorised modes of transport. Given the limited capacity of physical infrastructure of cities to accommodate the increased demand, this had led to traffic congestion in cities and increasing demand for fossil fuels. Consequently, levels of exhaust air pollutants and carbon dioxide emissions intensify. Further, commuting times increase, as passenger trip lengths increase. Over time, quality of life declines and the majority of people are worse off than originally.

Figure 1 describes this *development trap*, commonly referred to as the *vicious cycle of mobility* (Ortúzar and Willumsen, 2011).

Figure 1. The vicious circle of public and private transportation modes.



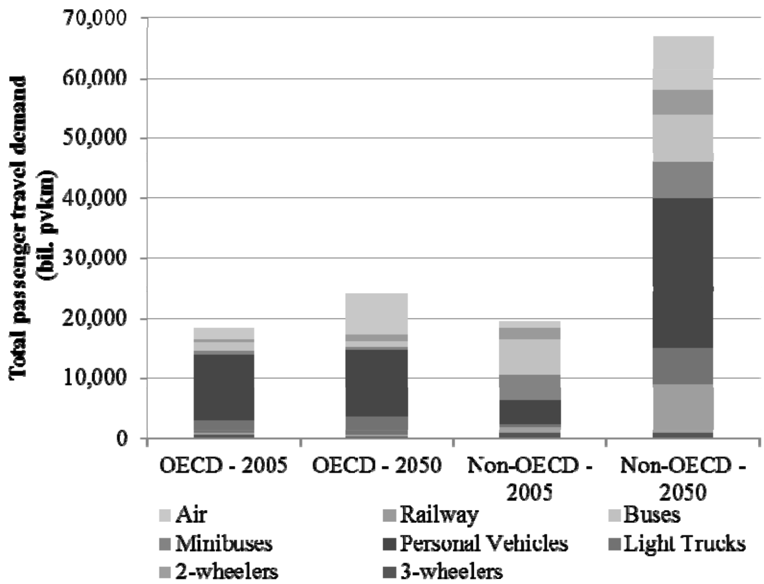
Source: Prepared by the authors.

The following paragraphs briefly detail each of the components that contribute to an unsustainable vicious circle of mobility.

2.1. Rising travel demand

The world's passenger travel demand is projected to dramatically increase over the coming decades, particularly in rapidly expanding cities. As shown in Figure 2, projections of travel demand in 2050 assume that demand in non-OECD countries will double, reaching 67,000 billion passenger kilometres (p.km). In OECD countries, on the other hand, travel demand growth is expected to be more moderate, as developed countries have reached a mature level of economic development. By 2050, the total demand in OECD nations is projected to be 24,200 billion p.km, a 30% increase compared to 2005 levels (IEA, 2009). This expansion is primarily due to increasing mileage of road vehicle modes. For instance, in North America, the average daily travel distance is expected to rise from 55 km (in 1990) to 130 km (in 2050) (ESRI, 2004).

Figure 2. Projection of passenger travel demand by mode in OECD and non-OECD countries.



Source: IEA 2009.

2.2. Increasing private vehicle ownership

Together with rising travel demand, world vehicle ownership is foreseen to expand steadily.

Table 1 lays out the projected vehicle ownership and private vehicle fleets in developed and emerging economies. While in mature economies, the level of saturation is being reached, in most fast growing economies, ownership of motorised private vehicles is expected to boom. According to Dargay (2007), private vehicle ownership increases sharply when countries reach an average income of $5,000-20,000. Therefore, in cities in emerging economies such as China, India, Indonesia, and Brazil, motorisation is expected to shoot up as the middle class expands. In India, for example, the stock of private vehicles is expected to rise from 17.4 to 156 million by 2030, which equates to a yearly increase of 7%.

Table 1. Projection of private motorised vehicles in selected developed and emerging economies in 2002 and 2050.

Country	Vehicles per 1000 Population		Total vehicle fleet (millions)	
	2002	2030	2002	2030
Canada	581	812	18.2	30.0
USA	812	849	234	314
France	576	779	35.3	50.3
Germany	586	705	48.3	57.5
Japan	599	716	76.3	86.6
Republic of Korea	293	609	13.9	30.5
Australia	632	772	12.5	18.4
Brazil	144	574	2.2	11.7
China	16	269	20.5	390
Indonesia	29	166	6.2	46.1
India	17	110	17.4	156
Malaysia	240	677	5.9	23.8
Thailand	127	592	8.1	44.6

Source: Dargay et al. (2007).

2.3. Congestion

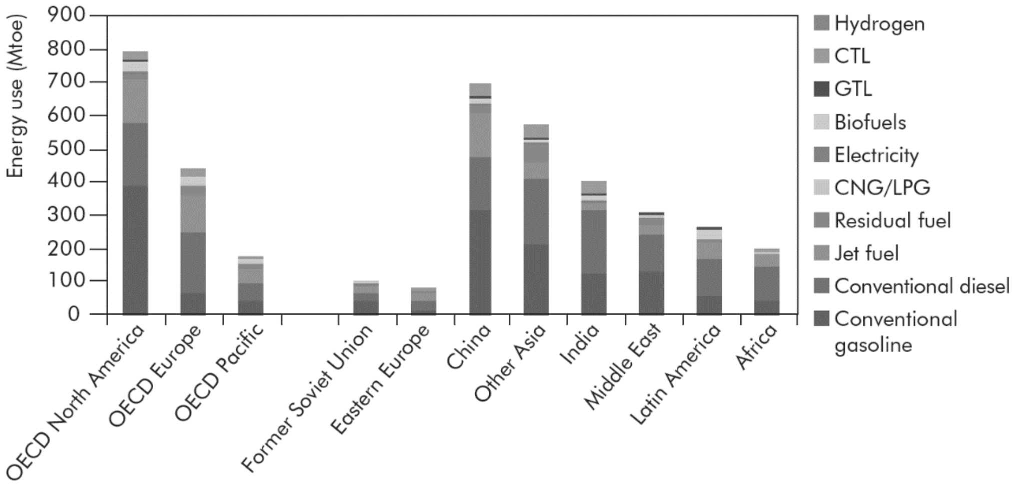
Congestion occurs when the volume of traffic reaches maximum infrastructure capacity. This happens when the number of vehicles and passengers go beyond the capacity of roads and cities spaces. The space needed to carry the same amount of passengers by private cars is much higher than moving by public modes. Low and Gleeson (2003) claim the relative capacities for a bus line and a train are 7,000 and 50,000 people per hour respectively, whereas only 2,500 passengers per hour move as one lane traffic in the same space.

When cars are clogged in the traffic and under stop-and-go conditions, fuel consumption steady increases (Black, 2000). For example, in the U.S., wasted fuel spent during congestion is about 14.8 billion of litres (UNEP, 2011). A sensitivity analysis conducted under traffic activity indicates that congestion is the most important contributor to carbon monoxide and total hydrocarbon emissions (DoTRS, 2001; Zhang et al., 2011). This leads to thousands of premature deaths, especially in cities in developing countries. Time wasted in traffic is also a key backbone of citizens' quality of life. In cities in South America, such as Lima and São Paulo, commuters loose an average of four hours a day commuting from home to work.

2.4. Increasing dependence on fossil fuels

At a global level, following a *business as usual* trend, transport energy consumption is expected to increase by 80% between 2005 and 2050 (IEA, 2009). This rise will be particularly sharp in the fast growing economies across Asia such as India and Indonesia as well as China. In developing nations, the road sector is growing at 3.3% annually, which will lead to a two-fold hike of fossil fuel consumption with the next 20 years. As shown in **Error! Reference source not found.**, North America will be responsible for the consumption of 800 Mtoe transport-related fuels, followed by China (700 Mtoe) and other Asian nations (600 Mtoe). Although the diffusion of alternative fuels is expected to grow by 2050, the transport sector will continue to be dependent on conventional oil and natural gas based fuels.

Figure 3. Projection of road transport fuel share by 2050 (Note CTL: Coal to Liquids; GTL: Gas to Liquids; CNG/LPG: Compressed Natural Gas/Liquefied Petroleum Gas).



Source: IEA, 2009.

2.5. Climate change

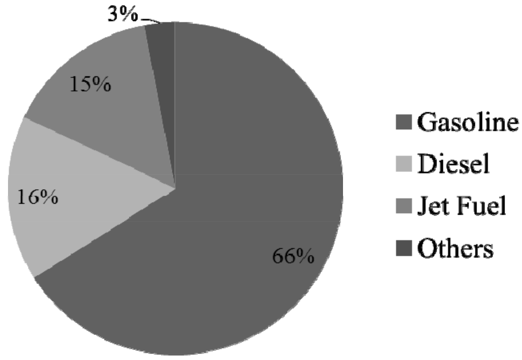
Combustion of fossil fuels results in the emission of carbon dioxide – the largest anthropogenic greenhouse gas. Carbon dioxide is released when hydrocarbons react in the internal combustion engines with oxygen[†]. Fuels with higher carbon content are therefore more prone to emit higher levels of carbon dioxide (Portugal-Pereira, 2011)[‡]. As shown in As shown in **Error! Reference source not found.**, 82% of total CO_2-related emissions from road transport come from diesel and gasoline fuels (IEA, 2012).

[†] Assuming completed combustion:

$$C_xH_y + \left(x + \frac{y}{4}\right) O_2 \rightarrow xCO_2 + \left(\frac{y}{2}\right) H_2O$$

[‡] According to IPCC methodological guideline, carbon dioxide emissions is given as follows:
$[CO_2]$ $[g/kg_{Fuel}]$ = C content $[\%_{w/w}]$ · 44/12·1000.

Figure 4. Share of carbon dioxide emissions in transport fuels.



Source: IEA, 2012.

2.6. Local air pollution

As stated above, congestion decreases the average speed of traffic flow that affects optimal combustion conditions. Incomplete combustion of fuels in vehicular engines results in harmful tailpipe emissions. Major emissions are carbon monoxide (CO), hydrocarbons (HC), nitric oxide (NO), nitrogen dioxide (NO_2), nitrous oxide (N_2O), Volatile Organic Compounds (VOC), Particulate Matter (PM), and sulphur oxides (SO_x). Air pollutants are associated with human disorders, including cancer, cardiovascular, respiratory and neurological diseases, skin allergies and eye inflammation (WHO, 2013). Unlike other emitters, road vehicles are diffuse sources of pollutants close to people's breathing zone (Takeshita, 2012), which is particularly risky to human health. This is especially true in developing countries, where emission standards and mitigation strategies lag behind Western countries. Every year urban outdoor air pollution is estimated to cause 1.3 million premature deaths worldwide (WHO, 2011).

III. SUSTAINABLE SOLUTIONS TOWARDS A MOBILITY PARADIGM SHIFT

Cities need to move towards new patterns of transportation based on *sustainable* principles. Sustainable mobility supports the environment through the protection of the global climate, ecosystems, public health and natural resources. It also supports other pillars of sustainable development, namely economic (job creation, balanced regional development, trade activities) and social dimensions (inclusive development, poverty reduction, equity). This leads towards a virtuous cycle of mobility rather than the vicious tendency described in the earlier sections.

"Compacting" and overlapping multifunctional layers within cities reduces travel demand, decreasing the number of trips and their duration. This fosters walking and cycling trips, while reduce the trips of private vehicles. At the same time, cities should improve mass transit services, increasing the number of users and quality of services. Thus, the number of private vehicles decreases, circulation flux improves and fossil fuel consumption goes down, which leads to lower emission of GHG and improved air quality. Overall, citizens enjoy better wellbeing and quality of life, as portrayed in Figure 5

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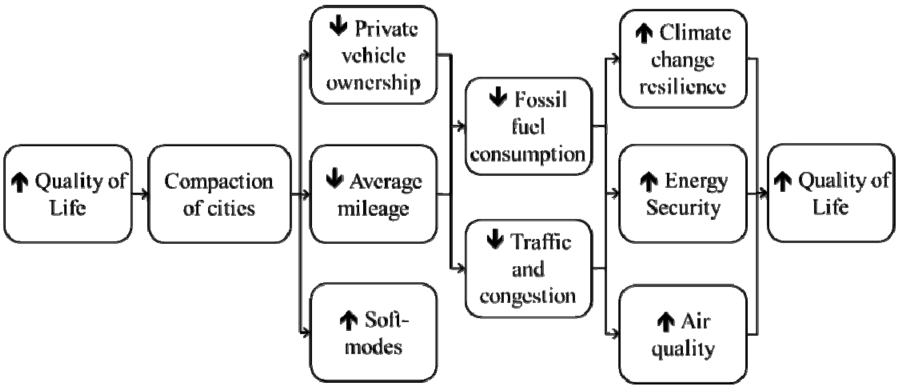
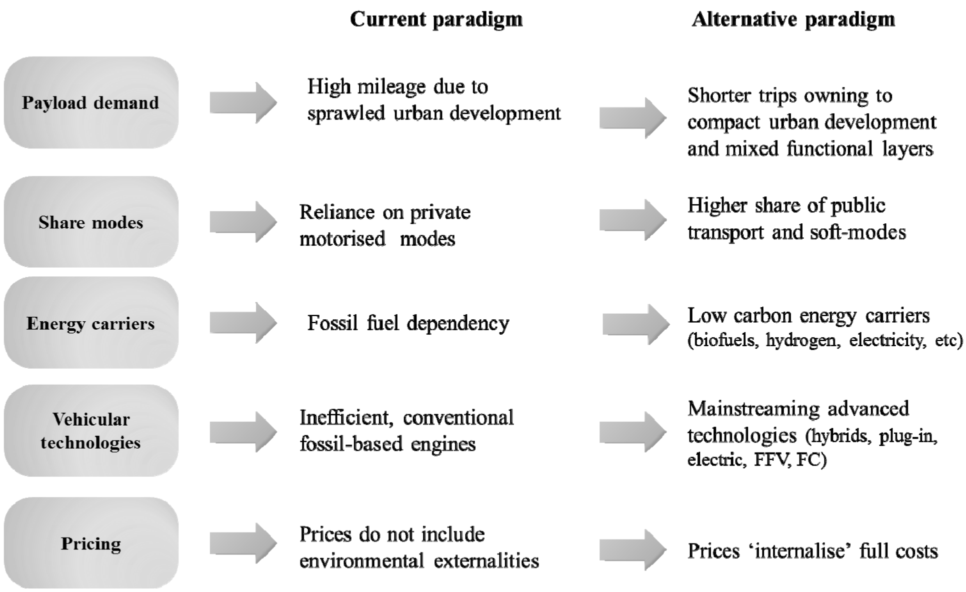
Figure 5: A virtuous cycle of sustainable mobility



Source: prepared by the authors.

A vision for sustainable mobility underlines radical shift from the *status quo* to an alternative low-carbon and innovative path. Reducing travel demand and share of private motorised trips, energy shift and technological changes will undoubtedly be part of the strategy. Figure 6 presents the current unsustainable tendencies and possible paths towards sustainability. The following discussion briefly discusses three proposed strategies to move towards a sustainable mobility paradigm: (i) reduce the share of private motorised trips (ii), energy shift, and (iii) diffusion of low-carbon vehicular technologies.

Figure 6: Strategies towards sustainable mobility in cities.



Source: prepared by the authors.

3.1 Reduce private motorised share mode trips

Reversing the rising tendency of vehicle ownership underlines a modal shift by improving public transportation and facilitating conditions to boost soft-modes. In the literature (Santos et al., 2010b), a wide number of integrated physical and soft policies are suggested as potential instruments to manage this modal shift. An increasing investment in public transport infrastructure, combined with restrictions on the use of private vehicles, can reduce traffic congestion and inherent externalities. Cities such as Curitiba, Brazil, London and Singapore have implemented measures to integrate public transport policies at a city level. Integration of land-use policies aiming at compaction and overlapping of functional layers within the cities is also essential towards modal shift. Reducing the number and length of daily trips indirectly promotes walking and cycling as a core urban mobility mode. Actions to make streets more soft-mode friendly include lower the traffic speed limits, construction of wide sidewalks and dedicated cycle paths, among others. For instance, in Copenhagen more than one third of commuters use the bicycle in their daily activities, which brings several positive externalities to the city. The promotion of car-sharing and car-polling programs, eco-driving and educational campaigns, are also triggers for behavioural change towards less impactful transport modes.

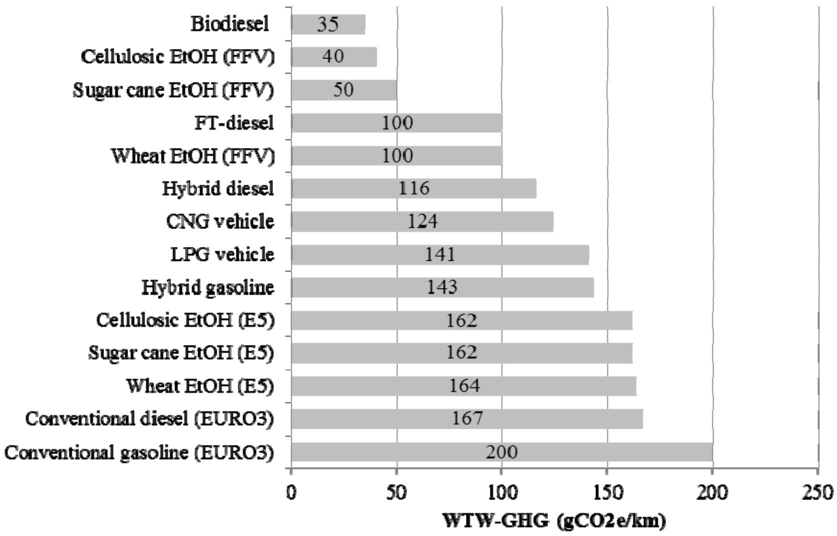
3.2 Fuel shift

Shifting from fossil carbon fuels toward low carbon energy carriers would decrease drastically CO_2 emissions from the transport sector. Alternative fuels, such as ethanol and biodiesel, are produced from biomass feedstock and described as carbon *neutral*. This is because the carbon released during vehicle utilisation is assumed to be absorbed by biomass growth through photosynthesis biological processes (Tilman et al., 2006). Although some critical voices advocate that large-scale conventional biofuels are highly dependent on fossil fuels and might raise land-use and food security issues, it has been argued that sustainable biofuel production can effectively mitigate climate change (Portugal-Pereira, 2011). Recently, attention has been focussed on advanced alternative fuels, produced from cellulosic and other non-edible feedstock. These fuels present greater potential to tackle GHG and do not directly interfere with food production chains (Portugal-Pereira, 2011), although expansion of this crop would result in land conversion, which could negatively affect biodiversity and ecosystem services.

Another attractive energy carrier is hydrogen. Produced from both biomass feedstock and conventional fuels (coal or natural gas), during its combustion nothing more than vapour is released, minimising tailpipe emission in urban areas.

Error! Reference source not found. presents the full life cycle (from *well-to-wheel,* WTW) GHG emissions of selected conventional and alternative fuels. Alternative fuels present a potential of reducing up to 83% GHG emissions per driven km.

Figure 7. WTW-GHG emissions from selected conventional and alternative fuels.



Note: EtOH – Ethanol; FT – Fischer-Tropsch; CNG – Compressed Natural Gas; LPG – Liquid Petroleum Gas; SR-H2-FC – Steam-Reformer Hydrogen Fuel Cell.

Source: prepared by authors based on JRC (2011).

3.3 Diffusion of low-carbon vehicular technologies

Advanced engine technologies show effective potential to increase vehicular fuel efficiency, and therefore to reduce the fuel input per vehicle kilometre. At the forefront of low-carbon technologies are the Hybrid Electric Vehicles (HEV). HEV use two different propulsion systems, as they combine a conventional internal combustion and an electric engine. This allows a higher efficiency of propulsion and lower tailpipe emissions than conventional engines. HEV reveal a potential to reduce up to 60% fuel consumption in vehicles. For instance, the Toyota Prius, the best-selling of all hybrid car models, uses 4.7 litres of fuel/ 100 km.

Major automotive manufactures have also starting commercialising electric and plug-in vehicles. These technologies are free of tailpipe emissions, as batteries power the engine rather than an internal combustion engine. Therefore, these propulsion systems ought to efficiently to reduce air pollution in cities. Regarding climate change mitigation potential, there are still controversial viewpoints regarding life-cycle emissions of such vehicles. In cities such as New Delhi or Beijing, where electricity generation mix is heavily dependent on coal, the power generated is carbon intensive and gains in GHG are diminished. However, in countries where renewables are part of the energy generation matrix, such as Brazil, electric propulsion vehicles would bring several local and global environmental co-benefits.

Flexible Fuel Vehicles (FFV) are also an effective strategy to reduce fossil fuel dependence and air pollution in cities. FFV are capable of running on any proportion of blended ethanol fuels. Their propulsion system can burn any ethanol/gasoline mix, as a fuel composition sensor adjusts fuel injection and spark timing according to the oxygen content of the fuel. FFV are believed to curb impacts of the transport sector on urban air pollution. In Brazil, engines are designed to have a high compression ratio, which maximises the benefits of high oxygen content of ethanol and reduces fuel consumption. As a result, according to Rovere (2002), exhaust emissions in urban areas in Brazil have lessened significantly since 1999, including carbon monoxide (15%), hydrocarbons (15.2%), and nitrogen oxides (21.4%).

IV. CASE STUDY ANALYSIS

4.1 New Delhi

i. Overview

With a total population of 16.7[§] million (Census of India, 2011) for the broader National Capital Territory, Delhi is now the second largest city in India (after Mumbai). Formal planning was begun in 1957 with the establishment of the Delhi Development Authority mandated to produce a master plan for the city (Ahmad et al, 2013). In an attempt to accommodate a growing population, zones were designated for growth around the city. Consequently it has a polycentric structure with large urban sub-centres quite far apart and with sprawling mixed land use in between. Although a state in its own right, the pull of Delhi has spurred the growth of cities at its borders (e.g.: Gurgaon in Haryana; Noida and Ghaziabad in Uttar Pradesh), so at its largest extent, the wider National Capital Region incorporates many towns in neighbouring states within its sphere of influence.

ii. Challenges

Road length in Delhi expanded by more than a factor of three (8,380-30,985km) between 1971 and 2008. However, the growth in vehicles was around 10 times that (a 31-fold increase from 0.18 - 5.62 million) which lead not only to massive congestion but also to increased air pollution (Gurjar and Lelieveld, 2005). As a result, Delhi is the most motorised city in India with 1.9 million cars in 2009 (171 veh./1000 habitants), which exceeds the combined vehicle populations of Chennai, Kolkata, Lucknow and Mumbai (GoI, 2012). Although urban areas in India have motorisation rates which are higher than the national average, Delhi's is already far past the projected level for the country as a whole in 2030. It is therefore unsurprising that pollution from vehicles is cited as the main contributor to poor air quality in the city, accounting for two-thirds of total air pollution (MOEF, 1997).

The casualties due to accidents on Delhi roads quadrupled between the 1970s and 1990s (Sen et al., 2010), most of them being pedestrians and cyclists (Pucher et al., 2005). Furthermore data presented by Tiwari (2003) showed that a drop in the proportion of traffic fatalities from car users appeared to come directly at the expense of pedestrians towards the end of the period 1990-1999. At the global level, carbon emissions from diesel consumption alone in Delhi increased by a factor of four between 1980 and 2000. In such a city, sustainable mobility has clear health components and many actions taken by the city are aimed as much at improving air quality as easing congestion.

iii. Sustainable mobility solutions

Since the late 1990s, government at both the national and local level has taken action to address transport problems in Delhi. Initially command and control measures were used to reduce

[§] Provisional Figure for 2011.

pollution. The phase out of commercial vehicles over 15 years old and banning the use of leaded petrol are two notable examples (Kathuria, 2002). Similarly, in response to public pressure , the Supreme Court of India mandated the compulsory use of Compressed Natural Gas (CNG) in all public transport vehicles. The Delhi government was ordered to complete the necessary changes to the entire fleet by March 2001 (Goyal & Sidhartha, 2003). Consequently, Delhi runs the largest fleet of CNG vehicles in the world (Guttikunda, 2008).

Against this backdrop, Delhi had long held ambitions to develop a metro system in the city. The opportunity to finally push through with the project was seized in the run up the 2010 Commonwealth Games, when the Governments of India and Japan agreed to cooperate on the project. A key factor in this was the establishment of the Delhi Metro Railway Corporation, which could circumvent much of the bureaucracy which had hampered previous attempts (Siemiatycki, 2006). The Delhi metro is an ambitious project set out in four phases to connect all parts of the city. The first two phases consisting of 190km over 6 lines were completed by 2010 (Sahai and Bishop, 2010). This constitutes just under half of the total projected coverage, which by 2021 will be over 400 km in length (Sreedharan, 2008) and connect the city not just radially but concentrically.

Beyond improving the public transport of Delhi, the metro incorporated a number of innovative features into its design, the most notable of which is the use of a regenerative braking system, which generates energy from the braking phase of the trains' operation and feeds it back to the system. Around a third of the electricity consumed in the metro is generated in this manner (Sreedharan, 2008) and has been instrumental in making the Delhi metro the world's first railway project registered under the Clean Development Mechanism (CDM). Some 41,160 tons of CO_2 are calculated to be saved annually from this system (UNFCCC, 2007).

Doll & Balaban (2013) assess that co-benefits from the Delhi metro could accrue from three sources: (i) the increasing ridership, (ii) increasing the contribution of car users who switch to the metro, and (iii) the cleanliness of electricity generation used for the metro. However, the authors note that in case of the last two factors, achieving such measures require coordination that extends beyond the remit of metro operation itself, into wider transport policy and into the realms of town planning. A suite of carrot and stick measures is needed which actively promotes use of one mode over another (i.e. away from private car use). Otherwise an 'all of the above' policy can simply lead to gridlock as competing entities vie for resources and revenue, which only serves to frustrate the delivery of an efficient transport system.

Whilst construction of a metro eases congestion, it arguably promotes further development along its corridor, prompting further growth of the city. It remains an open question whether alternative solutions could be deployed which deliver mobility to the masses while also constraining urban growth. However, such concerns in the capital city of one of the world's major emerging economies are likely to take a back seat. It is somewhat ironic that the active participation of (middle class) civil society in bringing the case to the Supreme Court to mandate cleaner fuels are also active in blocking a bus rapid transit (BRT) scheme, claiming it hinders the mobility of motorists.

4.2 Toyama City

i. Overview

Toyama prefecture is located in Central-West Japan on the northern coast of the Sea of Japan in the Hokuriku Region. The capital city of the prefecture is Toyama city, the second largest city in Hokuriku after Kanazawa. The city's population is approximately 420,000 people including seven municipalities that merged into the city in 2005. The population of its metropolitan area is estimated to be 540,000, spread over an area of about 1,240 square kilometres.

As is the case with other Japanese local cities, Toyama city has been experiencing suburbanisation and loss of population from the city centre. The city faces an increasingly disproportionate age distribution within its population as the number of older citizens grows and the city must deal with problems associated with aging. Against this background, the city has taken up a series of policies to revitalise the city centre through implementing the concept of the compact city and ensuring provision of affordable and convenient public transport (Takami & Hatoyama, 2008).

ii. Challenges

The development of Toyama's urban area over the past 40 years has been unusually sprawling compared to most Japanese cities. Consequently, the city has the second largest proportion of car owners per capita in Japan. As a result of car-dependent urban sprawl, public transport in the city has experienced a drastic decline. In particular, shuttle bus users decreased nearly 70% from 1990 to 2006, which further resulted in cutbacks in bus routes and frequency of service. At the same time, ownership of ordinary passenger cars grew 1.4 times and of compact cars 6.5 times compared to the 1990 level. According to an analysis of transportation use in the city, 72.2% of the city's population use cars for general purposes and about 84% to commute (City of Toyama, 2009). In addition to the issue of urban sprawl, Takami and Hatoyama (2008) identify other social and demographic challenges in Toyama, namely, an aging population, a decreasing population density, and deterioration of the city centre.

iii. Sustainable Mobility Solutions

In order to respond to these challenges, Toyama city decided to formulate proactive policies to mitigate the problems in the early 2000s (City of Toyama, 2013). The plan aims at renovating public transport and gradually inducing people to live closer to areas concentrated around convenient public transportation access points. As public transportation routes radiate outward from Toyama Station, the city's initial investments seek to strengthen these transportation systems.

The city further developed its transport plan into an Eco-Model City Action Plan as part of the national government Eco-Model City initiative, which recognises cities with proactive sustainable plans and policies. Currently 200 cities have been recognised as Eco-Model cities. Eco-Model cities are required to formulate very detailed action plans with specific quantitative GHG reduction targets, for which the city must report progress on implementation.

The Toyama Eco-Model Action Plan integrates demographic planning actions with transport-related options. It is based on three main sections: (i) a public transport policy package, (ii) a planning and demographic policy package, and (iii) a supplemental private transport policy package. Each policy option has detailed numerical targets, as seen in Appendix A. The policy options are an interesting combination of transport and development-planning provisions. Toyama city first looked at what transport infrastructure they had, then tried to improve it. The city uses a combination of financial and planning policies to increase local resident accessibility to public transport, centred around three policy packages:

As a first step, Toyama identified public transportation routes that radiate outward from Toyama Station, with the city's initial investments seeking to strengthen these transportation systems. The city has also introduced a light rail transit (LRT) system by taking over an unprofitable railway line being operated by West Japan Railway Co. (JR-West), and laying some light rail lines in existing road lanes. In a further step, the LRT project extended to another tram line, operated by Toyama Chihou Tetsudou Inc. and completed in December 2009. Under the Eco-model city action plan, Toyama is also planning to provide more LRT in areas where LRT has not been provided. Also, the City is to increase convenience of public transport by enhancing the inter-connectivity of different public transport routes. Apart from the railways and LRTs, the City also promotes bus services. Within the city, a private company (Toyama Chihou Tetsudou) operates conventional bus services, but the city itself also operates some traditionally unprofitable bus routes.

Simultaneously, the city is trying to increase population density in the Toyama city centre. In order to do so, it provides subsidies for moving into the city centre, as well as for building new houses in the area. The demographic incentives are reinforced by other policies that enhance the attractiveness of the city centre. The city, for example, is trying to regenerate the economically stagnated areas within the central business district (CBD). The city also has a series of policy options for curbing private transport, including encouraging behaviour change (e.g. through car-free days) to promotion of walking and bicycle use. The city also sponsors group competitions to demonstrate low-carbon activities in the transport sector. The City of Toyama estimates that a reduction of approximately 570,000 t-CO_2 will be achieved through the new public transport schemes by 2013, and about 1 million t-CO_2 by 2030 (Table 2).

Table 2. Estimation of GHG reduction of Toyama city.

	Reduction by 2013	Reduction by 2030	Reduction by 2050
Promotion of public transport	17,715	195,359	266,039
Development in CBD and stations	105,260	153,466	166,983
Compact city policies	1,119	91,673	182,411
Compact cities and environmental enterprises	422,777	655,676	945,520

Source: City of Toyama, 2009.

The policy groups and options have specific quantitative targets, as shown in Appendix A, and progress on each option have been monitored. There is, however, a serious implementation problem: although there are detailed quantifiable targets for each option, the total of the monitored GHG reduction has only made modest progress to their own expectations. Also, some of the options have only an indirect association with the GHG reductions, e.g. giving subsidy to incentivise people to live in the CBD, which are notoriously difficult to accurately quantify. Fundamentally, quantification of all the options may not be realistic. Toyama city is planning to revise the current Eco-model action plan by 2014. It is expected that the new plan will respond to these issues.

V. DISCUSSION

5.1 Co-benefits of sustainable mobility strategies

A co-benefits approach implies the integration of global climate considerations into local level policy packages. Within the sustainable mobility context, it refers to strategies and programs to simultaneously address environmental and socio-economic goals (air pollution, noise, and road traffic accidents), whilst promoting climate change mitigation targets and reduction of fossil fuel dependence of road vehicle fleets. Therefore co-benefit policies result in multiple outputs both at local and global levels. This is seen as being particularly relevant when local governments have limited financial resources and social priorities dictate the political agenda. Thus, a co-benefit policy strategy attempts to address local needs, while mainstreaming climate change mitigation plans. As shown in Table 3**Error! Reference source not found.**, this approach takes two dimensions, one of scale (global and local) and one of impacts (environmental and socio-economic). Taken together they fill a quadrant which addresses economic prosperity, social equity and local environmental regeneration, while tackling GHG emissions and reducing fossil fuel dependence.

Table 3. Co-benefits of sustainable mobility policies.

	Environment Dimension	**Socio-economic Dimension**
Global Level	- GHG mitigation - Fossil fuel dependence reduction	- Increasing resilience towards natural disasters - Less economic losses due to extreme climate events
Local Level	- Improvement of air quality - Noise reduction	- Reduced risks to public health - Time saving in traffic - Lower levels of stress during congestion - Promotion of social equity and liveability - Reduction of road accident risk - Lower costs of road infrastructure maintenance - Higher city attractiveness (business/tourism)

Source: Prepared by the authors.

5.2 Qualitative assessment of environmental and socio-economic win-win solutions

The case studies presented in this paper reveal a complementary assessment of co-benefits in two very different contexts: one a megacity and capital of the second most populous country in the world, the other a small city with high vehicle ownership and facing the looming effects of ageing and depopulation in a highly developed country.

In the case of Delhi, the city is struggling to accommodate an increasingly affluent population's demand for motor vehicles and to cope with its inherent environmental impacts. The metro system plan anticipated a wide potential to environmental co-benefits through a reduction of vehicle ridership. However, in practical terms, the metro itself does not necessarily lead to a decrease in motorisation.

As highlighted by Doll and Balaban (2013), there is the need for wider and more integrated planning if co-benefits are to be maximised. It is not good enough to simply construct a metro if little or no thought is given to its use or users. Metros are a means not an end in itself. Integrated environmental planning would go beyond individual projects to consider how to restrict car use, through both incentives and disincentives (carrots and sticks) such as restricting parking (or increasing its cost) and promoting public transport. The risk with fragmented policies is that they may end up working against each other at the city scale and lead to further paralysis. A degree of realism is required in appreciating that global environmental concerns are rarely, if ever the main or sole driver to transport initiatives and similarly, the same can be said for local environmental concerns (although this may change as the environmental situation deteriorates). The co-benefits approach aims to bring in such considerations with the developmental aspects.

Similarly, in developed countries, local governments also prioritise policies that address local community's needs. The needs and concerns of Toyama are almost completely opposite to those of Delhi. Nevertheless, it has managed to devise policies which promote public transport in combination with urban planning initiatives, aiming simultaneously to reduce private vehicle ownership. In this case, Toyama needs to maintain its attractiveness to new residents and sees its position as one of the 13 Japanese 'eco-cities' with the potential to attract residents who value quality of life and 'liveability'. In this sense, there is an indirect driver to tackle environmental issues. This may become more pressing in the developed world as changing demographic structures and level of economic development encourage cities to look beyond traditional economic indicators. Here, access to public transport and relocating elderly residents in the city results in reduction of air pollution, mitigation of GHG emissions and better quality of life.

VI. FINAL REMARKS

In this paper, the authors present the *vicious cycle of transport*, which explains why increasing motorisation leads to poorer quality of life. Both cities in emerging and developed economies suffer from a vicious cycle, as higher incomes commonly results in high private ownership and ridership, and reduced public transportation infrastructure. This leads to urban congestion and inherent environmental externalities, resulting in decreasing liveability of cities. This study presents a qualitative assessment of global and local environmental co-benefits from sustainable mobility policy strategies to tackle the environmental externalities of the road transport sector. To this end, policy packages to pursue congestion reduction have been evaluated, including promotion of public transport infrastructure and soft-mode programs.

The analysis suggests that implementing a co-benefit approach to simultaneously reduce global (GHG) and local air pollutant emissions can tackle urban congestion and promote social equity and economic prosperity. The co-benefits approach can be applied flexibly to many different contexts as its nature varies according to local priorities. The implication of this is that the integration of climate concerns can be mainstreamed into transport policy across many levels of development.

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APPENDIX A. Policy package of climate change mitigation strategies and carbon dioxide reduction goals for Toyama City

Policy Package	Measures (number and description)	Timescale	t-CO2
1-a	LRT networking development	2013	17,715
		2030	195,359
#1-a-1:	Shift to LRT of the Toyama port line -Continue safe operation of loop line -Conducted maintenance of facility by the City for secure and safe operation		
#1-a-2:	Shift to loop line from the city train -Kept the current facility, conducted maintenance and made plan for constructing new station at Nishi-machi, the center of the city.		
#1-a-3:	Combine South and North tram lines (plan) -Formulated the basic plan for combination of South and North tram lines -Had consultation with operators		
#1-a-4:	Shift to LRT from Kamidaki line of Toyama Chiho Train (Plan) -Survey for shift to LRT was initially planned, city consulted with Toyama Chiho Train for entering city (LRT) trains into Kamidaki line -Conducted a pilot program of increased frequency to promotion ridership and revenue		
1-b	JR related development	Target same with 1-a	
#1-b-1:	Land reallocation (station zoning plan) in Toyama station area -Compensation to owners for removal of buildings in order to construct open space at the front of south exit of Toyama station (project progress rate is 43.9%)		
#1-b-2:	Interchange in Toyama station area -Started constructing viaduct (elevated station)		
#1-b-3:	Shift to regular trains of JR Hokuriku line -Developed the first management plan and determined investment ratio and stake to a preparatory company		
#1-b-4:	Improvement of main train stations area -Improvement of open space, bicycle pool, toilet and sign in main stations - Established a town promotion committee by local citizens		
#1-b-5:	Upgrading of transportation of city trains -Operated stably systems of guide display and announcement		
#1-b-6:	Image enhancement -Introduced a large non-step bus with excellent design to a main bus line		
1-c	Promotion of general public transport and modal sift	Target same with 1-a	
#1-c-1:	Pilot program for activation of JR Takayama main line -Keep increased operation schedule, a few temporally stations, and P & R parking lot		
#1-c-2:	Pilot program for P&R at Toyama port line -Keep P&R parking lot at not only Toyama port line but also another line		
#1-c-3:	Testing operation of a electric bus -Tested actual operation of electric bus at a bus route		
#1-c-4:	Community bus -Introduced community bus into no-public transportation area, supported money-losing routes operated by private sectors and locally operated bus		

Policy Package	Measures (number and description)	Timescale t-CO2	
#1-c-5:	IC card -Introduced IC card system to local train lines and ID card of city officials		
#1-c-6:	Promotion of public transportation use for elderly people -Introduced IC card for pass		
#1-c-7:	Pilot program for operation of environmentally friendly boats for students' learning -Continued the pilot program		
1-d	modal sift	Target same with 1-a	
#1-d-1:	Voluntary return of drivers licenses of elderly people -Provided public transportation pass to people 65 years old who voluntarily returned drivers licenses		
2-a	Increase population in city centre	2013	8,641
		2030	58,665
#2-a-1:	Promotion of suitable housing in the town -Subsidiary for city housing		
#2-a-2:	Promotion of constructing houses near public transportation -Subsidiary for housing		
#2-a-3:	Public renting service (private apartment) -Implementation of the service		
#2-a-4:	Promotion of elderly people to relocate from their own houses to those in town near public transportation for elderly people -PR on the system		
2-b	Increase viability in city centre	Target same with 2-a	
#2-b-1:	Community bus in downtown area -Introduced community bus in the several routes		
#2-b-3:	Regeneration of Nishi-machi South area -Established and subsidy to a preparation office		
#2-b-4:	Regeneration of Nishi-machi East-south area -Constructed buildings -Subsidy to establish a management office		
#2-b-5:	Regeneration of Chuo street -Constructed buildings -Subsidy to establish a management office		
#2-b-6:	Control of large construction at suburb -Implemented regulation		
#2-b-7:	Introduction of facilities related to local daily lives -Opened agricultural food markets in the downtown -Established a rehabilitation center for elderly people to a vacant lot -Combined public facilities and fish market and relocated to a vacant lot		
#2-b-8:	Shopping sale to attract costumers -Implemented in a local business union and a big shopping mall		
#2-b-9:	Introduction new shops -Subsidy to renovation and rental		
#2-b-10:	River development project -Still under planning basic plan for city center (not yet established) - Park golf course and open space in public transportation area		
2-c	Increase livability in city centre, etc.	Target same with 2-a	
#2-c-1:	PR on housing subsidy system -Implemented PR on the system		
#2-c-2:	Collecting information of empty houses		

Policy Package	Measures (number and description)	Timescale	t-CO2
	-Collected information of empty houses with cooperation of housing association		
#2-c-3:	Eco-smooth road -Considered newly implemented location	2013	20
		2030	88
3-a	Carbon efficiency of housings		
#3-a-2:	Subsidy to housing with eco-system in public transportation area -Survey and review of incentive scheme	2013	187
		2030	5,548
#3-a-3:	Subsidy to renovation of detached house in residential and public transportation area -Implemented the incentive -PR activity	2013	87
		2030	4,688
3-c	Residential development alongside with public transportation	2013	0
		2030	2,774
#3-c-1:	Subsidy to housing development in public transportation area -Survey and research about plan and demand in the area	2013	0
		2030	2,774
4-a	Residential development alongside with public transportation		
#4-a-1:	Car free day and eco-commute -Implemented car free day around Toyama prefecture - Implemented car free day of city officials for 2 days in every month	2013	468
		2030	414
#4-a-2:	Promotion of Bicycle use -Implemented group registration system and one day pass and increased members	2013	146
		2030	146
#4-a-3:	Electric Vehicle (EV) City plan -Facilitated a battery charger (200v) in the city hall -Introduced 2 EV for official cars	2013	0
		2030	58,365
4-b	Public awareness		
#4-b-1:	Team Toyama -Now 345 teams with a total of 20298 participants. 10 teams are in transport sector	2013	121
		2030	1,679
4-d	City office management		
#4-d-7:	Low pollution car -Introduced 2 EV car for official use	2013	21
		2030	89