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Indicator model for benchmarking the transition to a low carbon urban mobility system

Application results from three Scandinavian cities

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- Krithi Venkat

Abstract

Cities today consume over 80% of the world's energy and are responsible for 75% of the total GHG emissions. Over 80% of the population in Europe live in Urban areas. The mobility system, being at the heart of urban activities is responsible for the movement of people, goods and services and is responsible for attracting investments into cities. Playing such a key role in urban development, the sector contributed to over 25% of the GHG emissions from urban areas in Europe. The European Union has thus set out specific targets to decarbonize the mobility sector. With the increasing need for the transition to a low carbon mobility system, it has been identified that there is a need for a benchmarking model that is tested on sectoral frontrunners to enable performance evaluation and guide transitions.

Being informed by this need, this study aims at the development of a benchmarking model based on the Avoid-Shift-Improve framework for the evaluation of a low carbon mobility system. The model has been developed based on specific measures targeted at addressing behavioural and technological change required in the mobility system to help aid the GHG emission reduction of urban mobility system have been identified.

The model has been tested on the three Scandinavian capital cities of Stockholm, Copenhagen and Oslo, considered as sectoral forerunners due to their diverse activities to reduce GHG emissions from the mobility system. The results of the tests show that the model is able to predict the priorities of the city and the resultant low carbon mobility score is correlated positively with GHG emission reductions. The study also highlights the specific areas of improvement for the three cities and the different considerations that go into the selection of specific measures to improve the system.

Key Words: Low carbon mobility, Sustainable urban transport, Avoid-Shift-Improve

Executive Summary

In the European Union the transport sector contributes to over 24% of the total GHG emissions second only to the energy sector. While all other major sectors saw a considerable decline in GHG emissions, emissions from the transport sector in the EU saw a 36% increase between 1990-2007 and a moderate levelling off after 2008. It has been established by the EU that emissions from the transport needs to decrease by 67% by 2050 in order to meet the target of an overall 60% decrease in GHG emissions from the transport sector by 2050. While on the other hand, suggesting that as long as the mobility sector is dependent on fossil fuels and mobility is mainly achieved through motorized means, transport related challenges will continue to persist.

Addressing these issues required the consideration of both the mobility behaviour and practices that a specific city/area follows as well as the transport supply, controlled by the fuel and vehicle market. The main strategies suggested for this transition by the European Environmental Agency in their *Transport and Environment Reporting Mechanism* report, follow the so called Avoid-Shift-Improve framework suggested by Dalkmann and Brannigan (2007). There is also the recognition that we need to direct measures at ensuring a behavioural shift to ensure the development of a low carbon mobility system that contributes to an improvement in quality of life. This need has been corroborated by the EU, various national level transport research organizations as well as a number of academic publications.

Informed by these developments, the following research questions were used to guide the study:

1. What are the key parameters to consider in characterizing and benchmarking LCM in cities?
2. Does the developed model meet the main criteria of indicating the performance of the system in its transition to becoming a low carbon system?
    a. Is there a correlation between the developed model and the rate of transport emission reduction?
    b. Can the model explain the priorities of the mobility system cities evaluated?
3. Can the model be used to identify possible pathways for the improvement of the existing low carbon mobility system in the selected cities?

The aim of the study is to develop and test an indicators model based on the Avoid-Shift-Improve framework. Due to the maturity and experience in the efforts to minimize emissions from the transport sector and the stark similarity of their objectives with those of low carbon mobility system the three Scandinavian cities- Stockholm, Copenhagen and Oslo, well known for their mobility improvement efforts and with significant freedom to influence the budget allocated to mobility measures, to test the developed low carbon mobility indicator system have been selected to test the model.

Selection of performance indicators was made based on the measures required to transition to a low carbon mobility system, according to the Avoid-Shift-Improve framework. It has been identified that the measures are mainly characterized as

1. Regulatory
2. Informative
3. Infrastructure
4. Technological and
5. Economic

Parameters are then identified and assigned based on the presence and the performance of these measures. Due to lack of information with regards to the contribution of these measures singularly to the main objective of reducing GHG emissions from the transportation sector, all parameters are weighed equally and aggregated in order to form more comprehensive performance benchmarks.

Comparing the variables impacted by measures under each of the three main strategies of the framework with a formula devised by He et al. (2011) to calculate the total emission of the transport sector of a city revealed that measures categorized under the avoid strategy have highest impact on the GHG emission reduction followed by the shift strategy and then finally the improve strategy. This is mainly owing to the lack of or reduced use of motorized transport, enabled by measures of the avoid strategy, the relatively lower use of private motorized transport and heightened use of shared mass mobility services resulting from the measures of the shift strategy and improved efficiency and quality of vehicles and fuels used for both private and public motorized modes.

Along with the *low carbon mobility* score, three separate scores, each for the Avoid, Shift and Improve strategies are calculated and the following results were noted. The model, when tested for a correlation with emission reduction data from the transport sector for the three cities showed a strong correlation with the *low carbon mobility* score, confirming that the design of the model meets the objective of evaluating the performance of emission reduction measures.

On further analysis of the city level scores, Copenhagen ranked first among the three cities with the highest *low carbon mobility* score, followed by Oslo and then Stockholm. At the strategy level, it was identified that the cities are leaders in their own field, with Copenhagen taking the lead in the Avoid score, Stockholm in the Shift score and Oslo in the Improve score. The scores reflect specific conscious efforts of the government (city and national level) to develop the mobility system in the cities over the last two decades, explaining their lead in their respective categories.

It has been identified, based on this research, that the model can be made more robust. In order to identify the relative importance of parameters used in the indicator set, multivariate analysis techniques such as principal component analysis need to be performed. The results of this PCA may be used to inform the weighting of each of the parameters in the model. Additionally, the causal linkages between the indicator and scores should be tested in order to enable more informed choices for the selection of mitigation measures in cities. Finally, there is also a need to test and optimize the robustness of the model through uncertainty and sensitivity analysis using variance based techniques.

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1 Introduction

The United nation defines urbanization as the movement of people from rural to urban areas (UN Habitat, 2004). The concept of urbanization has been found to be quite closely linked to industrialization and modernization and encompasses social, economic, political and environmental realms of human life (United Nations Department of Economic and Social Affairs, 2014). It was not until years into the era of industrialization and beyond, that the impact of the urban sprawl on the human health and the environment was noticed. Over the past few decades we have seen an exponential rise in the rate of population increase in urban areas. It has been predicted that around 70% of the world's population will live in urban areas by 2050 (United Nations, 2008). Cities today, consume over 80% of the world's energy and resources and contribute to 75% of the world's CO_2 emissions.

Nearly 80% of the European population lives in urban areas contributing to over 11% of the world's total greenhouse gas (GHG) emission (EEA, 2015b). The European Union has committed to a 40% reduction in GHG emissions (measured as CO_2 equivalents) based on 1990 levels by 2030 in order to combat the effects of climate change (European Commission, 2015). The transport sector contributing to about 24% of the GHG emissions in the EU (majority of which is due to road transport), comes second only after the energy sector. As cities grow, it becomes increasingly important to develop the mobility system in the city in order to keep people, services and goods moving. Additionally, it is a good transport system that attracts investment from businesses into the city (Nordic Council of Ministers, 2012). GHG emissions from the mobility sector increased by around 36% between 1990 and 2007 while emissions decreased from all other sectors (European Comission, 2016). It was not until after 2008 that the EU saw a drop in GHG emissions in the transport sector (Fig.1) mainly caused due to innovations in the automobile industry coupled with the increase in oil prices, that brought about the increase in energy efficiency of vehicles. Despite these efforts, emissions from the transport sector were found to be 14.5% higher than 1990 levels. It has been suggested that as long as the mobility sector is dependent on fossil fuels and mobility is mainly achieved through motorized means, transport related challenges will continue to persist, especially in transportation hotspots such as Europe (Geels et. al., 2012). It has been predicted that emissions from the transport needs to decrease by 67% by 2050 in order to meet the target of an overall 60% decrease in GHG emissions from the transport sector by 2050 (EEA, 2014b). Addressing these issues required the consideration of both mobility behavior and practices that a specific city/area follows but also the transport supply, controlled by the fuel and vehicle market (Geels et. al., 2012). Owing to the high figures of reduction needed in the EU, the main focus of the EU has been to lower emissions from the transport sector.

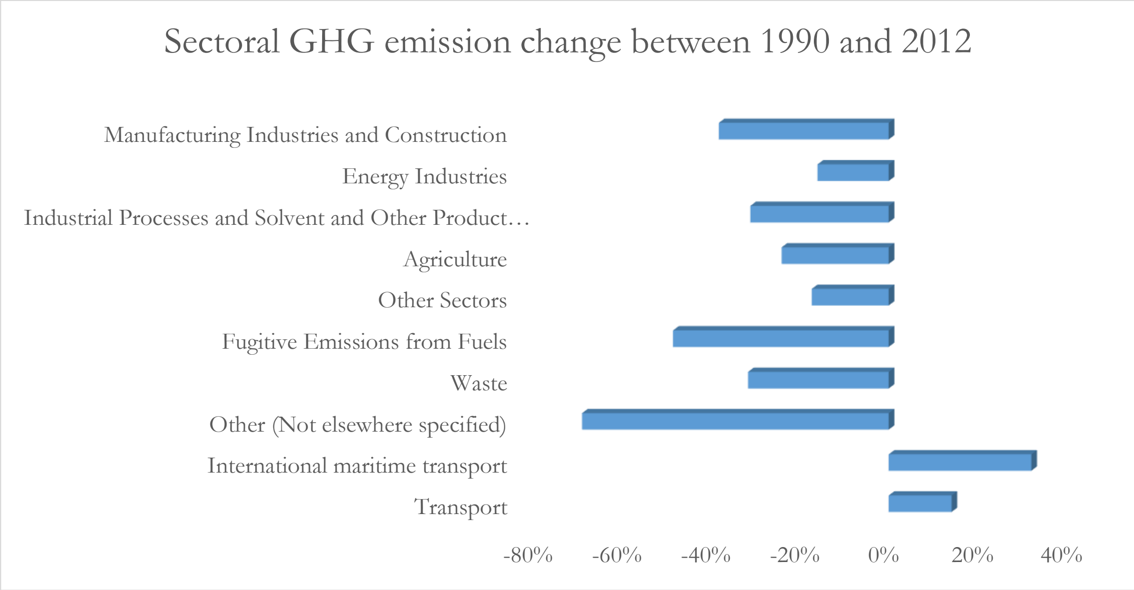


Figure 1 Change in GHG emissions in the European Union by sector from 1990 to 2012 (EEA, 2014b)

1.1 European mobility system and the need for a benchmarking model

Some of the main drivers for the increased rate of transport has been found to be increased innovation in vehicle technologies, improved multi-modal mobility infrastructure and the low cost of transport fuel. This has resulted in the increase in air pollution and associated health problems and thus a decline in the quality of life (Kiesewetter, et al., 2015). The European urban landscape, characterized by high population densities and relatively high GDP, is known to be a traffic hotspot with increased traffic congestion, predominated by private cars, and corresponding air pollution (EEA, 2014a; Dratva, et al., 2010).

In order to combat the projected rising demand for transport and the corresponding increase in passenger cars, fuel use and air pollution, the European Commission in 2011 set out 40 major initiatives needed to develop the EU's transport system, reduce emissions from the sector and reduce the dependence imported oil, while supporting growth and employment in all European cities (EC, 2011). Progress towards targets set in 2011 were measured in 2015 as a midterm assessment, which revealed that environmental trends of indicators either showed a mixed picture of a deteriorating trend. Progress made in meeting goals set, specifically in the transport sector in member states has not been measured due to the lack of data and the complicated nature of evaluations needed (EEA, 2015a). The TERM report of 2015 highlights that GHG emission from the transport sector has increased by almost 20% of 1990 emissions. Majority of this emission is due to road transport emission, which has also increased by 17%. The only two sectors that have not seen a downward trend are rail and inland navigation.

Despite the high figures, EU seems to be on track to meet its goal of 60% reduction of transport GHG emissions by 2050. However, a further reduction of at least 10% is needed to meet the mid-term mark by 2030. Also, based on the EC's own predictions, the 2011 white paper 'decarbonization targets will not be met unless more ambitious measures are put in place' (EEA, 2015a p.10). Kammerlander et. al. in their paper *A resource-efficient and sufficient future mobility system for improved well-being in Europe* state that, meeting these ambitious reduction targets requires a more holistic perspective and needs to include both behavioural changes as well as technological advancements (Kammerlander, et al., 2015).

Additionally, the transition to a low carbon mobility system is also faced by the following challenges (GTZ, 2010).

1. Time lag between decisions and effects: It has been noted that certain measures have the required impact only in the longer term. This will be achieved only if a continuity in political willingness and decision making
2. The cross-cutting nature of transport: The mobility sector is influenced by decisions in a wide range of urban departments and similarly, decisions in the transport sector need recommendations and planning aid from other urban departments, that may not prioritize environmental externalities at a similar level of importance. It is thus of paramount importance to establish a system of integrated planning and decision making.
3. Presence of a fragmented target group: The need and demand for mobility is felt by all social groups with varied characteristics. It is thus important to meet the needs of all of these groups to ensure improved service provision and thus quality of life. Measures thus need to be catered to clusters of groups in order to have a sustainable impact on the overall goal of reducing emissions

Over the years, development has been centered around societal advancements that came with increased personal disposable incomes, higher vehicle ownership and increased need for freight transport. There is thus a need to identify and low carbon mobility strategies and roadmaps that provide for a pathway into a modern, sustainable and stable society (GTZ, 2010).

In order to tackle these problems and those of climate change, global warming and energy security, the European Commission proposes the concept of 'decarbonization' in the mobility sector and states that "Low or zero carbon mobility with low energy consumption is essential for a sustainable future and competitive cities where people, businesses and culture can thrive" (UITP, 2011). The accepted and selected framework for the transition to the low carbon mobility system as given in the 2013 TERM report is the Avoid-Shift-Improve framework developed by Dalkmann & Brannigan in 2007 (EEA, 2013).

In order to identify the impact of the mitigation measures adopted and to evaluate the performance of the entire mobility system providing a basis for decision making it is important to have specific understandable indicators based on robust frameworks (GIZ, 2011b). The GEF identifies that measuring and quantifying global environmental benefits is an important basis for choosing the best sets of interventions in implementing emission reduction projects. Price et. al. also identifies the lack of benchmarking models for the transition to low carbon mobility systems.

1.2 Research Aim

Based on an in-depth literature review it has been identified that the Avoid-Shift-Improve framework developed by Dalkmann & Brannigan in 2007 best describes the transition to a low carbon mobility system. The aim of this thesis is to develop a indicator based benchmarking model based on the Avoid-Shift-Improve framework to evaluate the performance to a low carbon mobility system.

The following research questions were used to guide the study:

1) What are the key parameters to consider in characterizing and benchmarking LCM in cities?

2) Does the developed model meet the main criteria of indicating the performance of the system in its transition to becoming a low carbon system?
    a. Is there a correlation between the developed model and the rate of transport emission reduction?
    b. Can the model explain the priorities of the mobility system cities evaluated?
3) Can the model be used to identify possible pathways for the improvement of the existing low carbon mobility system in the selected cities?

1.3 Overview of the methodology

A number of approaches have been used to answer the research questions guiding this thesis. Primarily, an in-depth literature review has been conducted to identify the main measures that contribute to the achievement of the objectives under the Avoid-Shift-Improve framework and to clearly define the overlapping effects of the measures in meeting the objectives. Specific indicators corresponding to these measures were identified to initiate the development of the benchmarking model. The model has been tested on the performance of three cities identified as forerunners in the area of sustainable and low carbon mobility. Data collection was based on interviews with transport planners and strategists working with the municipalities as well as external transport companies in the three cities. Finally, data collected has been modeled to test the benchmarking framework developed and identify possible areas of improvement. For a more detailed explanation of the methodology adopted for the study, see Chapter 3.

1.4 Scope and Limitations

As the research primarily seeks to develop a benchmarking system for the transition to a low carbon mobility system, it is important to define the system boundaries considered for the study.

This thesis focusses on the measures that governments (municipal, county and national level) can implement in order to aid the transition to a low carbon mobility system.

The data collected from the three test cities in order to test the model developed is based on the methodology adopted for data collection by responsible authorities in the cities. For the purpose of this study, it has been chosen to not deal with the inconsistencies in these methodologies and accept the data that has been presented and verified by the city officials.

The development of the indicator based system has been restricted by the lack of information regarding causal relationships between specific measures identified and the corresponding GHG emission reduction. The model developed thus adopts a scheme of equal weights that may not be directly representative of the real life scenario.

1.5 Audience

The intended audience for this thesis is municipal and regional level public authorities involved in mobility related decision making. These include transport planners and strategist, urban planners, municipal and regional level governmental authorities responsible for decisions with respect to budget allocation and dissemination. Additionally, the model developed may also be of keen interest to academicians working on the development and optimization of indicators for sustainable transportation systems and low carbon mobility systems.

2 Literature review

The purpose of this chapter is to elaborate the concept of low carbon mobility systems, the Avoid-Shift-Improve framework of analyzing the system and the justification for why this model is the most appropriate for analysis.

2.1 Sustainable transport

Being one of the basic necessities of today that provides access to economic and social opportunities to urban dwellers and contributes to economic growth and the uptake of a modern lifestyle, urban mobility forms one of the critical aspects of the urban environment that needs to become more sustainable in order to continue to provide these benefits while keeping the negative environmental consequences at a minimum (Thynell, Mohan, & Tiwari, 2010; Richardson, 2005).

World Business Council for Sustainable Development defines sustainable mobility as 'the ability to meet society's need to move freely, gain access, communicate, trade and establish relationships without sacrificing other essential human or ecological values, today or in the future'. The European Commission identifies the need for smart, inclusive, and sustainable growth highlighted by the importance of a modernised and sustainable European transport system for the future development of the Union and stresses the need to address the urban dimension of transport. Within the same communication, the European Commission recognises that 'Sustainable Urban Mobility Plans' are about fostering a balanced development and a better integration of the different urban mobility modes. It therefore emphasises citizen and stakeholder engagement, as well as fostering changes in mobility behaviour (European Commission, 2013).

Litman and Burwell in their research in 2006 explained how the concept of sustainable transportation is embedded in the core goal sustainable development. They emphasized this through their finding of 'sustainability tends to support transportation planning and market reforms that result in more diverse and economically efficient transportation systems, and more compact land use patterns that reduce automobile dependency. These reforms help increase economic efficiency, reduce resource consumption and harmful environmental impacts, and improve mobility for non-drivers'.Litman and Burwell thus re-emphasize the need for integration in creating a sustainable transport network. Zimmerman and Fang in their research in 2015 emphasized the importance and benefits of public transport networks as perfect examples of integration with economic systems.

One of the most comprehensive frameworks to understand urban mobility systems has been given by The institute for transport and development policy where urban mobility systems are characterized as non-motorized modes of transport like walking and using bicycles and motorized means, further classified into private light motor vehicles, heavy motor vehicles for passenger and goods transport and public transport systems with heavy motor vehicles and mass transit systems. The institute for transport and development policy in their report on *'A paradigm shift towards sustainable low carbon transport'* in 2010, state that the key characteristics that define the sustainability of an urban mobility system are

a. Transport volume
b. Transport modes
c. Transportation technologies
d. Transport pricing
e. Resilience to climate change

2.2 Aspects of sustainable mobility and the need for an integrated approach

Zimmerman and Fang explore the concept of constructing transport hubs that addresses the issue of last mile connectivity. Such connectivity has been explained in a basic way by WRI Ross Centre for Sustainable Cities as 'connecting people from their homes to transport hubs'. Hence, an integrated public transport system includes having to walk less than a mile to the nearest mode of public transport which might include a taxi, three-wheeler, bus, BRTS, tram, or train, a hub.

Considering these frameworks for addressing urban sustainable mobility and the importance of an integrated approach in addressing urban mobility systems, the World Business Council for Sustainable Development in their report detail 19 main aspects that decision makers need to consider. These are as follows,

- Affordability of public transport for the poorest group
- Accessibility for mobility-impaired groups
- Air polluting emissions
- Noise hindrance
- Fatalities
- Access to mobility services
- Quality of public area
- Urban functional diversity
- Commuting travel time
- Economic opportunity
- Net public finance
- Mobility space usage
- Emissions of greenhouse gases
- Congestion and delays
- Energy efficiency
- Opportunity for active mobility
- Intermodal integration
- Comfort and pleasure
- Security

Barbra Richardson in her research proposed a framework for the analysis of passenger and freight transportation systems separately. She identified safety, congestion, fuel consumption, vehicle emission and access as her main indicators for sustainability and analysed the model to identify interdependencies with other indicators. Figure 2 represents the interrelations she identified within the passenger travel system.

She and address the different aspects that influence these, while being aware of the fact that a change in these influencers could affect other associated indicator systems as well. By this states that to change any of the major indicators in the positive direction, it is important to identify what Richardson emphasises the importance of integration and the adoption of a systems approach in addressing urban sustainable mobility.

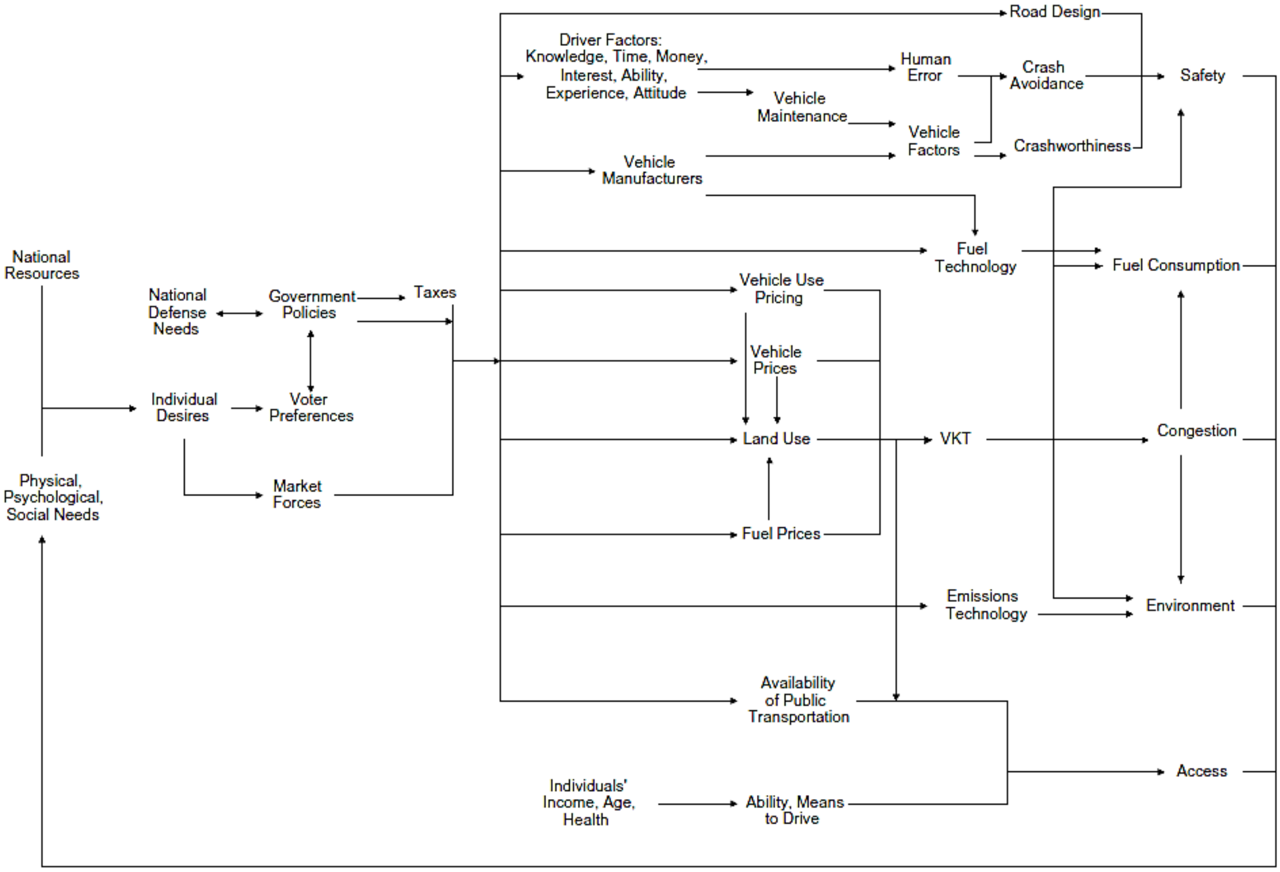


Figure 2 Factors influencing sustainability of passenger transport systems (Richardson, 2005)

2.3 Low Carbon Mobility Systems

The mobility sector plays a huge role in the adding to the impacts of climate change. Over 24% of the world's GHG emission comes from the transport sector, with over 75% of these originating from road transport (IEA, 2012). Emissions from the mobility sector are constantly on the rise and will continue to be so due to the high requirement of movement of people, goods and services. This is especially true in the global south where the rate of increase in population is directly proportional to the rate of increase in transport demand and the corresponding GHG emissions (IEA, 2013). Despite the devastating impacts this sector has on the environment and society, it has been extremely difficult to set forth measures to directly transition to a low carbon mobility system. This is mainly due to the need for mobility coupled with the high cost of high-density energy carriers like hydrogen fuel cells and electric batteries or the use of biofuels which have ambiguous environmental impact (Schafer, 2012; Kahn Ribeiro, et al., 2013).

In order to solve the issues related to emissions from the transport sector it is important to deconstruct these. Waisman et.al. state that the four main determinants of emissions from the transport sector are the volume of mobility, the modal structure, the carbon intensity of the fuel used and the energy intensity of the mode. Waisman et.al. in their study titled *The transportation* *sector and low-carbon growth pathways,* classified the first two determinants as “Behavioural” and the last two as “Technology” bas ed on work done by Chapman in 2007 and Schafer in 2012.

Additionally, He et al. in 2011, developed the following equation to calculate the GHG emissions of the transportation sector based on the framework proposed by Wright and Fulton in 2005. (He, Meng, Wang, & He, 2011; UNEP, 2015)

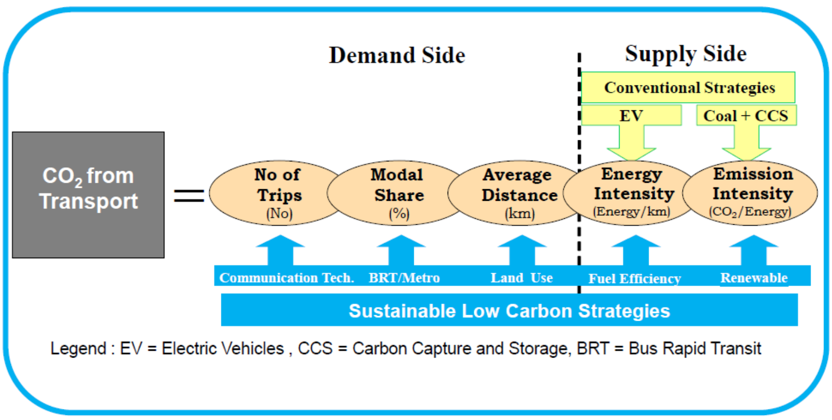
Total CO2 emission gm/capita/day	=	ΣMax shift in modal share (%) x Total number of trips/capita/day in mode x Avg travel distance	Demand control parameters
		x Fuel economy x Carbon emission intensity	Supply control parameters

On the same lines as the categorization made by Wiseman et.al., the UNEP has categorized the variables that directly impact GHG emissions into transport demand control parameters and transport supply control parameters as seen in the above equation. This classification can be used to identify and design the mitigation strategies to combat the increasing GHG emissions from the transport sector (UNEP, 2015).

To understand the transition to a low carbon mobility system better, it is important to state the main objectives of this transition. Nakamyra and Hayashu in 2013, described the main objectives of the low carbon mobility system as follows.

1. Reduced need to travel
2. Reduce car usage
3. Improve alternative modes
4. Improve road network for improved modes
5. Improve vehicles and fuels

The UNEP report titled *Promoting Low Carbon Mobility in India* identifies the following strategies targeted at specific variables from the above equation, as shown below.



Strategies For Reducing Emissions From Transport

2.4 The Avoid-Shift-Improve framework

The institute for transport and development policy through their research on financing options and funding strategies for sustainable transport, they emphasize the ASI- Avoid, Shift and Improve, approach as developed by Dalkmann and Brannigan in 2007 as their basis for the paradigm shift to low carbon mobility systems. The framework, first promoted by the UNEP and GIZ has been accepted world over by academics and policy advocates and is referred to in discussions pertaining to the transition to a low carbon mobility system in countries all over the world especially, India, China, Brazil and now even in the EU. The annual TERM report released by the European Environmental Agency proposes the ASI approach for the decaarbonization of the mobility system. The three strategies of the framework are defined as follows.

- Avoid: Avoiding travel or the use of motorized modes Ex: By the integration of land use in mobility planning, cities or neighbourhoods in cities can become more self-sufficient with the placement of basic necessities such as schools, shopping complexes, work places etc. in closer quarters to each other in order to primarily avoid the use of private motorized modes of transport.
- Shift: Shifting to more environmentally friendly modes of transport such as public transport for the unavoidable trips to be made or the promotion of multi modal journeys and thus the modal shift from the fossil fuel consuming private motor vehicles that dominate urban transportation practices today
- Improve technological aspects of the private motorized modes of transport for better fuel efficiency, cleaner energy use etc.

The ASI framework approaches GHG emissions reduction by avoiding/reducing demand for car travel, shifting travel to more efficient travel modes, and improving energy efficiency of travel encompass a large range of possible cost-effective mitigation options for the transport sector. The best choice of options varies by technologies, geography, natural resources, policy framework and myriad other factors. The local economy, geography, population, and culture all influence the feasibility and effectiveness of each option. Policies and measures must be tailored to local conditions by carefully assessing the existing situation and consulting with relevant stakeholders (GEF, 2013).

It is also important to support new measures with appropriate legal frameworks, training, capacity building, and public awareness campaigns. In addition to reducing GHG emissions, these changes will bring about other benefits, including reduction of local air pollutants, mitigation of traffic congestion, and improved access to affordable and efficient transport modes (GEF, 2013). Additionally, the following cobenefits have been observed as a result of implementing measures to reduce GHG emissions from the transport sector.

1. Increased energy security due to the decreased dependence on fossil fuels, thus avoiding resource conflicts and fuel price shocks
2. Reduced land demand as measures focus on semi-dense, mixed land use patterns that help control urban sprawl
3. Improves competitiveness and attractiveness of cities attracting increased business investment along with highly qualified workers and employees
4. Access to emission certificates and carbon related funding schemes that can be used to further improve the mobility system

These co-benefits are attractive to local policymakers, practitioners, and other stakeholders. Local air pollutants and GHGs have a common source in motorized traffic, which may also create congestion, noise and accidents. By addressing these issues simultaneously through climate change mitigation efforts, the development and climate agendas can be integrated, potentially offering large cost reductions, as well as reductions of health and ecosystem risks.6 Actions taken to reduce GHG emissions from transport can also generate co-benefits for economic development and energy security (GEF, 2013).
These measures have been mainly categorized under the following categories, and represented in the form of the CUTE matrix in order to understand the different areas where mitigation measures can be developed (Hayashi & Nakamura, 2013).

Policy/technology options (CUTE Matrix)

Strategies / Means	AVOID	SHIFT	IMPROVE
Technologies	• Transport oriented development (TOD) • Poly-centric development • Efficient freight distribution	• Railways and BRT development • Interchange improvement among railway, BRT, bus and para-transit modes • Facilities for personal mobility and pedestrians	• Development of electric vehicles • Development of biomass fuel • "Smart grid" development
Regulations	• Land-use control	• Separation of bus/para-transit trunk and feeder routes • Local circulating service • Control on driving and parking	• Emissions standards • "Top-runner" approach
Information	• Telecommuting • Online shopping • Lifestyle change	• ITS public transport operation	• "Eco-driving" • ITS traffic-flow management • Vehicle performance labeling
Economy	• Subsidies and taxation to location	• Park & ride • Cooperative fare systems among modes	• Fuel tax/carbon tax • Subsidies and taxation to low-emissions vehicles

2.5 Factors affecting urban passenger transport patterns

Urban transportation patterns are governed by certain key attributes that govern the transport demand of the city. These are mainly urban form, quality of infrastructure and service provision and finally socio-economic factors. It is important to note here that these factors should not be considered in isolation and although the interaction between them may not be quantified, they must be recognized and considered during the decision making process (Dratva, et al., 2010).

2.5.1 Urban form

Urban mobility demand is generally known to be relatively lower in higher density areas. This was first proposed in 1989 by Newman and Kenworthy in their research on the impact of increased urban density on transport fuel consumption. This finding has been further corroborated by Karathodorou et al. in 2010. The study suggested that the reduction in travel demand is mainly linked to reduced travel distances, increased trips by walk and bike, thus impacting the amount of fuel used for transport. Additional to reduced fuel consumption, the study also highlights the viability of using public transport more frequently due to reduced travel time.

It has been identified that metropolitan areas have higher car usage than central city areas. This is mainly due to higher travel distances and the infeasibility of increased public transport infrastructure and service provision. Within the main city, the use of sustainable mobility modes has been recorded to be around 60% in European cities, ranging up to 86.1% in Barcelona and 87.2% in Paris in 2009 (EMTA, 2012, 2012a).

2.5.2 Quality of transport infrastructure and service

The quality of infrastructure and service provision has had a huge impact on the modal choice of inhabitants. Targeted infrastructure and perception improvement measures promoting non-motorized modes adopted by cities has shown to have a direct correlation with an increase modal share (EEA, 2013).

It has been established that cultural practices of modal preferences are not embedded in populations. A good example of targeted biking policies resulting in the direct increase in the modal share of biking and walking trips are in Copenhagen with 42% and Amsterdam 68%. Specific policies coupled with strong political will play a key role in implementing these policies and ensuring investments in infrastructure development (EEA, 2013).

The EU project Bypad-Bicycle Policy audit for cities with the lowest levels of bicycle usage has shown that although promotional campaigns for the use of non-motorized modes has an impact in driving the use of these modes, and are the cheapest measures to do so, investment to improve biking safety has a greater impact on improving the modal share of biking trips (EEA, 2013).

Santos et al. in 2013 also established that improvements in infrastructure development helps address barriers related to perception of safety with regards to a specific mode. The provision of high quality biking, walking infrastructure or increased public transport infrastructure, promoted a greater uptake of the mode. Length of the journey and travel time also play a keen role in defining the modal split of a city. It is important to identify the purpose of travel in order to identify targeted mobility strategies to improve modal choices made. The European Platform on Mobility management has identified, that the most common journeys mad in urban areas are for It has been established by Banister in 2008 that almost 25% of the journeys made in metropolitan regions are for work, education and business trips. Also, the EC has identified that commuting times are the longest in European capital cities. There is a higher potential for commuters to transition to the use of personalized motorized mobility modes in these cities due to the perceived increase in travel times (EPOMM TEMS, 2016).

Targeted improvements in public transport measures have thus been put in place in these cities to ensure a higher uptake of more sustainable modes. Despite these, it has been recorded that cities such as Stockholm, Rotterdam, Prague, Warsaw, Bucharest, Budapest and London record an average travel time for journeys to work and school of over 30 minutes. Banister explains the reason behind this to be the increased urban sprawl and stresses that although the travel time may have remained the same, travelling speeds have increased considerably. Additionally, the TERM report 2013, suggests that increased provision of high speed public transport networks could be the cause of increased urban sprawl thus resulting in increased travel distances.

It is thus important to consider city and population characteristics before delivering mobility solutions in order to have the desired results that do not have contradictory effects on the mobility system (EEA, 2013).

2.5.3 Socio-economic factors

To a great extent, it has been found that socio-economic factors impact travel demand and travel behavior and GDP has been identified as a defining factor. Cost associated with mobility include vehicle acquisition cost, cost of public transport, fuel price, quality of public transport, cost of parking and time cost of travel (EEA, 2013). It has been found that with the increase in GDP, travel demand as well as personal vehicle ownership has seen an increasing trend. Additionally, car owners have been found to underestimate the true cost of their journeys in terms of cost of maintenance, fuel cost and time lost while in traffic due to which private modes have been given preference (Santos et al, 2013).

Despite this, research has shown that there are certain cities such as Hamburg and Helsinki that have shown a decreasing trend or reduction in the rare of increase of the use of private vehicles. Some of the main reasons that have been identified for these are the high cost of vehicle ownership, including vehicle and annual road tax, lowering status of the passenger car, efficiency of the public transport system and increased ease of multi-modal travel (Tsamboulas, 2001).

Regulatory mechanisms such as car free zones, increased price of parking, reduction in street parking and environmental taxes/congestion charging have found to have great impact on reducing the use of private vehicles and increase acceptance and usage of public transport and non-motorized means such as biking and walking (ITDP, 2011).

2.6 Factors influencing indicators for urban sustainability

Urban sustainability plans, and indicators for the same, vary according to the needs and goals of the city (Brandon & Lombardi, 2005; Verbruggen & Kuik, 1991). Shen et. al in 2001 were able to identify some important aspects that need to be considered while setting up indicators and indicator systems for cities. Some of these are listed as follows. These were based on their analysis of 9 sustainability plans in cities around the world that they were able to compare with the International Urban Sustainability Indicator List. Some of these factors include

1. Presence of a long or short term city development plan and priorities there in (Environmental vs economic)
2. Commitment and availability of resources for monitoring and transparent communication through reporting
3. Presence of a local body that is commited and willing to take ownership over achieveing the sustainability goals.
4. Presence of urbanizations studies/research projects and subsequent advocacy
5. Top down or bottom up push for change (Government enforced or citizen initiated)
6. Status, perception and awards the city reveived
7. Existing infrastructure and practices (Cultural aspects and practices that have been in place over time) related to urban environment and development
8. Indicator selection needs to be based on the needs of the city and the exact area/theme/sector of application

Although not exhaustive, this list shows us the difficulty in arriving at an all encompassing common indicator system for cities around the world. It is thus important to identify how best to being about universality of these indicator systems to ensure comparability of results and implementation of pathways adoopted for best practices identified.

3 Methodology

The research questions proposed in Chapter 1, guides the methodology adopted for this thesis. Based on these, five main tasks have been identified in order to take this analysis to completion.

1. Identify the main measures/actions that correspond to the Avoid-Shift-Improve framework
2. Identify specific measurable indicators corresponding to the measures identified
3. Develop the low carbon mobility index based on the ASI framework
4. Collect data corresponding to the indicators identified and calculate the low carbon mobility score for the selected cities.
5. Test the model developed by
    a. Analysing the relationship of the scores produced with the progress towards meeting the objective, transport GHG emission reduction, based on the transport GHG emission trends observed in the three cities
    b. Using the scores to explain the priorities of the cities based on the measures currently adopted by the cities
    c. Identifying the required rate of reduction in GHG emissions and possible areas of improvement in terms of measures adopted in order to reach the target emission reduction

3.1 Data collection

There are two main methods of data collection that have been used in this study- Literature review and interviews.

3.1.1 Literature Review

An in-depth literature of academic articles, books, governmental documents and consultancy reports has been conducted in order to inform all the above mentioned tasks, mainly the identification of measures and corresponding indicators based on the ASI framework, the methodology for the construction of the index and the collection of city specific mobility data, currently adopted measures, targets and future plans. Additionally, municipal and national level statistics presented in governmental websites have also been referred to for the purpose of city data collection, used to test the developed model.

3.1.2 Interviews

Semi-structured interviews were conducted with transport planners and strategists (Table 1) from the three cities selected in order to gather more information regarding the different measures implemented within the mobility system, the barriers faced during the implementation of the same and the decision making process on mobility measures in their respective cities.

Table 1 List of officials interviewed on the low carbon mobility systems in Stockholm, Copenhagen and Oslo

Interviewee	Position	Date
Daniel firth	Transport Strategist, Stockholm Stad	7th April 2016
Pernille Aga	Project Manager, Ruter As, Public transport in Oslo and Akershus	15th April 2016
Guri Tajet	Project oil-free and energy-efficient buildings, Climate and Energy Program, City of Oslo	18th April 2016
Helge Jenson	Chief engineer/Planning Division, Agency for Urban Environment, City of Oslo	18th April 2016
Thor Haatveit	Directorate General, Public transport and railways department, Ministry of Transport and Communications	19th April 2016
Eva Sunnerstedt	Clean Vehicles in Stockholm, Stockholm stad	3rd May 2016
Ulrik Djupdræt	Transport planner, City of Copenhagen	12th May 2016

The following interview guide was used for the interviews with all officials. These however were shortened for specific interviewees such as authorities working solely with the planning and promotion of non-motorized modes, public transport companies and officials from the Ministry of transport.

- Main actors and the stakeholders involved in sustainable transport planning and implementation in the city.
- Organizational structure of the department of transport in the municipality and information on how strategies are planned and decisions are made.
- Awareness regarding the Avoid-Shift-Improve framework
- The current priorities of the sustainable urban mobility plan of the city, how this plan was developed.
- Challenges faced by the municipality while trying to implement these actions and how these are countered.
- The relationship between different levels of government, i.e, autonomy the municipality has in terms of decision making with respect to national level regulations.
- Main mobility measures implemented in order to reduce GHG emissions from the transport sector.
- Measures in collaboration with other departments in the municipality. How these planned, implemented and disputes reconciled
- How the municipality monitor's progress towards targets and goals set

3.2 Developing the LCM Index

The following steps describe the method adopted for the construction of the Low Carbon Mobility Index. The OECD guifeline for the development of composite indicators has been used to guide the process of the index development (OECD, 2008).

3.2.1 Selection of indicators and parameter

In order to select performance indicators for transport emission mitigation measures, it is first important to identify these measures. Based on a literature review of all possible measures that contribute to the reduction of transport related GHG and corresponding comparison of objective of the measures, these have been categorized under the three strategies of the ASI framework and are as listed below.

Avoid

1. Biking infrastructure development
    a. Increasing bicycle parking facilities
    b. Increasing the length of bicycle paths
    c. Implementation of dedicated biking lanes
    d. Traffic signals for bikers
2. Concentrated urban development
    a. Compact Development policies
3. Sectoral collaborations
    a. Promotion of use of telecommunications for meetings
4. Walkability infrastructure development
    a. Increasing sidewalk length
    b. Separation of walking area from vehicular traffic

Shift

1. Concentrated urban development
    a. Transit corridor development
    b. Compact development policies around main transport nodes
2. Mobility information systems
    a. ICTs for live traffic information
    b. ICTs for integration of multi modal mobility network
3. Public transport infrastructure development
    a. Increasing public transport capacity-increasing public transport frequency
    b. Increasing public transport capacity-increasing public transport lines/fleet size
    c. Integration with motorized modes-Presence of park and ride facilities
    d. Integration with non-motorized modes-Presence of bicycle carriers in public transport vehicles
    e. Integration with non-motorized modes-Presence of bicycle parking stations near public transport vehicles
4. Road infrastructure development
    a. Road infrastructure development
    b. Tunnel road network to meet demand in compact cities
5. Sectoral collaborations
    a. Working with companies and schools to plan and implement mobility of employees
6. Traffic demand control
    a. Fossil Fuel price control
    b. Parking capacity control
    c. Parking control through pricing
    d. Tax on fossil fuels

   e. Traffic Control through congestion/environmental fee
   f. Traffic Control through road tax
   g. Traffic Control through vehicle registration tax

Improve

1. Financial incentives for LEVs
   a. Exemption of LEVs from congestion/environmental tax
   b. Exemption of LEVs from parking charges
   c. Exemption of LEVs from Road tax
   d. Exemption of LEVs from vehicle registration tax
   e. Financial incentives for shared mobility modes
2. Subsidies for alternative fuel
   a. Fuel Efficiency control
   b. Fuel Economy standards
   c. Fuel quality restrictions
   d. New motorized mobility services
   e. New non-motorized mobility services
   f. Vehicle emission standards
3. LEV infrastructure development
   a. Access to alternative fuels at fossil fuel stations
   b. Alternative fuel company collaboration-market attraction
   c. Charging station installation
   d. LEV company collaborations-market attraction
   e. Transition to LEV municipal fleet-create demand
4. Sectoral collaborations
   a. Working with companies to procure LEVs for company vehicle fleet
5. Zoning
   a. Low Emission zones

Based on the identified measures that contribute to the development of a low carbon mobility system a comprehensive indicator system has been developed. As mentioned earlier, the Avoid-Shift-Improve framework has been used to guide the process of indicator selection. The indicators used in this system have been identified is based on an extensive literature review of indicators for sustainable transport such as those used under the EU Transport and Environment Mechanism (TERM core set of indicators), World business council for sustainable mobility, CIVITAS, Lund University Department of Technology and Society and Victoria Transport Policy Institute (VTPI) and the main aspects of a low carbon mobility system described by the EU in the TERM report, GIZ and the Institute for Transportation and Development Policy.

An initial set of 150 parameters were identifies corresponding to over 70 measures. These parameters were then evaluated based on the following criteria, resulting in 43 selected parateters as listed in Tables 2, 3 & 4. The criteria given by Hermans et.al. in 2008 in their study on Developing a theoretical framework for Road Safety Performance Indicators and a Methodology for creating a Performance Index, has been used. Only indicators that meet the following criteria have been selected for use to construct the low carbon mobility index.

1. Relevant/Valid: Can the indicator be associated with the larger objective of the model? Is it action oriented and suitable for establishing a performance target?
2. Measurable: Is the indicator measurable?
3. Understandable: Is the indicator clearly defined to meet the greater objective of the model?
4. Available data: Is the data for the indicator easily available? Will the data be available over a desired time span? Can it be updated on a regular basis?
5. Reliable: has the data been collected using a scientific method? Is the source for the data reliable?
6. Coherent/comparable: Is the indicator comparable across locations and is it coherent in time?
7. Specific: Does the indicator focus on a specific level and is it detailed enough?
8. Sensitive: is the indicator capable of reflecting changes in the index over time?

The main objective of the model is to evaluate the performance of the measures adopted by the city to transition to a low carbon mobility system. Specific performance indicators and proxy indicators have been identified based on the measures identified under the Avoid, Shift and Improve strategies, where the scores for the three strategies are composite indicators. The description of the strategy indicator informing the indicator selection is as follows.

Table 2 Definition, Indicators and parameters corresponding to the Avoid Strategy

Performance indicators that aid the avoidance of travel all together and/or the use of motorized means of transport	
Indicator	Parameter
Compaction	Compact Development-density of population
	Public transport proximity
Uptake	Modal share of journeys by walk
	Modal share of Journeys by bike
Infrastructure	Length of bicycle paths
	Integration with non-motorized modes-allowance of bicycles on public transport busses
	Integration with non-motorized modes-allowance of bicycles on public transport metros and light rail
	Integration with non-motorized modes-Presence of bicycle carriers in public transport vehicles
	Integration with non-motorized modes-Presence of bicycle parking stations near public transport stations
	Financial incentives in the form of loans or subsidies for purchasing regular/electric bicycles
	Restricted motorized vehicle use in commercial zones/Pedestrian streets/Car free zones/auto free zone

Table 3 Definition, Indicators and parameters corresponding to the Shift Strategy

Performance indicators that aid the transition to the use of more efficient shared modes of transport rather than the use of motorized modes of private transport	
Indicator	Parameter
Access Restriction	Low Emission zones
	Bus only lanes
Mobility information	ICTs for live traffic information
	ICTs for multi modal mobility network
Public transport uptake	Modal share of journeys by public transport
Public transport infrastructure development	Increasing public transport capacity-increasing public transport lines/fleet size
	Integration with motorized modes-Presence of park and ride facilities
	Integration with non-motorized modes-allowance of bicycles on public transport busses
	Integration with non-motorized modes-allowance of bicycles on public transport metros and light rail
	Integration with non-motorized modes-Presence of bicycle carriers in public transport vehicles
	Integration with non-motorized modes-Presence of bicycle parking stations near public transport stations
	Mass rapid transport system
	Proximity
	Connecting major commercial, residential and employment hubs
Traffic demand control	Fossil Fuel price control
	Tax on fossil fuels
	Traffic Control through congestion/environmental fee
	Traffic Control through Annual Road tax/Circulation fee
	Traffic Control through vehicle registration tax
	Parking control through pricing
	Parking capacity control
	Parking control-off street / non-sidewalk parking
	Traffic Control through VAT

Table 4 Definition, Indicators and parameters corresponding to the Improve Strategy

Indicators of measures that aid the transition to more energy efficient vehicles and fuels for transport	
Indicator	Parameter
Access Management	Exemption of LEVs on bus lanes
Financial incentives for LEVs	Exemption of LEVs from congestion/environmental tax
	Exemption of LEVs from parking charges
	Exemption of LEVs from Annual Road tax/Circulation fee
	Exemption of LEVs from vehicle registration tax
	Incentives for shared mobility modes-lower cost of tolls/tax/exempted from driving in the bus lane
	Subsidies for alternative fuel
	Financial incentives in the form of loans or subsidies for purchasing regular/electric bicycles
	Exemption of LEVs from VAT
Fuel Efficiency control	Fuel Economy standards
	Fuel quality restrictions
	Vehicle emission standards
	New motorized mobility services-ride shares, carpools etc..
	New non-motorized mobility services-bike shares/rentals
LEV infrastructure development	Charging station installation
	Transition to LEV municipal fleet-create demand
	Access to alternative fuels at fuel stations
	Alternative fuel company collaboration-market attraction
	LEV company collaborations-market attraction

3.2.2 Missing Values and Normalization

Before normalizing, the parameters are screened for missing values. Only two parameters were identified where missing values existed-Exemption of LEVs from Vehicle registration tax and Exemption of LEVs from congestion/environmental tax for the cities of Stockholm and Copenhagen respectively, where both these indicators were not applicable due to the absence of the taxes altogether. Since the absence of such financial mechanisms have been scored negatively, a similar negative score has been assigned to the missing values.

The standardization method or the Z-Score method has been selected for normalization. This is due to the lack of benchmarking values for the indicators in the system. Data for each parameter has been gathered from municipality and national data portals and based on interviews conducted with municipality personnel responsible for strategic planning and execution of transport measures in each city. Each parameter has been standardized on to the same scale with a mean of 0 and a standard deviation of 1 based on the mean and the standard deviation of the existing data set using the following formula (OECD, 2008).

$$\text{Z score} = \frac{(\text{X} - \text{Mean})}{\text{Standard Deviation}}$$

3.2.3 Weighting

Indicators are usually combined to form an index by weighting each indicator differently based on the impact each indicator has on the original objective (Hermans et. al. 2008). Weighting of indicators may be based on statistical quality of the data like factor analysis (FA) and Principal Component Analysis (PCA) or based on participatory techniques such as Budget Allocation

Process or Analytical Hierarchical Process. However, indicators may also be equally weighted based on the availability of information defining the relative importance of each parameter in meeting the ultimate goal of transport GHG emission reduction. This method results in lowest level of disagreement among large variance in individuals' weightings (Hagerty & Land , 2007).

Thus, due to the lack of clarity regarding the direct impact of each parameter on the Low Carbon Mobility index calculated, the method of equal weighting has been selected.

3.2.4 Aggregation

In order to maintain equal weights for all parameters, the formula used for calculating the scores is as follows,

$$LCM\ Index_x = \sum P_{x,q} / \mathrm{Q}$$

Where,

x-is the City under consideration
q-is the parameter number which ranges from 1 to 43
Q- is the total number of parameters in the entire model

The strategy indicator scores (Avoid score, Shift score and Improve score) have also been calculated using the same formula keeping the denominator as Q.

4 Testing the model: Results from three Scandinavian Cities

Known for their increasing efforts in the area of sustainable urban development, the cities in Scandinavia have over the years, built in sustainability effort into all realms of urban environment. Transport being one of the major causes of environmental concern in cities, has been considered one of the top priorities for Scandinavian cities. The main objectives of efforts to ensure and improve sustainable mobility in Scandinavian cities are as follows (Nordic Council of Ministers, 2012),

Environmental objective

- ensure reduction of GHG emissions from the sector
- increase the importance of green spaces, helping preserve biodiversity

Society

- improve access to key services and amenities
- improve wellbeing of citizens

Economy

- reduce time cost of travel
- maintenance cost of road networks

It is important to note that the objectives described directly relate to the main objectives of a low carbon mobility system. Over the years, these cities have made concentrated efforts to incentivize non-motorized modes, of travel such as biking and walking, and public transport by incorporating concepts of urban planning and land use management into transport planning (Nordic Council of Ministers, 2012). It has also been identified that Scandinavian cities have several political and institutional similarities both at the local and national level for decision making. They also have certain differences in terms of the relationship within this organizational structure which help aid the development of more refined policy recommendations and foster fruitful knowledge transfer between these cities (Hrelja, et al., 2013).

Due to the maturity and experience in the efforts to minimize emissions from the transport sector and the stark similarity of their objectives with those of low carbon mobility system, it would be extremely useful to consider three Scandinavian cities- Stockholm, Copenhagen and Oslo, well known for their mobility improvement efforts and with significant freedom to influence the budget allocated to mobility measures, to test the developed low carbon mobility indicator system.

In order to test the model developed on the three cities, data regarding the different mobility measures and their performance has been gathered through a literature review of the city mobility strategies, city plans and online open source data provided by the municipalities. Additionally, interviews with transport professionals have been conducted in the cities to understand the historical perspective of the development of the current mobility system.

4.1 Stockholm

Being the capital of Sweden, Stockholm is home to a population of over 900,000 inhabitants, which is around 22% that of that whole country. Located at the central eastern coast of Sweden, Stockholm has a very unique geography. The city is cut across by the Lake Mälaren, Sweden's third largest lake. The city is also fragmented into 14 different islands that are continuous with Stockholm's archipelago. The demographics of the city are built up by a majority of residents that work in the service sector accounting for over 85% of the total jobs in Stockholm. As Sweden's financial center, Stockholm is host a number of multinational high technology industries, banks, insurance companies etc.. The city also accounts for about 29% of the country's GDP. The entire municipal area of Stockholm is made up of 26 municipalities, with a population of 2.2 million inhabitants, making it the most populous city in the Nordic region.

Decisions on urban mobility strategies and planning in the city of Stockholm are governed by the City council, the City executive board and the Transport division and the Vice Mayor of the Transport Division.

The City Council of Stockholm convenes weekly in meeting that are open to the public and is responsible for decision-making and setting goals that act as a guideline for all activities of the municipality and all other operators. Goals and targets set by the Council are informed by national level targets and measures implemented are in line with the policy packages offered by the national government. As members of the City Council are unable to study specific details of a particular matter, this responsibility is transferred to the City Executive Board. The Executive Boards of Stockholm, headed by the Mayor and Vice Mayor heading the transport division, receives all the facts with regards to the decisions to be made by the council. The proposals are reviewed by the Executive boards before being passed at the City Council level. The Executive board also has the responsibility of ensuring successful implementation, follow up and evaluation of specific mobility measures selected to meet the goals set. The specific measures implemented by the transport division of the municipality are based on these goals set by the council. The transport division of the municipality reports to the Executive board and is responsible for implement executive decisions made by the Board (Stockholm Stad, 2012).

4.1.1 Mobility in Stockholm: Measures, Targets and Indexing results

Stockholm has been considered as one of the cleanest capitals in the world and has been awarded the European Green Capital Award in 2010. The city prioritizes environmental improvement in its functioning and is known for its administrative system that has integrated sustainability into the planning, budget allocation, reporting and monitoring processes. The city's most current plan, *The Walkable City*, defines the target of the city to be fossil fuel free by 2050. (Stockholm Stad, 2012; Stockholm Stad, 2012 a)

The mobility sector in Stockholm is responsible for over 40% of the total GHG emissions in the city. Figure 3 shows the transport GHG emission trend in Stockholm.

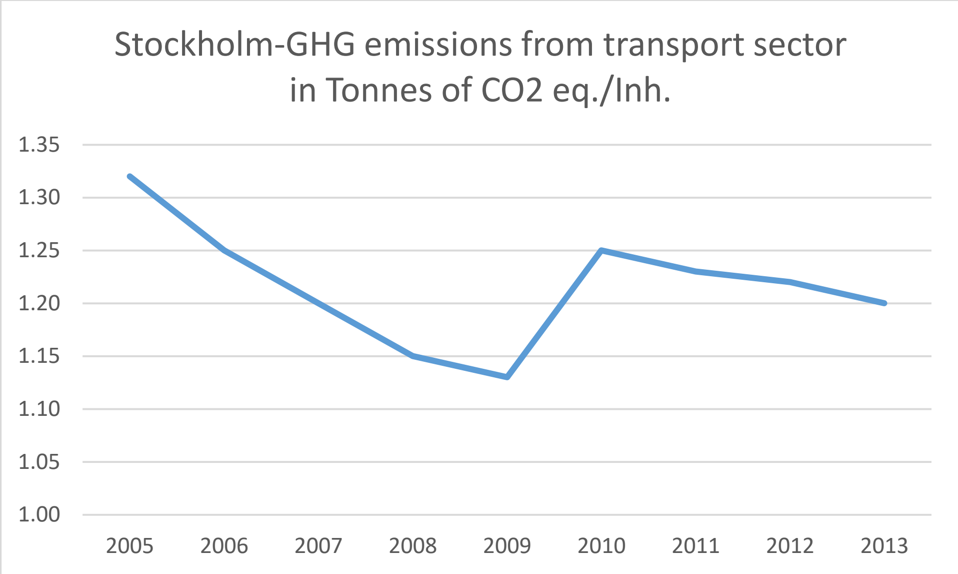


Figure 3 Stockholm-GHG emissions from transport sector in Tones of CO2 eq./Inh.

One of the main challenges of thee mobility sector in Stockholm has been recognized as congestion due to an increased number of passenger cars. The city over the last four to five decades has been prioritizing measures to tackle traffic congestion and promote transit oriented development. Alongside the development of public transport infrastructure and the road network, Stockholm has also adopted certain urban development policies that promote the setup of municipal services around larger transit stations to promote mixed land use development.

Measures on sustainable transport in Stockholm are guided by the urban mobility strategy released in 2012. The goals of the strategy have been set based on mobility priorities at that time and environmental aspects have deliberately not been focused on as the main issues at the time were to combat congestion. The plan has four main priorities,

1. Capacity building: Increasing capacities to meet growth and Traffic demand, allocating more space to modes that take least space
2. Reliability: Promoting mobility that is not necessarily faster but a more integrated and well informed system with ICTS to better inform passengers on how long the journeys are going to take
3. Attractiveness: Improving the attractiveness of the cities mobility modes and not just focus on road transport.
4. Sustainability: Identifying negative impacts and safety issues of the transport systems in the city and decision making on how to reduce them

Considering that the main focus for the development of the mobility system in the city has been directed towards public transport and road development, the city has recently adopted measures to improve the walkability and bikeability. These include improved infrastructure for pedestrians in the form of sidewalks and safety measures to separate pedestrian paths from direct contact with road traffic as well as traffic signals for bikers and pedestrians. Specifically, to promote biking, the city has recently adopted measures to improve biking infrastructure in the city with biking lanes, improved the shared bicycle market, laid out specific bicycle plans for winter months and improved bicycle parking facilities. The city targets an increase of the modal share of biking to 15% by 2030 and 100% increase in the number of cyclists by 2030 compared to 2012 levels.

In addition to public transport and non-motorized modes of transport, the city also runs the Stockholm Clean Vehicle Program that aims at improving access to cleaner fuel access to citizens. The municipality has collaborated with Low Emission Vehicle providers and fuel companies and procured LEVs for the municipal fleet in order to create demand to attract the companies to the city. Additionally, the city also offers multiple financial incentives for citizens using LEVs in the city such as exemptions from the congestion tax, parking fees and annual circulation fees. One of the targets for the city is to ensure that 100% of new car sales as of 202 in the city are LEVs. Overall, the city targets a 30% reduction in road traffic emission by 2030.

The model generated for the performance of the above mentioned low carbon mobility measures in the city, has been populated with municipality data from the urban mobility strategies, the city plan as well as municipality open source data (Appendix II). In line with the priorities of the city, the model has generated results as seen in Figure 4. It can be seen from the figure that Stockholm has received the highest score for the Shift strategy and lowest score for the avoid strategy.

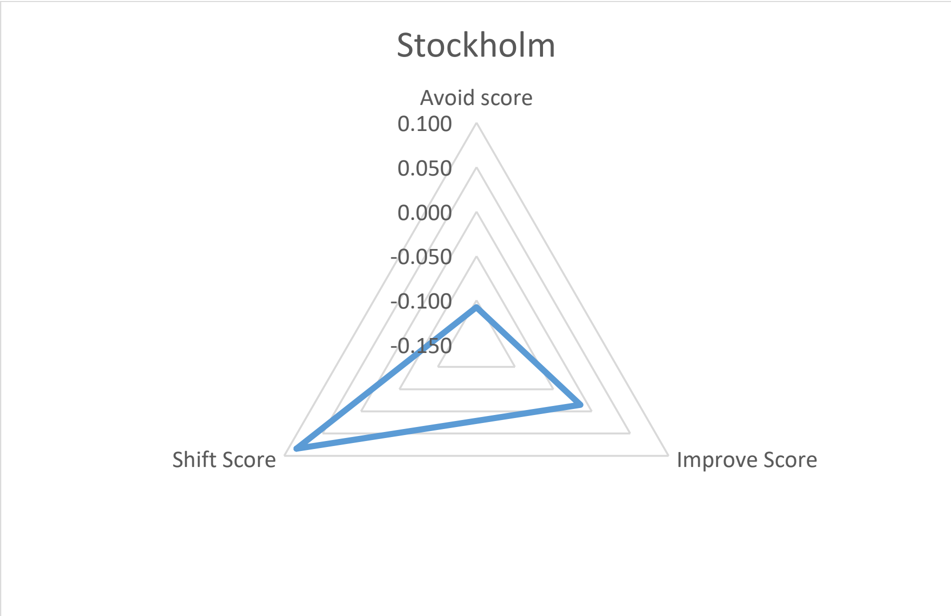


Figure 4 Stockholm Low Carbon Mobility index-Strategy scores

4.2 Copenhagen

The Danish Capital of Copenhagen has been recognized as one of the most sustainable cities in Europe over the years and has also received the top scores on the Green city index in 2009 and for the second time in 2014 for the Global Green Economy Index. The City has come to be known for its increasing sustainable and low carbon priorities and most of all its biking culture. Copenhagen is now being called the biking capital of Europe. With a population of over 500,000 residents, the main part of the city is situated on the eastern coast of the island of Zealand with a smaller part located on Amegar. The City is very closely connected to Malmo in Sweden through the strait of Orsund and is well known for the transportation network in the region.

The topography of the city is relatively flat and low-lying with some hilly areas in the north and valleys in running from the northeast to the southwest. The city is also home to three large lakes in the central regions that the municipality has used to its advantage for the development of green zones within the city (City of Copenhagen, 2011).

With increasing focus on environment and sustainability, the city aims to be carbon-neutral by 2025. Investments in offshore wind energy and solar panels have become more and more common in Copenhagen. The city is committed to identifying and implementing cleaner sources of energy production such as through biomass and waste incineration. The city also plans to deploy energy efficiency policies and aims for all new buildings post 2020 to be net-zero energy buildings.

4.2.1 Mobility in Copenhagen: Measures, Targets and Indexing results

The city also prioritizes mobility and promoting sustainable mobility behavior among inhabitants. The city targets the transition to a modal split with at least 75% of journeys made in the city to be on foot, by bike or by public transport. Additionally, the city plans to aid transition to ensure that 20-30% of private cars in the city to be fueled by electricity or biofuels in the city. In order to enable the transition to a low carbon city, all departments in the municipality collaborate with the planners in order to ensure appropriate infrastructure development. The city's streets and squares are designed to promote the use of non-motorized modes of transport rather than the use of private cars (City of Copenhagen, 2014).

Over the last 5 decades, Copenhagen has been planned to increase the population and employment density at the city center while developing the peripheral areas in the form of the five finger plan creating a transit corridor (Figure 5). The city has developed a mobility system with commuter trains, metro system, trams, busses and ferry connections (for regional transport). Historically, Copenhageners mainly used bicycles for commuting. This biking culture depreciated over the years due to the increased affordability of private cars and increased urban sprawl resulting in low density of urban areas. This resulted in increased travel distances and travel time. Over time, the increased use of cars resulted in increased air pollution and traffic congestion. (City of Copenhagen, 2012)

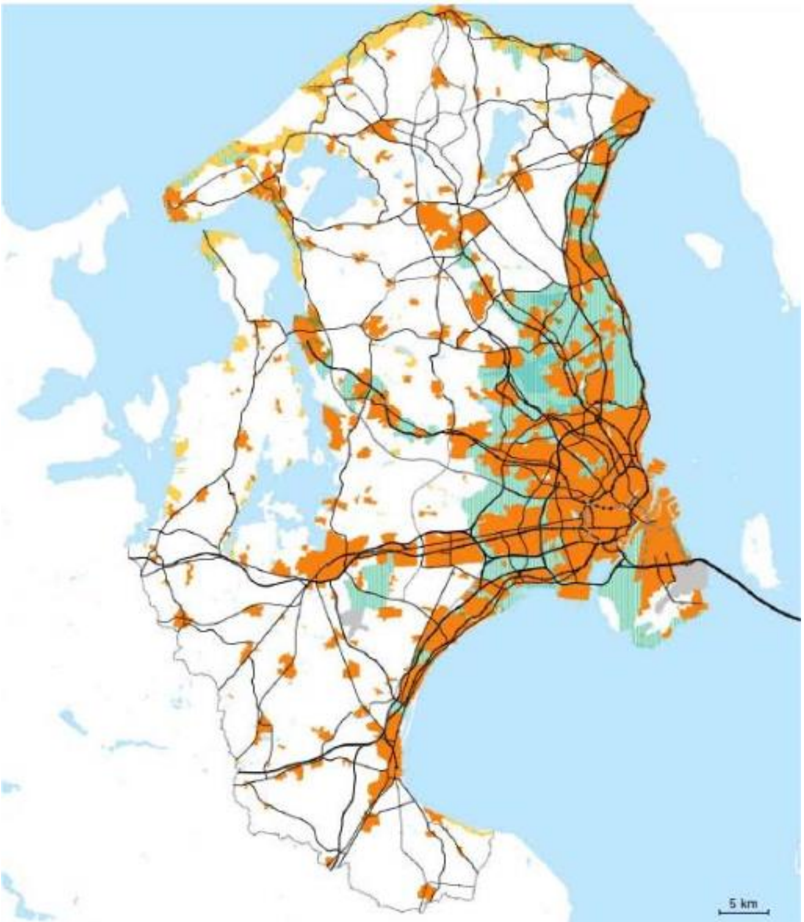


Figure 5 Five finger development pattern in Copenhagen

Urban planning and mobility planning in Copenhagen takes places in the Administration of Transport and Environment where the two departments work together in order to ensure absolute integration of environmental sustainability in urban and transport planning in the city. Similar to Stockholm, the municipality reports to the city council. The Transport and Environmental Administration report to one political head of Transport and Environment. The City council report to the ministry at the national level. Budgets are mainly set by the city council with specific allocations and targets for priority areas in the mobility system. The administration in the municipality has the freedom to develop most strategies except those that concern the implementation of national level taxes, levy's or regulations and national roads connected infrastructure. The Transport and Environmental Administration has gained credibility over its time of existence and now has the ability to propose specific targets and measures to be incorporated at the political level into the city budgets and sometimes even escalated to national level policies.

Carbon neutral strategies in Copenhagen are governed by the Copenhagen 2025 Climate Plan, Copenhagen biking strategy 2011-2025 and the Clean air Copenhagen project. Some of the main targets set under these strategies to be achieved by 2025 are as follows,

- 75% of the journeys are done on foot, bike or public transport
- 50% or all journeys to work or education are done by bike. This will equate to a reduction of 40,000 tonnes of CO_2 eq. per year compared to 2010
- 20% more passengers using public transport compared to 2009
- 11% CO_2 emission reduction target of 1.2 Mtonnes of CO_2 eq

Based on the current state of the mobility system in Copenhagen, data has been collected and fed into the Low Carbon Mobility benchmarking framework. The following results (Figure 6) were recorded for the Avoid, Shift and Improve Strategies. It can be seen that as per the efforts made by the city to improve the uptake of non-motorized modes, the city has fared best on the avoid strategy and due to the development of an intense public transport system, the city has got the second highest score for the shift strategy.

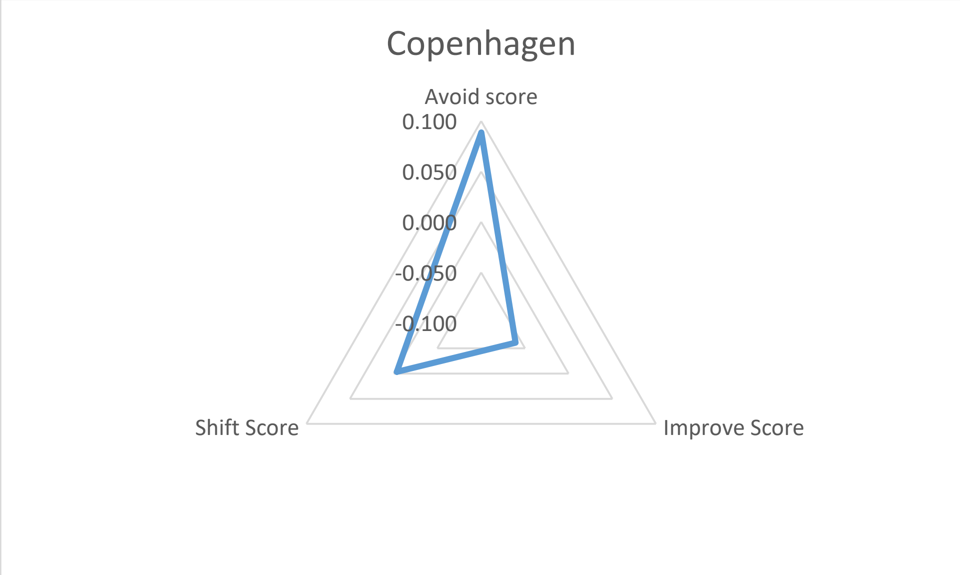


Figure 6 Copenhagen Low Carbon Mobility index-Strategy scores

In order to develop the city's mobility system further and meet the targets set, the city has planned a host or mobility strategies. The strategy to develop Copenhagen into the city of cyclists aims at development of infrastructure for bikers in the city. Additionally, the municipality aims to collaborate with 300 to 600 companies or offices in the city, to promote the use of electric bicycles. Measures to promote new fuels in the transport sector such as biofuel and electricity for private cars and hydrogen for public busses have been developed through demonstration projects. The city also plans to collaborate through joint ventures with LEV manufacturing and fuel producing companies to set up access to vehicle charging infrastructure and access to cleaner fuels. The city proposes attract these companies through the uptake of LEVs as a part of their own mobility needs. (City of Copenhagen, 2014)

4.3 Oslo

With a population of 658,390 the capital city Oslo is known to be one of the fastest growing cities in Europe. The City is located in the southern part of Norway and is on the northern most part of the Oslofjord. The city is surrounded in all directions by hills and mountains and is thus extremely hilly by itself. There are about 40 islands within the city limits of Oslo. The city is also home to a large number of lakes that form the primary source of potable water for the city. Environment and sustainability have been at the top of the municipal agenda and have been integrated in all departments of municipal service provision and in urban planning.

The governing structure in Oslo is similar to both Stockholm and Copenhagen but with some key points of differences. The city is headed by the city council and the city government that representing different parties but work together in the city hall. The budget for municipal activities is set by the City government initially which is then approved by the Council before distribution to respective departments in the municipality. These budgets set at the city council level are informed by national level plans and targets. The budget allocated to the municipal department unlike in Stockholm and Copenhagen, do not come with specific measures to be implemented. The municipal departments in Oslo have the freedom to implement decisions as per their requirements in order to meet the targets set by the city council and intern at the national level.

4.3.1 Mobility in Oslo: Measures, Targets and Indexing results

Over the decades, Oslo has been developed as a compact city. Efforts to reduce urban sprawl in the city have been put in place since the 1980s. The city is now known to have the highest rate of increase in population density in Europe. These efforts were mainly put in place to ensure reduced travel distances and controlled sustainable development within the municipality. The city is thus host to a highly developed public transport system consisting of a metro, tram and public bus network. The city also has a ferry network to connect the islands in the city limits with the mainland (Ministry of transport and communication Norway, 2014) (Ruter, 2015).

Public transport in Oslo is managed by an external company called Ruter. Ruter, similar to the relationship between the City Council and the municipality, has a strong say in the mobility related decision making process. The company is mainly funded by the municipal budget but also through income from tickets.

Over the last two decades, the priorities of the mobility system in Oslo has been to improve the currently existing public transport system. Efforts for improvement include measures to improve safety of the carriers as well as improve fuel quality and adoption of cleaner alternative fuels in the public transit system. The city aims to have a fossil free public transport system by 2020. For this purpose, the city has also invested in research and development, piloting the use of hydrogen and electric powered busses in the city. The city has also partnered with multiple LEV manufacturing companies that have set up showrooms in the city increasing access to LEVs. Oslo is now the city with maximum number of electric vehicles in the world. The city has also encouraged this uptake through financial exemptions and incentives. This helped increase electric vehicle numbers in the city. It has been found that the numbers increased to such a great extent that issues on traffic congestion were faced due to the high uptake of LEVs in the city. Certain incentives have thus been retracted to control traffic within the city. Oslo aims to be fossil fuel independent by 2030. Oslo, due to the hilly terrain of the city has historically had a lower uptake of bicycles. In order to improve this situation, the city provided government funding schemes for citizens for the purchase of electric bicycles. The city has also introduced numerous bicycle charging schemes in the city. (Ruter, 2015)

Upon testing the Low Carbon Mobility benchmarking model developed for this thesis with data from Oslo, the following results have been observed (Figure 7). Corresponding to the measures adopted, the city has scored highest in the improve strategy.

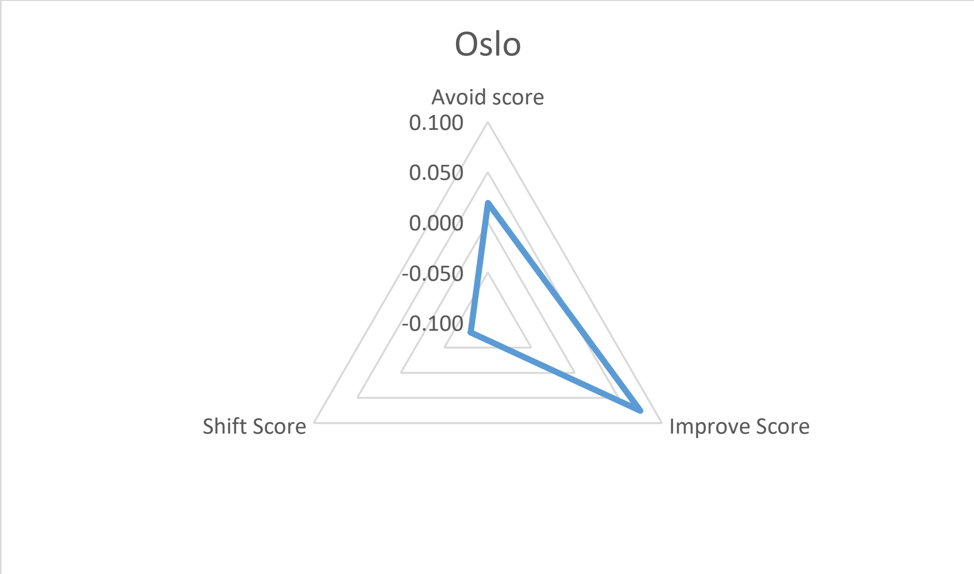


Figure 7 Oslo Low Carbon Mobility index-Strategy scores

In order to improve the mobility system further, the city proposes the following efforts

1. Ban on the entry of cars into the city center by 2019
2. Rollout of battery electric busses by 2020
3. Transition to renewable energy for passenger ferries
4. Increasing the number of and promotion of car sharing schemes
5. Increasing public transport capacity through the construction of an additional metro line
6. Improving the city toll to an environmental tax by applying differentiated charging schemes
7. Development of specific climate budgets for mitigation strategies

5 Discussion

The following chapter of analysis brings forward the results of the tests performed on the model developed in order to assess the ability of the framework to meet its objectives. Section 5.1 and 5.2 help answer Research Question 2,

> Does the developed model meet the main criteria of indicating the performance of the system in its transition to becoming a low carbon system?
> a. Is there a correlation between the developed model and the rate of transport emission reduction?
> b. Can the model explain the priorities of the mobility system of the cities?

And section 5.3 helps answer Research Question 3

> Can the model be used to identify possible pathways for the improvement of the existing low carbon mobility system in the selected cities?

5.1 Correlation with rate of GHG emission

In order to test the model generated, the relationship of the resultant scores with the rate of change of GHG emission was checked by means of a correlation analysis.

The low carbon mobility scores were found to have a strong linear correlation with the GHG emission reduction rate in the three cities. The correlation table with the Pearson's correlation coefficient are as shown below,

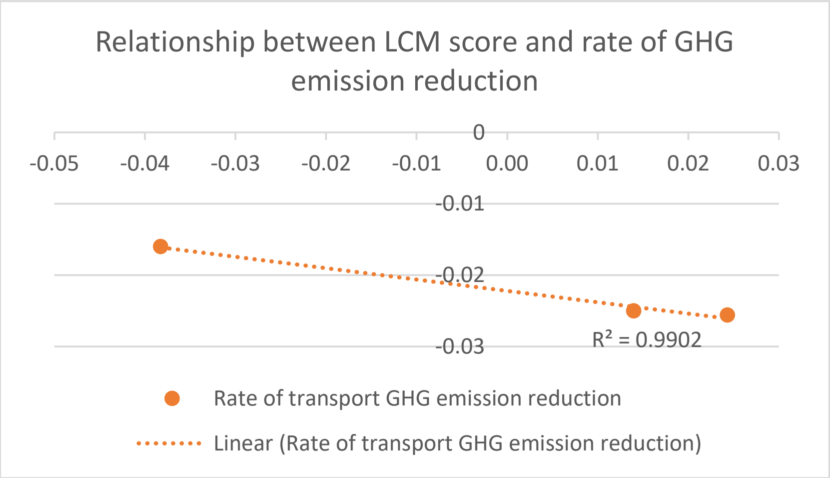
Table 5 Table showing correlation between the LCM score and the rate of change of GHG emission

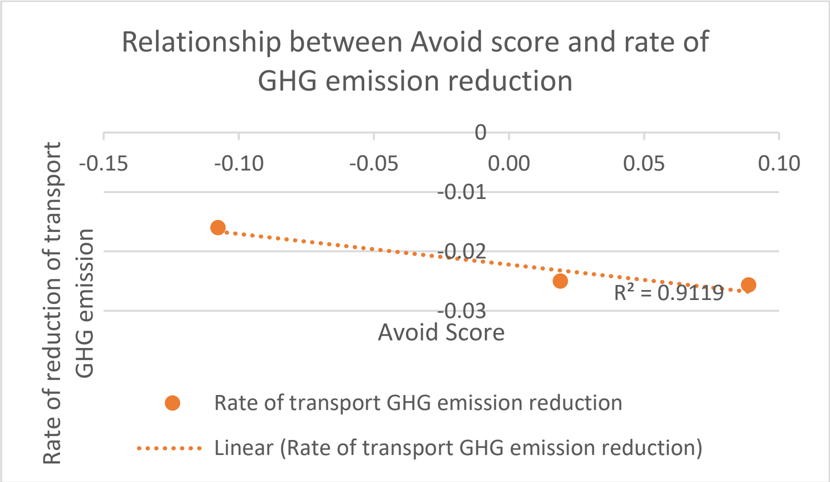
	LCM score	*Avoid*	*Shift*	*Improve*	*Rate of Change of GHG emission*
LCM score	1				
Avoid	0.979637	1			
Shift	-0.80158	-0.66521	1		
Improve	0.028366	-0.17291	-0.62039	1	
Rate of emission reduction	-0.99508	-0.95491	0.856889	-0.1273	1

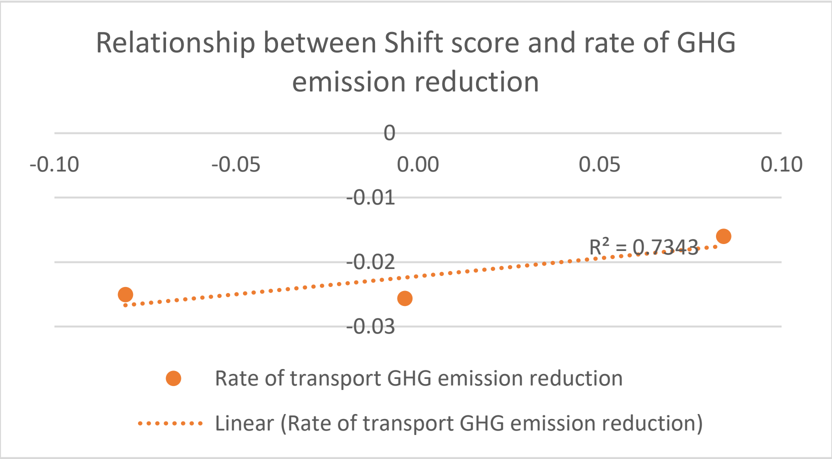
It can be seen from the table that there is a direct linear negative correlation (r=-0.99) between the LCM score (Mean=0 Stdev.=0.03) and the rate of change of GHG emissions (Mean=-0.022, Stdev=0.005), implying that in cities with higher LCM scores, the rate of transport GHG emission reduction is also high.

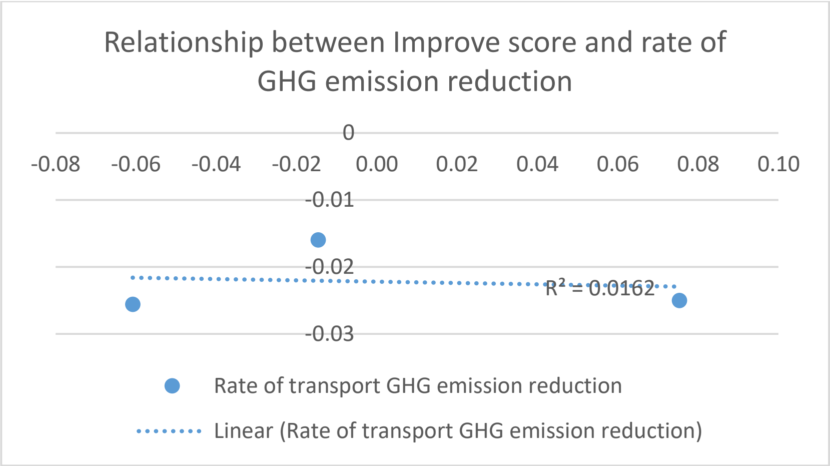
Analyzing the strategy scores, there is a direct negative linear correlation (r=-0. 95491) between the Avoid score (Mean=0 Stdev.=0.09) and the rate of change of GHG emissions as well. For the Shift scores (Mean=0, Stdev.= 0.08), it is seen that the relationship is a strong direct linear positive correlation with r=0.85688. The Improve score on the other hand is seen to not be correlated with the change in GHG emissions.

The strong correlation of the LCM score with the rate of change of transport GHG emission confirms that the model developed represents the results in line with the objective that it was designed for.



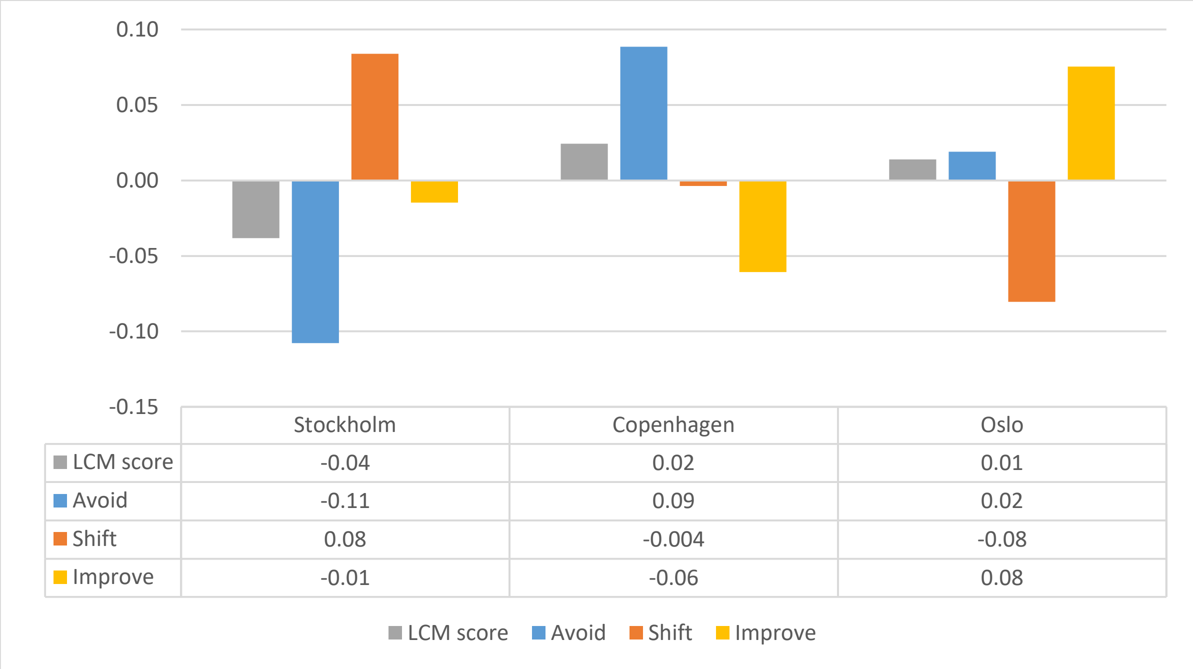






5.2 Low Carbon mobility score

The Low Carbon Mobility Index, as described earlier, proposes to indicate the performance of the different measures the cities have adopted to help aid reduction in transport related GHG emissions. It can be seen from the scores that Copenhagen seems to have achieved a system with the best overall performance when compared to Stockholm and Oslo. In order to understand the reason behind these scores better, the following sections provide a detailed analysis of each of the strategy scores that contribute to the LCM Index.



	Stockholm	Copenhagen	Oslo
LCM score	-0.04	0.02	0.01
Avoid	-0.11	0.09	0.02
Shift	0.08	-0.004	-0.08
Improve	-0.01	-0.06	0.08

Figure 8 Breakdown of the Low carbon mobility score for the cities under consideration

5.2.1 Avoid score

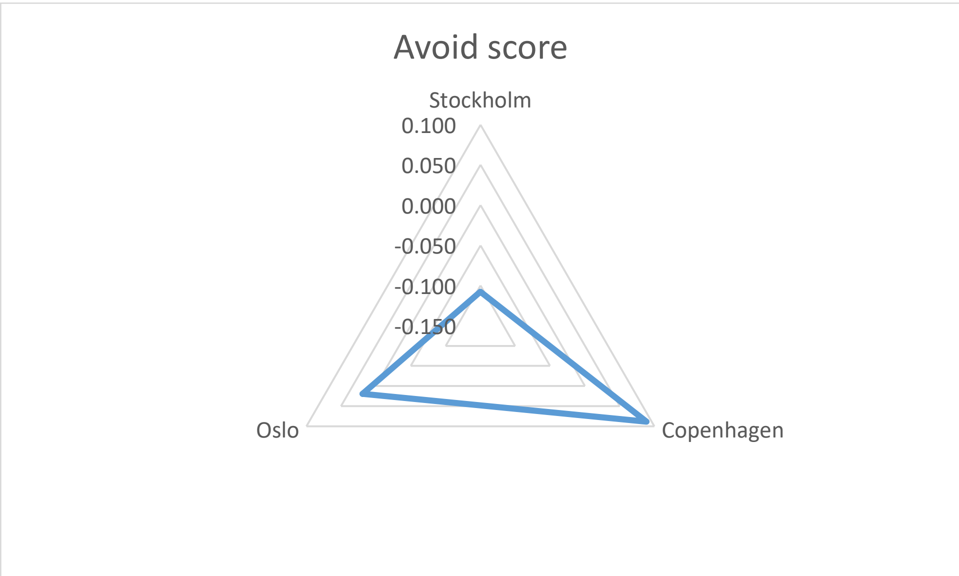


Figure 9 Performance of cities on the Avoid strategy score

It can be seen that Copenhagen, among the three cities, has received the leading score for avoidance. This is mainly due to the extensive infrastructure and regulations the city has put in place to improve attractiveness and safety of biking and walking. Additionally, in order to promote the use of non-motorized modes, the city has integrated the biking system with the public transport network by installing bicycle carriers in all busses, metros and trains.

Table 6 Breakdown of Avoid strategy score

	Stockholm	Copenhagen	Oslo
Compaction	-0.37	1.13	-0.76
Uptake	0.31	0.02	-0.33
Infrastructure	-4.57	2.67	1.91

Stockholm on the other hand has received the lowest score for avoidance owing to poor infrastructure for biking and walking. Some of the factors contributing to this low score are the lack of integration between public transport and biking. Unlike in Copenhagen and Oslo, the public transport network in Stockholm lack infrastructure to enable the carrying and storage of bicycles on board. Additionally, citizens are not allowed to carry their bikes on public transport networks during rush hour except for the busses which do not allow bicycles at any time. Oslo on the other hand, ranked second, is in this place due to the low population density in the city and lower proximity to public transport networks.

5.2.2 Shift Score

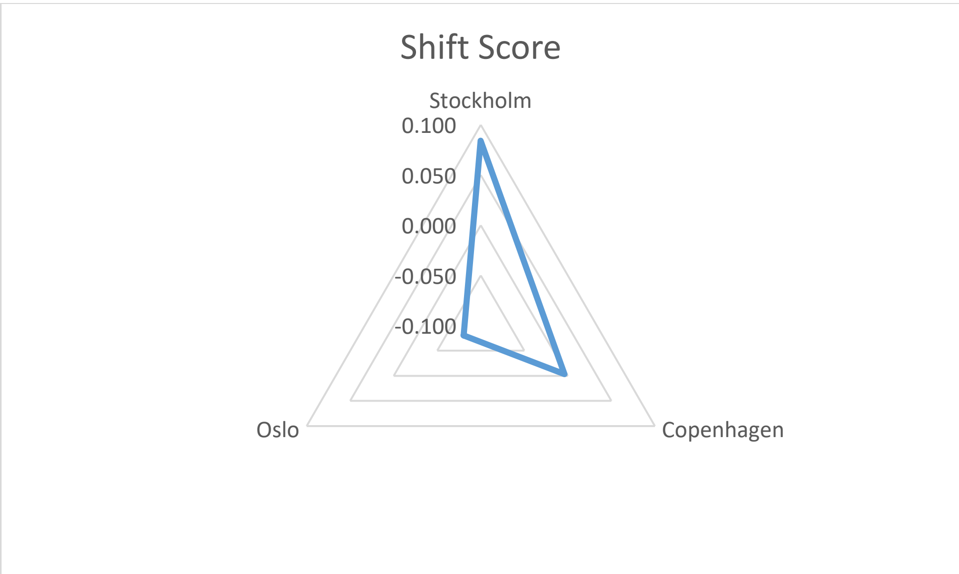


Figure 10 Performance of cities on the Shift strategy score

Table 7 Breakdown of Shift strategy score

	Stockholm	Copenhagen	Oslo
Access Restriction	0.58	0.02	-1.79
Mobility information	0.00	0.00	0.00
Public transport infrastructure development	2.11	-2.03	-0.08
Public transport uptake	0.93	-1.06	0.13
Traffic demand control	0.0001	2.36	-2.36

As it can be seen, Stockholm has received the highest score for the shift strategy. This is mainly due to the developmental efforts invested into improving the public transport system in Stockholm. Measures range from maintenance and increasing road capacity to increasing public transport capacity and accessibility with about 65% of the public transport stations at 400m from residential areas and offices. Due to these developmental efforts, the public transport uptake in Stockholm is the highest with over 30% of the journeys being made on public transport systems. Due to the integration of the ticketing system in Stockholm coupled with the multiple park and ride facilities at the cities peripheries, Stockholm attracts high public transport usage. In addition to direct measures that have impacted the high quality and acceptance of the public transport system, the congestion charge levied by the municipality has been one of the most curtail policy instruments to facilitate the shift to public transit systems. It has been found that the number of journeys using passenger cars dropped considerably in the years after the implementation of the charge. This shift is clearly visible when compared to the number of journey made by public transport.

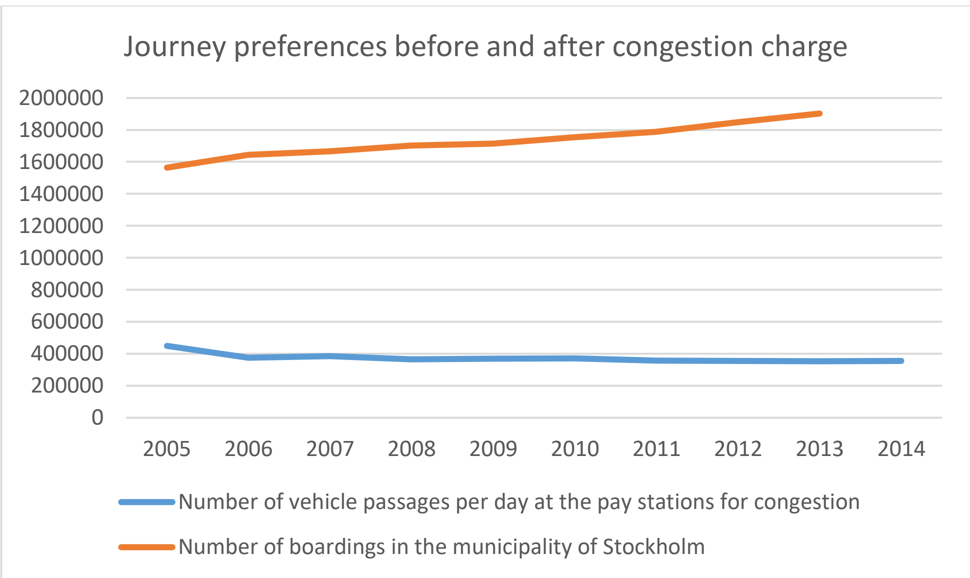


Figure 11 Stockholm Journey preferences before and after congestion charge

Copenhagen, receiving the next best score for the shift strategy has one of the best integrated public transport network and intense traffic demand control measure. The intense traffic control measures are mainly due to Denmark's high tax rates for the purchase and use of private cars. Additionally, the annual circulation tax for private cars in Denmark decided based on the environmental performance of the vehicle, keeping a further check on the efficiency of the vehicles on the streets and meeting the aim of reducing private car usage.

Although the city center of Oslo has a high population density, the peripheral areas in Oslo and neighbouring municipalities have low population density. While comparing the population density in the city center of around 4200 inhabitants/sq.km, the population of the Greater Oslo area is only about 27 to 28 inhabitants/sq.km, promoting the ownership and use of passenger cars. Additionally, Oslo has received the lowest score for traffic demand control. This is mainly due to the presence of a fixed annual circulation tax of EUR 350, not considering the environmental performance of the vehicle. Another contributing factor to higher car ownership in the city is due to the high per capita GDP in Oslo. While the government has put a range of traffic control measures and taxes, the cost of purchasing and using a private car is a lot less than the time cost of transport using public transport systems.

5.2.3 Improve Score

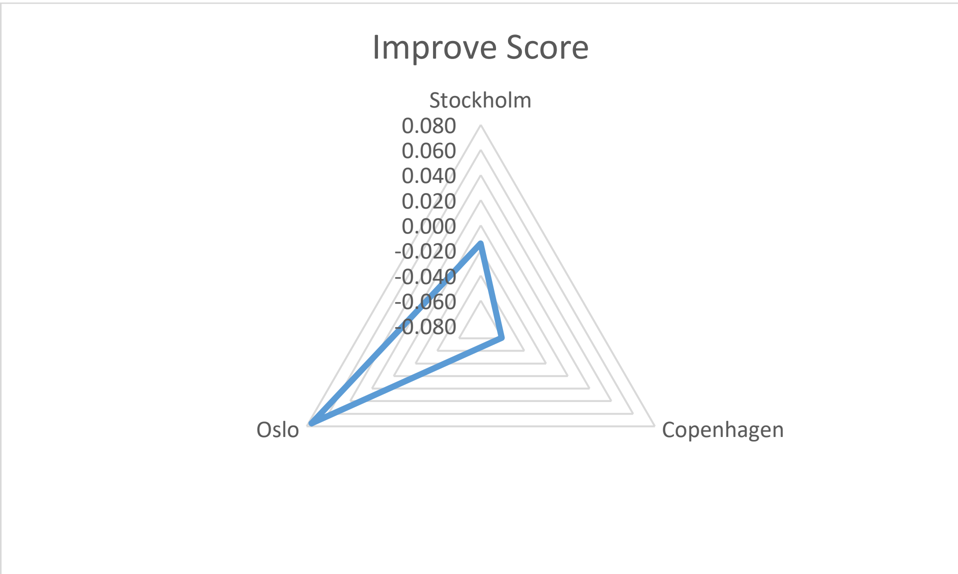


Figure 12 Performance of cities on the Improve strategy score

Table 8 Breakdown of Improve strategy score

	Stockholm	Copenhagen	Oslo
Access Management	0.58	0.35	0.66
Financial Incentives for LEVs	-0.58	-2.31	2.89
Fuel Efficiency control	-0.59	-0.58	1.16
LEV infrastructure development	-0.95	0.28	0.67
LEV uptake	-0.99	-0.03	1.01

Owing to the large number of incentives and infrastructure development for electric vehicles, Oslo has received the highest score for the improve strategy. Oslo has the highest uptake of electric vehicles with 15% of their total passenger car fleet. Additional to this, Oslo has high standards for fuel efficiency and has also provided its citizens with a large number of financial incentives to transition to electric vehicles. One of the main contributing factor to the increased electrification of the private car flees is due to the accessibility of public free charging stations. The city has over 1000 free electric vehicle charging stations. Additionally, due to the high car ownership in the peripheral and neighbouring municipal areas, the city has established over 6000 park and ride facilities equipped with vehicle charging stations promoting the use of multi-modal journeys. The city is also planning to completely ban the use of cars on municipal roads in the city center by 2019 with the main aim of slashing the GHG emissions in the city by 50% of 1990 by 2020.

In the case of Copenhagen, it is seen that the main reason behind the low score for the improve strategy is the lack of financial incentive for the transition to LEVs in the private car fleet. Stockholm on the other hand has the lowest score due to the low infrastructure development for electric vehicles and hence a lower uptake value. The city however has a large percentage of the passenger fleet fueled by biofuels (around 17%) and has extensive infrastructure for the same. The major strength in Stockholm is the uptake of LEVs fueled by biofuels rather than electricity. Almost 98% of the public transport busses in the city are hybrid vehicles fueled by biofuels. Additionally, the municipality has ensured that almost 40% of all the fuel stations in the city stock biofuels to ensure accessibility of cleaner fuels.

5.3 Considerations for the selection of measures

Based on the results of the analysis, the specific areas of improvement for the three cities have been identified. However, before measures are elected and adopted, certain factors need to be taken into consideration such as the efficiency of the measures to meet the overarching goal of reducing GHG emissions and the different barriers that the municipality will face while implementing measures. The following section describes these factors that aid the selection of appropriate measures for the improvement a low carbon mobility system

5.3.1 Efficiency of measures under the ASI framework

In order to assess the performance of measures adopted, it is important to define the main goal of the measures and the means to achieving this goal. As mentioned earlier, the main objectives that directly contribute to the reduction of GHG emissions from the transport sector are as follows (Nakamura & Hayashi, 2013),

1. Reduced need to travel
2. Reduce car usage
3. Improve alternative modes
4. Improve road network for improved modes
5. Improve vehicles and fuels

Additionally, from the formula proposed by He et. al. 2011, the GHG emissions of the transport sector are directly proportional to the following parameters,

1. Vehicle kilometers travelled
2. Modal split
3. Number of trips/mode
4. Number of passengers per mode
5. Fuel efficiency of the vehicle by mode
6. Emission intensity of the vehicle by mode
7. Fuel quality used

The measures corresponding to the Avoid strategy are, as mentioned earlier, directed at the elimination of the use of motorized vehicles and to reduce the need to travel. Measures range from long term efforts to promote higher population and employment density through compaction to the technological advancements in order to avoid work related travel and transported oriented work culture. Considering these measures and the expected outcome of reduced travel and/or an increase in the modal split of non-motorized modes, the resultant emissions from the transport sector are bound to go down by a greater percentage as trips will be made on non-motorized modes. Thus measures falling under the avoid category will reduce GHG emissions corresponding to the transport sector to a greater extent compared to the Shift and Improve categories.

Measures that promote the shift of the modal share from individual private motorized transport to shared and efficient public transport systems will have the next best effect on the GHG emissions from the transport sector. This is mainly because the emissions from the use of shared modes will be averaged out over the number of occupants/riders thus making the mode a lot more efficient. The efficiency of these measures would be most effective however, in combination with efforts from the improve strategy.

It is important to take into consideration that these strategies implemented in isolation may not have the desired outcome even though they directly contribute to the majority of the influencing factors towards reaching the desired aim of reducing GHG emissions.

Measures that are adopted to control transport related GHG emissions, mainly fall under the two categories of demand control and supply control measures. These measures directly interact with each other to deliver the desired outcome of the applied measures. A good example for this would be the construction of biking lanes. The mere presence of these biking lanes may not have as much of an effect on the increased modal share of biking as compared to the combined effect of increased biking lanes, improved integration with public transport facilities, increased safety of storage and parking facilities in the city and finally, increased proximity of destinations. This will not only make biking infrastructure more accessible, but due to the shorter distances that need to be travelled, it reduces travel time which is one of the most important factors determining passenger transport patterns.

Similarly, although an increase in public transport infrastructure in the city may see increased uptake, the implementation of traffic control measures to reduce passenger car usage along with an improvement of public transit systems results in a greater uptake of the passenger transport system. This is as observed in Stockholm (Figure 11).

It can thus be concluded that although the measures contributing towards the objective of the avoid strategy have the highest potential to reduce GHG emissions, measures are constrained by the factors that determine passenger transport patterns.

5.3.2 Barriers to the implementation of urban low carbon mobility solutions

Based on discussions with the mobility professionals in the respective cities, certain key barriers for the implementation of low carbon mobility measures have been identified. These are in line with those identified by the TRANSFORM project and are as stated below.

5.3.2.1 City Characteristics

Physical assortment of cities has been laid out as one of the most challenging issues to overcome by mobility planners. City topography and climatic conditions have been found to affect passenger behavior to a great extent. A good example of this is to observe the lower uptake of bicycles in Oslo due to the hilly terrain and extreme cold during the winter months. Additionally, infrastructure projects such as building of metro or tram lines have faced tremendous difficulties and costs due to the scattered nature of islands in Stockholm.

Additional to the topography, the lack of space in the streets due to historical development policies that have resulted in compact development without the provision of space of further development has also been identified in Oslo where there due to the narrow roads in the city, there is no space for setting up of bicycle lanes.

5.3.2.2 Institutional capacity

Institutional capacity, especially financial capacity has been cited as one thee most common barriers in the implementation of low carbon mobility strategies. Cities have however employed measures to try and circumvent the high investment projects by adopting lower cost alternatives that have the potential to meet the goal to a certain extent.

A good example for this would be that in Oslo, the municipality, instead of building an additional transit ring for high speed traffic around the city decided to increase the frequency and capacity of the public transit stations in the peripheral areas of the city. This measure resulted in meeting the demand for transport, while avoiding the use of passenger cars. Another good example of using low cost measures is noticed in Stockholm where the municipality initially promoted the use of bicycles in the city through the use of low cost promoting campaigns in order to gauge the demand of bicycle infrastructure. Although these promotional activities were not enough to encourage the use of bicycles in the city, authorities observed a marginal increase in the number of journeys by bicycle.

Regulatory measures such as the congestion charging, city tolls or environmental taxes have found to be important sources of income for the implementation of other low carbon mobility measures. Although the time cost of research on developing the scheme and setting the price have been found to be high, these schemes have had the potential to provide increased funds for the development of additional mobility infrastructure in cities. Stockholm proposes to use a part of the congestion fee that is to be hiked in 2016, for the purpose of building a new metro line in the city.

5.3.2.3 Political Will

Political will has been found to play a key role in deciding the importance of specific measures in the city based on the overarching priorities of the parties in power. Certain measures, identified as the best solutions to a given problem, may not be in line with the political agenda of the party in power. It is important to note that over and above city development measures, political parties have the added burden of identifying and avoiding measures that have the potential to lose votes for them in the next elections. Additionally, national level governments may need to own certain parts of the city properties due to their exclusion from municipal jurisdiction. Any decisions with regard to these properties pose the possibilities of conflict of interest between the municipal and national level governments.

5.3.2.4 Public acceptance

Public acceptance and involvement has been found to pay a marginal role in the implementation of low carbon mobility measures. They however do impact the uptake of these measures to a great extent. Measures need to be coordinated and need to form a package in order to nudge citizens to take up specific behavioral practices that promote low carbon mobility in cities. For example, in Copenhagen, the bicycle usage in the city saw steep rise when bicycle promotional activities and infrastructure development were coupled with integration with the public transport systems. This resulted in the use of multi-modal journeys and the increased use on non-motorized modes in the city.

6 Conclusions

The following chapter presents the conclusions that can be drawn from the research directly in response to the research questions posed and resents certain key recommendations that can help guide further research into the topic.

6.1 Response to research questions

1. What are the key parameters to consider in characterizing and benchmarking LCM in cities?

The parameters that have been identified are based on the specific measures that aid the transition to a low carbon mobility system. When characterized under the ASI model, these have been identified as

Avoid: Compaction, Uptake of non-motorized modes, Infrastructure promoting non-motorized modes of transport

Shift: Access Restriction, Mobility information, Public transport infrastructure development, Public transport uptake, Traffic demand control

Improve: Access Management, Financial Incentives for LEVs, Fuel Efficiency control, LEV infrastructure development, LEV uptake

2. Does the developed model meet the main criteria of indicating the performance of the system in its transition to becoming a low carbon system?
    a. Is there a correlation between the developed model and the rate of transport emission reduction?

A positive correlation has been found between the low carbon mobility index developed and the rate of GHG emission reduction, indicating that when the low carbon mobility score is high, the GHG emission reduction is also high. Subsequently, it has also been identified that the Avoid score is also positively correlated with the GHG emission reduction. The Shift and the Improve scores however, show either a negative or no correlation with the GHG emission reduction. There is thus a necessity to further evaluate the model to identify specific areas of improvement for these two strategies.

    b. Can the model explain the priorities of the mobility system cities evaluated?

Based on the scores delivered by the model, it has been observed that the scores correlate with the specific measures that the cities have focused on over the last few decades. The city of Copenhagen, with the highest LCM score, has been developed over a long period of time with a lot of emphasis on emission reduction. The city was found to have the highest score in the avoid strategy corresponding to the specific measures to develop and promote non-motorized modal infrastructure. Stockholm, has received the highest scores for the shift strategy corresponding to measures over the last 4 to 5 decades on developing public transport and road infrastructure. Oslo on the other hand, has been found to have a high score for the improve strategy, in line with specific measures to incentivize the uptake of low emission vehicles in the city. The model is thus able to explain the priorities of the cities and help to identify specific areas of improvement.

3. Can the model be used to identify possible pathways for the improvement of the existing low carbon mobility system in the selected cities?

Based on the results of the model it can be seen that each city has specific areas for improvement. Stockholm has ranked lowest in the avoid strategy indicating possible improvements in measures promoting the use of non-motorized modes of transport in the city. Copenhagen has been found to have the lowest scores in the improve strategy, indicating the need for incentives and measures to aid the accessibility and uptake of LEVs in the city. The main area for concern for Oslo has been identified as measures relating to the shift strategy.

It has also been found that measures corresponding to the Avoid strategy have the potential to result in maximum GHG emission reduction followed by measured under the shift and then the improve strategy. These results however may only be theoretical as specific relationship between GHG emission reduction levels and these measures have not been established.

Additionally, before considering specific measures to set the pathway of low carbon mobility transition, the cities have paced specific barriers during the implementation of some of these measures. These are mainly, City characteristics, Political will, Public acceptance and institutional capacities. Thorough considerations have to be made before the selection of any of the measures for the transition to a low carbon mobility system.

6.2 Recommendations for improvement of the model:

It has been identified, based on this research, that the model can be made more robust. In order to identify the relative importance of parameters used in the indicator set, multivariate analysis techniques such as principal component analysis need to be performed. The results of this PCA may be used to inform the weighting of each of the parameters in the model. Additionally, the causal linkages between the indicator and scores should be tested in order to enable more informed choices selection of mitigation measures in cities. Finally, there is also a need to test and optimize the robustness of the model through uncertainty and sensitivity analysis using variance based techniques.

Bibliography

Banister, D. (2008). The sustainable mobility paradigm. *Transport Policy, 15*, 73-80.

Brandon, P., & Lombardi, P. (2005). *Evaluating sustainable development in the built environment.* Oxford: Blackwell.

Chapman, L. (2007). Transport and climate change: a review. *Journal of Transport Geography, 15*(5), 354-367.

City of Copenhagen. (2011). *Copenhagen Biking Strategy.* Copenhagen: City of Copenhagen.

City of Copenhagen. (2012). *Copenhagen 2025.* Copenhagen: City of Copenhagen.

City of Copenhagen. (2014). *Clean Air Copenhagen.* Copenhagen: City of Copenhagen.

Dalkmann, H., & Brannigan, C. (2007). *Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities.* Eschborn: Deutsche Gesellschaft fuer Technische Zusammenarbeit (GT Z).

Dratva, J., Zemp, E., Dietrich, F., Bridevaux, O., Rochat, T., Schindler, C., & Gerbase, W. (2010). Impact of road traffic noise annoyance on health-related quality of life: results a population-based study. *Quality of Life Research, 19*(1), 37–46.

EC. (2010). *Perception Survey on Quality of Life in European Cities: Analytical Report, Fieldwork: November 2009, Flash Eurobarometer No.277.* Brussles: European Commission.

EC. (2011). *The roadmap to a single European transport area — Towards a competitive and resource efficient transportsystem.* Brussels: Eurpean Commission. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0144&from=EN

EEA. (2013). *A Closer Look at Urban Transport.* Copenhagen, Denmark: European Environmental Agency.

EEA. (2014a). *Air quality in Europe - 2014 report.* Luxembourg.: European Environment Agency. Retrieved from http://www.eea.europa.eu//publications/air-quality-in-europe-2014

EEA. (2014b, June 03). *Total greenhouse gas (GHG) emission trends and projections.* European Environmental Agency. Retrieved from http://www.eea.europa.eu/data-and-maps/indicators/greenhouse-gas-emission-trends-5/assessment

EEA. (2015a). *Evaluating 15 years of transport and environmental policy integration TERM 2015: transport indicators tracking progress towards environmental targets in Europe.* Copenhagen, Denmark: European Environmental Agency.

EEA. (2015b). *The European Environment – State and Outlook 2015 (SOER 2015).* Brussels: The European Environmental Agency. Retrieved from http://www.eea.europa.eu/soer#tab-thematic-briefing

EEA, & BUND Germany. (2011). *City Scores.* Retrieved from Sootfree for the climate: http://sootfreecities.eu/city

EMTA. (2012). *Barometer 2009 of public transport in the European Metropolitin areas.* Paris: European Metropolitain Transport Authorities.

EMTA. (2012a). *Barometer 2011 of public transport in the European Metropolitin areas.* Paris: European Metropolitain Transport Authorities.

EPOMM. (2016). *The EPOMM Modal Split Tool.* European Platform for Mobility Management. Retrieved from EPOMM: http://www.epomm.eu/tems/index.phtml

EPOMM TEMS. (2016, June 1). *The EPOMM Modal Split Tool* . Retrieved from European Platform on Mobility Management- Managing Mobility for a better future: http://www.epomm.eu/tems/

European Comission. (2016, April 15). *Reducing emissions from transport.* Retrieved from European Comission: http://ec.europa.eu/clima/policies/transport/index_en.htm

European Commission. (2013). *Together towards competitive and resource efficient urban mobility.* Brussels: European Commission.

European Commission. (2015, March 6). *Environment Council approves the EU's intended nationally determined contribution to the new global climate agreement.* Retrieved from European Comission: http://ec.europa.eu/clima/news/articles/news_2015030601_en.htm

Geels, W., Kemp, R., Dudley, G., & Lyons, G. (2012). *Automobility in transition? A Socio-Technical Analysis of Sustainable Transport.* New York, USA: Routledge.

GEF. (2013). *Investing in sustainable transport and urban systems- The GEF experience.* Washington, USA: Global Environmental Facitliy. Retrieved from https://www.thegef.org/gef/sites/thegef.org/files/publication/26211_lowres.pdf

GIZ. (2010). *Sustainable Urban Transport: Avoid - Shift - Improve (ASI).* Bonn, Germany: GIZ. Retrieved from http://www.sutp.org/files/contents/documents/resources/E_Fact-Sheets-and-Policy-Briefs/SUTP_GIZ_FS_Avoid-Shift-Improve_EN.pdf

GIZ. (2011b). *Sustainable Transport Evaluation - Developing Practical Tools for Evaluation in the Context of the CDS process.* Eschborn, Germany: GIZ.

GTZ. (2010). *Beyond the fossil city: Towards low carbon transport and green growth.* Eschborn,: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

Hagerty, M., & Land , K. (2007). Constructing Summary Indices of Quality of Life: A Model for the Effect of Heterogeneous Importance Weights. *Sociological Methods Research, 35*, 455-496.

Hayashi, Y., & Nakamura, K. (2013). Designing Sustainable Low Carbon Transport Systems integrated with Regional development in Asia. *United Nations Centre for Regional Development workshop.* United Nations Centre for Regional Development.

He, D., Meng, F., Wang, M., & He, K. (2011). Impacts of Urban Transportation Mode Split on CO2 Emissions in Jinan, China. *Energies, 4*, 685-699. doi:10.3390/en4040685

Hermans, E., Brijs, J., & Wets, G. (2008). *Developing a theoretical framework for Road Safety Performance Indicators and a Methodology for creating a Performance Index.* Diepenbeek, Germany: Steunpunt Mobiliteit & Openbare Werken. Retrieved from http://www.steunpuntverkeersveiligheid.be/sites/default/files/RA-MOW-2008-010.pdf

Hrelja, R., Hansson, L., Richordson, T., Svensson, T., Lissandrello, E., Naess, P., . . . Longva, F. (2013). *Innovatioons for sustainable transport. Experiences and challenges in Scandinavien countries.* Linköping: VTI- The Swedish National Road and Transport Research Institute.

IEA. (2012). *World energy outlook 2012.* International Energy Agency, OECD.

IEA. (2013). *Policy pathways: A tale of renewed cities.* Paris: International Energy Agency, OECD.

ITDP. (2011). *Europe's Parking U-Turn: From accommodation to regulation.* New York, USA: Institute for Transportation and Development Policy.

Kahn Ribeiro, S., Figueroa,, M., Creutzig, F., Kobayashi, S., Dubeux, C., & Hupe, J. (2013). *Energy enduse: Transportation In The global energy assessment: Toward a more sustainable future.* Luxenburg: IIASA.

Kammerlander, M., Schanes, K., Hartwig, F., Jäger, J., Omann, I., & O'Keeffe, M. (2015). A resource-efficient and sufficient future mobility system for improved well-being in Europe. *European Journal of Futures Research, 3*(8). doi:10.1007/s40309-015-0065-x

Karathodorou , N., Graham, D., & Noland, R. (2010). Estimating the effect of urban density on fuel demand. *Energy Economics, 32*, 86-92.

Kiesewetter, G., Borken-Kleefeld, J., Schöpp, W., Heyes, C., Thunis, P., Bessagnet, B., . . . Amann, M. (2015). Modelling street level PM10 concentrations across Europe source apportionment and possible futures. *Atmos. Chem. Phys., 15*, 1539–1553. Retrieved from http://www.atmos-chem-phys.net/15/1539/2015/acp-15-1539-2015.pdf

Ministry of transport and communication Norway. (2014). *National Transport plan.* Oslo: Ministry of Transport and Communication.

Næss, P., Strand, A., Næss, T., & Nicolaisen, M. (2011). On their road to sustainability?: The challenge of sustainable mobility in urban planning and development in two Scandinavian capital regions. *Town Planning Review, 82*(3), 285-316.

Nakamura, K., & Hayashi, Y. (2013). Strategies and instruments for low-carbon urban transport: An international review on trends and effects. *Transport Policy, 29*, 264-274. Retrieved from https://www.researchgate.net/profile/Kazuki_Nakamura4/publication/271582478_Strategies_and_instruments_for_low-carbon_urban_transport_An_international_review_on_trends_and_effects/links/56121e2208aec422d1172f7d.pdf

Newman , P., & Kenworthy, J. (1989). Gasoline consumption and cities: a comparisin of US cities in a global survey. *Journal of American Planning Association, 55*(1), 24-36.

Newman, P., & Kenworthy, J. (1989a). *Cities and automibile dependence: An international Scourcebook.* Gower: Aldershot, UK.

Nordic Council of Ministers. (2012). *Nordic Solutions for Sustainable Cities.* Nordic Council of Ministers. Retrieved from http://www.hel.fi/hel2/ymk/julkaisut/nordic8Catalogue_060612.pdf

OECD. (2008). *Handbook on the construction of composite indicators: Methodology and user guide.* Paris, France: OECD.

Richardson, B. (2005). Sustainable transport: analysis frameworks. *Journal of Transport Geography*, 29-39.

Ruter. (2015). *Fossil Free 2020.* Oslo: Ruter.

Santos , G., Maoh, H., Potoglou, D., & von Brum, T. (2013). Factors influencing modal split of commuting journeys in medium-size European cities. *Journal of Transport Geography, 30*, 127-137.

Santos, G., Maoh, H., Potoglou, D., & Von Brum, T. (2013). Factors influencing modal split for commuting journeys in medium-size European cities. *Journal of transport Geography, 30*, 127-137.

Schafer, A. (2012). *Introducing behavioral change in transportation into energy/economy/environment models (No. 6234.* Washington, DC: World Bank.

Stockholm Stad. (2012 a). *Walkable city.* Stockholm: Stockholm stad.

Stockholm Stad. (2012). *Urban Mobility strategy.* Stockholm: Stockholm Stad.

StockholmStad. (2015). *Environmental Factsheet.* Retrieved from Stockholm City Municiplity: http://miljobarometern.stockholm.se/

Thynell, M., Mohan, D., & Tiwari, G. (2010). Sustainable transport and the modernisation of urban transport in Delhi and Stockholm. *Cities*, 421-429.

Toth-Szabo, Z., Várhelyi, A., Koglin, T., & Angjelevska, B. (2011). *Measuring sustainability of transport in the city – development of an indicator-set.* Lund, Sweden: Department of Technology and Society, Lund University.

Tsamboulas, D. (2001). Parking Fare Thresholds: A Policy Tool. *Transport Policy, 8*, 115-124.

UITP. (2011). *Towards low/zero-carbon urban mobility in Europe.* Brussels, Belgium: International Association of Public Transport.

UN Habitat. (2004). *Urban Indicator Guidelines.* Kenya: UN Habitat.

UNEP. (2015). *Promoting Low Carbon Transport in India.* UNEP. Retrieved from http://www.unep.org/transport/lowcarbon/PDFs/LCT_ProjectBooklet.pdf

United Nations. (2008). *World urbanization prospects - The 2007 revision.* New York, USA: United Nations.

United Nations Department of Economic and Social Affairs. (2014). *Population facts- Our urbanizing world.* USA: United Nations.

Verbruggen, H., & Kuik, O. (1991). *In search of indicators of sustainable development.*

VTPI. (2016). *Well measured: Developing Indicators for Sustainable and Livable Transport Planning.* Victoria, Canada: Victoria Transport Policy Institute. Retrieved from http://www.vtpi.org/wellmeas.pdf

Appendix I- Low Carbon Mobility Measures

Economic

- Financial incentives for LEVs
    - Exemption of LEVs from congestion/environmental tax
    - Exemption of LEVs from parking charges
    - Exemption of LEVs from Road tax
    - Exemption of LEVs from vehicle registration tax
    - Financial incentives for shared mobility modes
    - Subsidies for alternative fuel
- Traffic demand control
    - Fossil Fuel price control
    - Parking control through pricing
    - Tax on fossil fuels
    - Traffic Control through congestion/environmental fee
    - Traffic Control through road tax
    - Traffic Control through vehicle registration tax

Informative

- Mobility information systems
    - ICTs for live traffic information
    - ICTs for multi modal mobility network
- Sectoral collaborations
    - Working with companies and schools to plan and implement mobility of employees
    - Working with companies to procure LEVs for company vehicle fleet

Infrastructure

- Biking infrastructure development
    - Increasing bicycle parking facilities
    - Increasing the length of bicycle paths
- LEV infrastructure development
    - Charging station installation
    - Transition to LEV municipal fleet-create demand
- Public transport infrastructure development
    - Increasing public transport capacity-increasing public transport frequency
    - Increasing public transport capacity-increasing public transport lines/fleet size
    - Integration with motorized modes-Presence of park and ride facilities
    - Integration with non-motorized modes-Presence of bicycle carriers in public transport vehicles
    - Integration with non-motorized modes-Presence of bicycle parking stations near public transport vehicles
- Road infrastructure development
    - Road infrastructure development
    - Tunnel road network to meet demand in compact cities
- Walkability infrastructure development

    - Increasing sidewalk length

Infrastructure + Regulatory

- Concentrated urban development
    - Compact Development
    - Transit corridor development

Regulatory

- Fuel Efficiency control
    - Fuel Economy standards
    - Fuel quality restrictions
    - Vehicle emission standards
- Traffic demand control
    - Parking capacity control
- Zoning
    - Low Emission zones

Technology

- Fuel Efficiency control
    - New motorized mobility services
    - New non-motorized mobility services
- LEV infrastructure development
    - Access to alternative fuels at fossil fuel stations
    - Alternative fuel company collaboration-market attraction
    - LEV company collaborations-market attraction
- Sectoral collaborations
    - Promotion of use of telecommunications for meetings

Appendix II-Indicators, parameters and data for the construction of the low carbon mobility score

Avoid-shift-Improve	Indicators	Parameters	Stockholm	Copenhagen	Oslo
Avoid	Compaction	Density	4796.20	6800.00	4265.78
Avoid	Infrastructure	Increasing the length of bicycle paths	4053.19	4713.88	4615.38
Avoid	Uptake	Modal share of Journeys by bike	0.09	0.36	0.05
Avoid	Uptake	Modal share of journeys by walk	0.36	0.17	0.32
Avoid+Improve	Infrastructure	Financial incentives in the form of loans or subsidies for purchasing regular/electric bicycles	0.00	1.00	1.00
Avoid+shift	Infrastructure	Integration with non-motorized modes-allowance of bicycles on public transport busses	0.00	1.00	1.00
Avoid+shift	Infrastructure	Integration with non-motorized modes-allowance of bicycles on public transport metros and light rail	1.00	1.00	1.00
Avoid+shift	Infrastructure	Integration with non-motorized modes-Presence of bicycle carriers in public transport vehicles	0.00	1.00	0.75
Avoid+shift	Infrastructure	Integration with non-motorized modes-Presence of bicycle parking stations near public transport stations	1.00	1.00	1.00
Avoid	Infrastructure	Restricted motorized vehicle use in commercial zones/Pedestrian	1.00	1.00	1.00

		streets/Car free zones/auto free zone			
Improve	Access Management	Exemption of LEVs on bus lanes	1.00	1.00	0.00
Improve	Financial Incentives for LEVs	Exemption of LEVs from congestion/environmental tax	1.00	0.00	1.00
Improve	Financial Incentives for LEVs	Exemption of LEVs from parking charges	1.00	1.00	1.00
Improve	Financial Incentives for LEVs	Exemption of LEVs from Annual Road tax/Circulation fee	0.00	0.00	0.50
Improve	Financial Incentives for LEVs	Exemption of LEVs from vehicle registration tax	0.00	0.50	0.50
Improve	Financial Incentives for LEVs	Incentives for shared mobility modes-lower cost of tolls/tax/exempted from driving in the bus lane	1.00	1.00	0.00
Improve	Financial Incentives for LEVs	Subsidies for alternative fuel	1.00	0.00	1.00
Improve	Financial Incentives for LEVs	Exemption of LEVs from VAT	0.00	0.00	0.50
Improve	Fuel Efficiency control	Fuel quality restrictions	10.00	500.00	10.00
Improve	Fuel Efficiency control	Vehicle emission standards	4.00	4.00	6.00
Improve	Fuel Efficiency control	New motorized mobility services-ride shares, carpools etc..	1.00	1.00	1.00
Improve	Fuel Efficiency control	New non-motorized mobility services-bike shares/rentals	990.00	1860.00	1000.00
Improve	LEV infrastructure development	Charging station installation	300.00	600.00	1000.00
Improve	LEV infrastructure development	Transition to LEV municipal fleet-create demand	0.98	0.85	0.27
Improve	LEV infrastructure development	Access to alternative fuels at fuel stations	0.40	0.10	0.10

Improve	LEV uptake	LEV company collaborations-market attraction	0.05	0.10	0.15
Shift	Access Restriction	Low Emission zones	1.00	1.00	0.00
Shift	Access Restriction	Bus only lanes	1.00	1.00	1.00
Shift	Mobility information	ICTs for live traffic information	1.00	1.00	1.00
Shift	Mobility information	ICTs for multi modal mobility network	1.00	1.00	1.00
Shift	Public transport infrastructure development	Integration with motorized modes-Presence of park and ride facilities	3136.00	1082.00	6300.00
Shift	Public transport infrastructure development	Mass rapid transport system	1.00	1.00	1.00
Shift	Public transport infrastructure development	Connecting major comerical, residential and employment hubs	0.78	0.35	0.21
Shift	Public transport uptake	Increasing public transport capacity-increasing public transport frequency	0.30	0.20	0.26
Shift	Traffic demand control	Tax on fossil fuels	1.00	1.00	1.00
Shift	Traffic demand control	Traffic Control through congestion/environmental fee	6.47	0.00	10.00
Shift	Traffic demand control	Traffic Control through Annual Road tax/Circulation fee	1.00	1.00	0.00
Shift	Traffic demand control	Traffic Control through vehicle registration tax	0.00	0.93	0.20
Shift	Traffic demand control	Parking control through pricing	4.00	4.00	2.68
Shift	Traffic demand control	Parking capacity control efforts	0.00	1.00	1.00
Shift	Traffic demand control	Parking control-off street / non-sidewalk parking	1.00	1.00	0.00
Shift+Avoid	Compaction	Proximity	0.65	0.30	0.38
Shift	Traffic demand control	Traffic Control through VAT	0.25	0.25	0.25