# Sourcebook on Energy Efficient and Sustainable Urban Transport

**DISCLAIMERS**

The findings, suggestions, and conclusions presented in this publication are entirely those of the authors and should not be attributed in any manner to the Copenhagen Centre on Energy Efficiency, or the UNEP-CCC.

**December 2022**

# Preface

The transport sector has become one of the major sources of both local and global emissions. Today, around a quarter of global $CO_2$ emissions come from the transport sector. Of this, nearly 80% are from the road transport sector alone. An overall increase in GDP and incomes is driving demand for increased mobility and comfort in almost all countries.

While the global impacts from transport emissions may not be perceived in the short term, the local impacts of these emissions, including noise pollution, particularly on residents living in crowded urban settings, are perceived, almost instantaneously. These emissions, both air and noise pollution, have severe impacts on human health such as respiratory diseases (due to high levels of pollutants) and stress (due to high noise levels).

Despite this growing crisis, not enough has been done to curb urban transport emissions. Yet, a range of policy measures and instruments are available, meaning that rapid change is possible with concerted effort. This Sourcebook aims to create awareness about the negative impacts of energy inefficient, highly polluting, and unsustainable urban transport systems, among Urban Mayors, decision-makers, practitioners, and municipality representatives in small, medium, and large cities in developing countries. More importantly, the Sourcebook also presents in an accessible format, the available policy measures, which in many cases are low-cost measures, that can be embraced to tackle the challenge of shifting to sustainable urban transport systems.

In short, our objective with this Sourcebook is to support relevant stakeholders to make progress towards SDG 11, and in particular, target 11.2 which is to "provide access to safe, affordable, accessible, and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons".

**Gabriela Prata Dias**
Copenhagen Climate Centre

# Acronyms

| | |
|---|---|
| B2B | Business to business |
| B2C | Business to consumer |
| B2G | Business to groups |
| BMs | Business models |
| BMCS | Business model canvas for sustainability |
| BRT | Bus Rapid Transit |
| CBA | Cost Benefit Analysis |
| $CO_2$ | Carbon dioxide |
| CNG | Compressed natural gas |
| C2E2 | Copenhagen Centre on Energy Efficiency |
| EE | Energy efficiency |
| EIB | European Investment Bank |
| EVs | Electric vehicles |
| FI | Financial instruments |
| GHG | Greenhouse gas |
| IEA | International Energy Agency |
| LCMP | Low-carbon Comprehensive Mobility Plan |
| LIB | Lithium-ion batteries |
| Mtoe | Million tonnes equivalent |
| MBtu | Million British thermal unit |
| MCDA | Multi-Criteria Decision Analysis |
| NDC | Nationally determined contribution |
| NOx | Nitrogen oxides |
| NMT | Non-motorised transport |
| PM | Particulate matter |
| PPP | Public-private partnership |
| PSP | Peer-to-peer |
| PT | Public transport |
| RP | Revealed preference |
| SOx | Sulphur oxides |
| SP | stated preference |
| UNEP-CCC | United Nations Environment Program Copenhagen Climate Centre |
| VAT | Value added tax |
| V2G | Vehicle to Grid |
| WEO | World Energy Outlook |
| WTA | Willingness to accept |
| WTP | Willingness to pay |

# Contents

# Tables

# Figures

# Introduction

## Rationale

The rapid urbanisation and economic growth that has occurred in many developing countries during the last decades has led to, among other things, a steadily increasing demand for comfort and mobility. This has led to increased congestion and levels of both local and global emissions. The situation has been exacerbated by old and energy-inefficient vehicles (both private and public), and the existence of policies favouring private transport instead of public transport and non-motorised transport (NMT), such as biking and walking.

There exist various cost-effective policy measures, that can be easily implemented to curb this development, yet these have not been fully or consistently utilised in most non-OECD countries. One of the likely reasons is the existence of several barriers such as the lack of political will, which to some extent reflects the generally low levels of awareness about the negative impacts that unsustainable transport systems pose on the environment and society. Further, there is a general lack of understanding about the social, economic, and environmental benefits of more energy-efficient, sustainable, and equitable urban transport systems. Another likely reason is the lack of knowledge about the policy measures, often tried and tested elsewhere, that can be implemented to achieve more sustainable and equitable urban transport. Reversing this trend requires increased awareness among politicians and decision-makers at the national and city level and strengthened capacities to assess and implement the available policy measures.

Against this background, we see the need to raise awareness and strengthen the necessary capacity among city mayors, decision-makers, practitioners, as well as municipality representatives in developing countries to enable the implementation of the necessary policy measures. As such, this Sourcebook is an attempt to guide these stakeholders to select relevant policy measures, to enable the widespread uptake of more energy-efficient, sustainable, and equitable urban transport systems in their cities.

The relevance and appropriateness of policy measures may vary depending on local circumstances, such as the size of the city, existing transport infrastructure, and current and future demand for transport, amongst others. As an overall policy goal, greater energy efficiency (EE) will help reduce fuel consumption and both local and global emissions, thus delivering a range of social and environmental co-benefits. Promoting and facilitating a switch from private vehicles to non-motorised (NMT) transport is another cost-effective policy measure. There is a range of economic incentives/disincentives available to policymakers, introduced in many countries with positive results.

## Objective

This Sourcebook was developed by the Centre on Energy Efficiency (C2E2) under the United Nations Environment Program Copenhagen Climate Centre (UNEP-CCC) with a twofold objective in mind. Firstly, to raise awareness about the negative impacts of unsustainable, inefficient, and inequitable urban transport systems among city majors, policymakers and decision-makers, transport authorities, municipality representatives and their advisors in small, medium, and large-sized cities in developing countries. Secondly, to guide the stakeholders to design and implement more sustainable urban transport in their cities.

## Scope

The Sourcebook focuses on the various policy measures that can be implemented to make road transport in urban areas more sustainable and equitable. Although the policy measures suggested in this Sourcebook are primarily intended for implementation in cities in developing countries, they are, depending on the local circumstances, also applicable to cities in developed countries. Before going in-depth into the suggested policy measures, the Sourcebook describes the current situation for urban transport in many cities around the world. It presents some definitions of sustainable and equitable transport, the benefits of sustainable and equitable urban transport, as well as the negative impacts (both local and global) of unsustainable and inequitable urban transport.

## Audience

The Sourcebook is intended for city mayors, decision-makers, practitioners, as well as municipality representatives and other related stakeholders in small, medium, and large-sized cities in developing countries interested in improving current transport systems in their cities by making them sustainable and equitable, reducing local and global emissions at the same time. The Sourcebook is designed to be simple and as short as possible, divided into modules that can be understood in separation.

## How to use the Sourcebook

Although the modules of the Sourcebook can be used independently of one another depending on the user´s needs, it is recommended that the Sourcebook is read sequentially and in its entirety. This is because the Sourcebook has been developed and structured cohesively, with modules linked to each other. Going through the whole Sourcebook will allow the reader to understand the potential policies and policy measures available, and what is required for them to be successful.

## Content and Structure

The Sourcebook is composed of nine (9) modules as follows:

**Module 1** sets the context and provides the basis for a better understanding of what sustainable and equitable transport means.

**Module 2** presents in detail several technical options that in some cases may be capital intensive.

**Module 3** presents several non-technical options that could be implemented at a very low cost.

**Module 4** provides a general overview of the barriers encountered when trying to implement (technical and non-technical) solutions and policies applicable to urban transport.

**Module 5** introduces different business models (BMs), financial instruments, and risk-sharing mechanisms.

**Module 6** discusses methods and policies that make transport more energy efficient by managing transport demand.

**Module 7** discusses the availability of big data sources and how these can be used for planning energy-efficient transport.

**Module 8** briefly introduces two widely used approaches to assessing the social and environmental costs and benefits of sustainable transport options.

**Module 9** discusses training needs for implementing efficient energy transport in a developing country context.

Below is a more detailed description of the content of each of the modules.

**Module 1**. This module sets the context by briefly describing the current situation characterising the urban transport sector, in terms of emissions and impacts. Having a clear and common understanding among city mayors, municipality representatives, and their advisors about sustainable and equitable transport is crucial when assessing potential policy measures. The module provides the basis for a better understanding of what sustainable and equitable transport means. It also discusses how it can be achieved by briefly introducing a series of technical and non-technical options, which depending on the prevailing conditions of the city, could be chosen, and implemented in small, medium or/and large-sized cities.


Nelson Ndongala, Unsplash

**Module 2**. This module presents several well-accepted technical options that could help transform urban transport sectors to become more energy-efficient, equitable and sustainable. Some of these options are more applicable to small-sized cities while others are more applicable to medium and large-sized cities. The module gives a general overview of how these options perform in terms of mitigation potential, relative to a base case technology and the co-benefits they can deliver. Finally, the module presents the policy options available at the national and city level that can be used to promote these technical options, considering the barriers they may face, in particular financing.


Phuoc Anh Dang, Unsplash

**Module 3**. This module presents several non-technical and low-cost options that could contribute to a more energy-efficient, equitable, and sustainable urban transport sector. The module is, therefore, more applicable to small and medium-sized cities. The module provides the policy options that can be used to promote these non-technical options.


Sam te Kiefte, Unsplash

**Module 4**. The various technical and non-technical options suggested in modules 2 and 3 will face, most likely, several barriers which may hinder their implementation. Module 4 therefore provides a general overview of the most common barriers encountered when implementing policy measures through technical and non-technical solutions to achieve more energy-efficient, equitable, and sustainable urban transport. The module suggests a four-step process for the identification and analysis of the barriers. It furthermore discusses how to design potential measures to remove these barriers. It is recommended to involve all relevant stakeholders throughout the policy design process, from the very beginning to secure both expert insights and stakeholder buy-in.


Unsplash

**Module 5**. As discussed in Module 4, a lack of economic resources is one of the key barriers to achieving more environmentally friendly urban transportation systems. Therefore, this module presents examples of business models (BMs) and financial instruments (FIs) required to enable more sustainable urban transport systems to be turned into bankable projects.


Jason Goodman, Unsplash

**Module 6**. discusses methods to manage demand for urban transport. This includes methods that can be used for population projection in the context of sprawling cities, integrated approaches to green and energy-efficient transport, and how urban planning and investments in transport infrastructure can lead to improved demand for energy-efficient transport modes. Thus, this module discusses methods that encourage modal shift from cars to more environmentally friendly modes and to reduce overall vehicular transport. Moreover, the module elaborates on how to integrate green transport with other urban systems, climate change and sustainable development.


Finn, Unsplash

**Module 7**. Discusses the availability of big data sources and how these can be used for planning energy-efficient transport.


Carlos Muza, Unsplash

**Module 8**. The different options, both technical and non-technical covered in modules 3 and 4, will be difficult to implement if we only look at the financial returns. However, the options are widely acknowledged to have substantial mitigation benefits and other social, economic, and environmental co-benefits. Therefore, this module briefly introduces Cost Benefit Analysis (CBA) and Multi-Criteria Decision Analysis (MCDA) tools, which are commonly used to quantify the benefits of specific technology options, prioritise, and select these in a rational and objective manner.


Marvin Meyer, Unsplash

**Module 9**. This final module synthesises the content of the previous modules to develop a model training program, keeping in mind the present and future skills and knowledge requirements for energy-efficient and sustainable transport.


Campaign Creators, Unsplash

# Module 1. Sustainable and Equitable Urban Transport: context, definitions, and the impacts of unsustainable transport

## 1.1 SETTING THE CONTEXT

Transport is not only about negative externalities; societies need to function by providing several necessary services, transport being one of them. It makes possible the movement of people and goods, which is fundamental for life. Transport allows people to access health care, education, culture, and other amenities. Freight transport moves goods necessary for living and makes them accessible to consumers. However, for the transport sector to continue to provide these services in a way that is not harmful to the environment and societies, it must become environmentally friendlier, sustainable, and equitable. A sustainable and equitable transport sector will also make cities, particularly urban areas, more liveable.

Unfortunately, in many urbanised cities around the world, and in particular cities in developing countries, the road transport sector is associated instead with severe congestion (due to a large number of private vehicles, taxis, and buses), and high levels of air pollution (due to old, fuel-inefficient, and highly polluting vehicles). This has given rise to levels of local emissions such as particulate matter (PM), nitrogen oxides (NOx) and sulphur oxides (SOx) that often surpass the recommended standards. To a large extent, this can be attributed to policies that have favoured private motorisation instead of public and non-motorised transport (NMT).

According to the 2021 World Energy Outlook (WEO), the transport sector has had the fastest growth in $CO_2$ emissions of any sector during the last few years [1]. Of the total emissions from the transport sector, nearly 80% come from the road transport sector alone [2]. Figure 1.1 shows the $CO_2$ transport emissions trend during the last decade. Here we can observe a steady, although non-drastic, increase between 2010 and 2019, in both total and road transport emissions. The marked decline from the beginning of 2020 can be explained by the Covid-19 pandemic, during which economic activity was slowed down significantly, which led in turn to reduced demand for transport (both passenger and freight) and, therefore, reductions in the level of emissions. Nevertheless, although there is not much data available yet for 2021, there are reasons to believe the economic stimulus introduced by many countries led to economic recovery. This boosted in turn the demand for transport, and thereby, the levels of both global and local emissions have likely rebounded to pre-pandemic levels.

**Figure 1.1** $CO_2$ emissions transport sector (total and road), 2010 -2020.
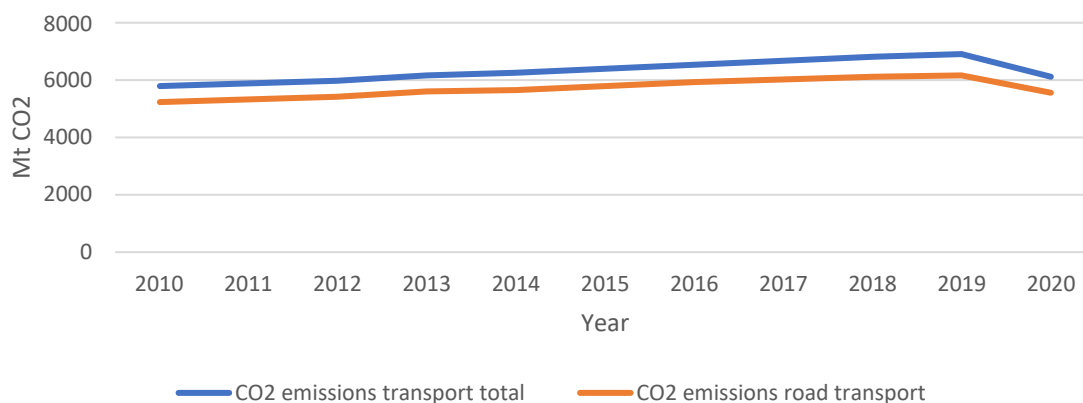


*Source: compiled by the author using data from ENERDATA.*

At the same time, the road transport sector offers significant potential for improvement through the implementation of a series of policy measures that could significantly contribute to achieving a more sustainable and equitable transport sector. In this context, we believe the distinction between a policy and a policy measure is needed. In this Sourcebook, we define a policy measure as the instrument or means used to achieve the objective of a specific policy (e.g., a more sustainable and equitable transport sector, reduction of emissions, behavioural change). For example, introducing an incentive/disincentive or implementing a campaign to promote a shift from private vehicles to public or NMT are all policy measures. Another example of a policy measure that can be implemented is the use of demand-side management; for example, promoting the ASI approach (avoid, shift, and improve), leading to changed behaviour among car owners. Where avoid refers to the possibility of avoiding the travel or reduce the distance of the travel, shift refers to the possibility of shifting, for example, from private car towards more friendly modes like non-motorised transport (walking and biking), and improve refers to the possibility of improving, for example, the fuel efficiency or/and the technology of the transport mode [3].

Policy measures do not need to be very capital intensive; they can be low cost and still generate significant benefits. Since capital-intensive investments are not always affordable, particularly not in developing countries, most of the policy measures suggested in this Sourcebook are low-cost measures, but that still may have significant positive impacts. For instance, improved fuel efficiency is considered one of the most cost-effective policy measures to decrease fuel consumption and thereby, emissions from road transport. Technically speaking, fuel efficiency refers to the distance a vehicle can travel with a certain amount of fuel (i.e., kilometres per litre). Thus, improving fuel efficiency means travelling the same distance with less amount of fuel or a longer distance with the same amount of fuel.

Significant fuel consumption and emissions reductions can be achieved through several fuel-efficiency improvement measures. These can be technical or non-technical or a combination of the two. Concerning technical measures resulting from fuel efficiency improvements, it is important to consider and mitigate the risk of car drivers eventually driving more. This is because the fuel savings generated by more efficient vehicles, or due to a change towards an environmentally friendlier driving style, (e.g., eco-driving), may encourage drivers to travel more often or for longer distances; something known as "the rebound effect". Therefore, it is advised to design and implement other supplementary policy measures that can be implemented in parallel. Some examples could be public awareness-raising

campaigns aimed at influencing car drivers to change their behaviour, the promotion of public transport use and non-motorised transport (NMT) like biking and walking, and pricing policies such as congestion charges and parking charges.

Technical policy measures could be, for example, the use of more fuel-efficient engines in vehicles, the installation of smart devices in vehicles that can guide the driver to a more friendly and thereby efficient driving style, the use of low-resistant tyres, and other similar measures.

Non-technical policy measures could be implemented through economic and non-economic incentives/disincentives such as fuel-pricing policies, toll roads and others. Another way of achieving reductions in fuel consumption is through improved driving techniques, which can be acquired in training courses like eco-driving. Eco-driving leads to friendlier and more relaxed driving, thus leading to lower fuel consumption and fewer traffic accidents.

However, despite the considerable potential the road transport sector represents in terms of emissions reductions, and in terms of becoming an environmentally friendlier and more sustainable sector, not enough has been done to exploit this potential. One likely reason for this inaction is the existence of several barriers that are, in one way or another, hindering the implementation of the required policy measures. These barriers can be divided into market, financial and technical. Market barriers are normally associated with weak existing regulatory frameworks, or simply the lack of them. Financial barriers can be in the form of limited budgets and high capital investment costs (depending on the policy measure). Technical barriers can be present in a lack of capacity among transport authorities, either at the city or municipality level, and a lack of familiarity with the available technical policy measures.

Another common barrier is the lack of political will among politicians and decision-makers; this is often due to a lack of awareness about the negative impacts unsustainable transport systems pose on the environment and society. To change this attitude among politicians, awareness-raising activities (e.g., information and dissemination campaigns) are needed.

In this context, it is also important to mention that the appropriateness of the policy measure/s to be implemented may vary depending on several local circumstances such as the size of the city, existing transport infrastructure, culture, and current and future expected demand for transport, amongst others. All these factors should be considered before deciding which policy measure is to be implemented. The absence of a thorough analysis regarding prevailing local conditions may jeopardise the expected outcome of a policy measure, or not deliver the expected result in full.

## 1.2 DEFINING SUSTAINABLE TRANSPORT

The definition of sustainable transport and how it is understood among politicians, policymakers, practitioners, and other transport sector stakeholders becomes crucial. Several definitions have been used in the transport policy literature, and it is difficult to choose one. However, one relevant definition of sustainable transport is the one given by Richardson as "one in which fuel consumption, emissions, safety, congestion, and social and economic access are of such levels that they can be sustained into the indefinite future without causing great or irreparable harm to future generations of people throughout the world" [4]. Complementing this, Rassafi and Vaziri state that "sustainable development with special focus on transportation can be measured by the degree of conformity between environment, economy, and social aspects on one hand, and transportation on the other hand" [5]. Another definition of sustainable transport is: "The goal of sustainable transportation is to ensure that environment, social and economic considerations are factored into decisions affecting transportation activity" [6]. We believe the first definition mentioned here makes a lot of sense, and it is also very much in line with what we understand as sustainable transport, and what a transport system should strive to achieve.

Thus, the definition of sustainable transport embraces several elements that together, as indicators, can show the degree of sustainability a transport system has or whether it is sustainable or not. Fuel efficiency is one of those elements, and improvements in fuel efficiency will contribute to a more sustainable transport system by reducing the amount of fuel used and, by extension, emissions levels.

Road and vehicle safety is another element, which as an indicator tells us how sustainable an urban transport system is. In this context, safety is associated with how safe passengers in private vehicles, public transport such as buses and taxis, as well as users of NMT, perceive the safety and quality of the infrastructure provided. For instance, in many countries, safety is an issue, especially for women who often experience harassment by other passengers or when walking to public transport access points, which in some cases are too distant for users, often require walking in the dark. Another aspect associated with the sustainability and equity of the transport sector is reliability. This is an important factor for many public transport users who have to plan and schedule their activities, relying on public transport systems that are often not punctual.

## 1.3 DEFINING EQUITABLE TRANSPORT

Transport equity can be defined as a situation where a particular mode of travel is safe, reliable, and improves mobility and accessibility, enabling all people to participate in socio-economic life. The process should lead to land use and transport systems that enable or improve health and wellbeing, environmental sustainability, and equitable access to resources, including workplaces and other amenities. Therefore, it also means that transport decisions are made with deep and meaningful community inputs and an understanding of the needs of different segments of the population.

To achieve equity, consultants, researchers, advocates, and governments must acknowledge and understand what equity is and, second, work to incorporate it into the internal structure of decision making in governments and relevant organisations. Specific proposals must ensure that the needs and concerns of disadvantaged groups are recognised by including such groups throughout the entirety of the plan, project, or policy-making process. In other words, we must work both internally and externally to ensure equity considerations are incorporated into transport policy decision making.

When considering transport equity, due regard for vulnerable groups is very important, especially the elderly, women, and children. Often, the provision of mobility infrastructure and the situation of the elderly has restricted their mobility to the extent that many prefer not to travel, pushing the elderly towards living a life dependent on others. However, changing social structures often force these same groups to live an independent life, thus compromising their well-being. Systemic support and mobility options must be provided so that the elderly and disadvantaged can move freely [7]. As cities continue to grow and (in many places) their economies continue to develop, levels of congestion and land prices are likely to rise, potentially exacerbating the social exclusion of the urban poor. High land prices force the urban poor to either squat in the inner parts of the city or live in areas with low land and property prices, mostly located in the peripheral areas. Low-income dwellers in cities typically experience high levels of social exclusion. They are forced into long daily commutes to and from low-paying jobs on overcrowded public transport systems, for which fares continue to rise and are thus left with insufficient mobility choices, as walking and cycling are generally not an option for those trips. Thus, the debate on where the urban poor reside and how they can access their workplaces using public transport modes is central to a more sustainable future for cities in the developing world [8].

Therefore, plans and projects should be prioritised in areas home to the most disadvantaged and shaped to consider their needs and concerns. When it comes to cycling, for example, recent academic and non-academic literature, such as institutional reports, shows that concerns and barriers include physical safety, such as the presence and quality of public transport, pedestrian and cycling infrastructure; personal security, such as real or perceived concerns about crime and other threats. This may include concerns about personal safety; racism; policing and harassment; and fear of displacement from gentrification affiliated with cycling investments.

The space needed by various urban passenger transport modes varies greatly depending on the size and the speed of vehicles. For equity of transport, sufficient infrastructure must be provided for modes that are used by the vulnerable segment of the population. Past studies have shown that public transport (PT) and non-motorised transport (NMT) can be up to 20 times more space-efficient compared to a typical car. However, the proportion of road space and overall space allocated to these modes is significantly less than the space allocated for cars and other personal vehicles.

Transport planning scenarios developed for the Low-carbon Comprehensive Mobility Plan (LCMP) prepared for the city of Rajkot in India are used to demonstrate the method. The indicators show that significantly less space is used by transport in a scenario that promotes higher use of PT and NMT modes, in comparison to the business-as-usual scenario. This provides evidence to alleviate chronic congestion expected from a car- and motorcycle-based transport development [9], [10].

Spatial equity is also a matter of concern. A significant indicator of marginalisation in Indian cities is the mismatch between infrastructure demand and supply. Accessibility studies have demonstrated how different areas within the same city enjoy variable amounts of accessibility to social infrastructures like schools and parks. Core areas of cities in developing countries, such as India, generally enjoy good levels of accessibility, while newly developing peripheral areas suffer most from the lack of adequate social infrastructure. Planning processes have failed to keep pace with market-led development. Sub-optimal levels of accessibility to social infrastructure can negatively affect human development, leading to increased marginalisation of communities. Land use plans should be such that there is a more equitable distribution of social infrastructure by preparing local accessibility plans using participatory methods [11], [12], [13].

## 1.4 THE SOCIAL, ECONOMIC, AND ENVIRONMENTAL IMPACTS OF UNSUSTAINABLE TRANSPORT

As mentioned above, the transport sector provides several benefits to society by making it possible for people to have access to various amenities and for food products and goods to be moved from one place to the other, eventually reaching consumers. However, if the transport sector is not sustainable and environmentally sound, it gives rise also to several negative externalities. For instance, road transport emissions can be divided into social (including public health), economic, and environmental (both local and global).

At the global level, the negative impacts, particularly those caused by steadily increasing levels of $CO_2$ emissions released into the atmosphere, are well known. For example, the increased average global temperature is having detrimental consequences such as melting glaciers, increased frequency of extreme events like droughts, flooding, and forest fires, some of which have been taking place in Australia and the USA, as well as in Europe during the last years. All these impacts are, most likely, irreversible. Increased levels of $CO_2$ emissions are also having direct and immediate impacts on the local environment. For example, the increased frequency of flooding has huge impacts on the local environment by severely affecting houses and in many cases, destroying them.

At the local level, negative externalities take the form of deteriorated urban settlements like buildings, parks, and monuments. However, the most significant externalities are the negative impacts on public health, particularly on the most vulnerable, children and the elderly. For instance, air pollutants like particulate matter (PM), especially if they are of enough small size (10μg or smaller) to bypass the respiratory system's own mucus filtering and penetrate the lungs. They may slow the ciliary function inhibiting the removal of harmful substances in the mucous flow, causing illnesses such as bronchitis.

In a similar way, pollutants like nitrogen oxides (NOx) can affect the respiratory tract, where nitrogen dioxides (NO2) are one of the most toxic pollutants. For example, one of the immediate symptoms, which can be observed at concentrations of around 0.5ppm NO2, is increased airway resistance. Intense exposure to NO2 decreases gaseous exchanges in the blood and increases respiratory symptoms leading to lower lung function [14]. Sulphur oxides (SOx) are formed when sulphur is burnt to affect the respiratory system and can be of severe concern in inner-city areas. The well-known 'pea soup' episode in London in December 1952 is one example of extremely high levels of SOx and PM (Figure 1.2).

All these negative externalities, whether they have an impact at the global level or at the local level (in both urban and rural areas), are also associated with economic implications. Climate change is already imposing considerable costs on societies due to necessary adaptation measures because of increased sea level, increased temperature and extreme events, and loss of income due to the productivity deterioration, leading to lower agricultural crop yields. Estimating the real long-term costs is difficult to calculate with certainty, though the impacts are incontrovertible and will result in higher public health costs and productivity losses.

Figure 1.2 London Smog



Unseen histories, Unsplash

Even today, extremely high concentrations of these pollutants can be found in several megacities worldwide, including Mexico City, Delhi, and Beijing. High levels of air pollutants also pose serious negative impacts on small and medium-sized cities, where the largest urban growth is expected to occur in the coming decades. The negative health impacts of these pollutants at high concentrations in inner cities may be worsened by local prevailing geographical conditions, e.g., cities located in a valley surrounded by mountains or other climatological conditions such as anticyclonic conditions and the occurrence of inversions during winter. Inversions are an atmospheric phenomenon that occurs when cold air, which sits closer to the ground than warmer air, traps air pollutants at low air layers, with the well-known consequences for human health.

Air pollution from road transport has a direct impact on human health, including premature death. The release of air pollutants like the ones already mentioned in inner-city areas, besides the severe impacts these pose on human health, also contributes to the deterioration of buildings, monuments, and the depletion of materials. Combined, these impacts directly affect the economy due to increased expenditures on health care, loss of life (due to premature death), and the restoration of buildings and monuments.

At the global level, the increased level of $CO_2$ emissions is causing severe impacts on the climate with consequences such as increased extreme weather events, higher temperatures, melting glaciers, and increased sea levels. Figure 1.3 shows the relationships between increased road transportation due to increased economic activity and its impacts on the environment (both local and global). Many of these impacts are already taking place in several countries, with the poorest countries being the most affected. For instance, low-lying countries and small island states are extremely exposed to increased sea level and are the first to face the impacts of climate change. At the same time these countries are not, on the whole, the ones characterised by large polluting industries, nor home to many vehicles.

Figure 1.3 Relationship between economic activity and the impacts of road transport.
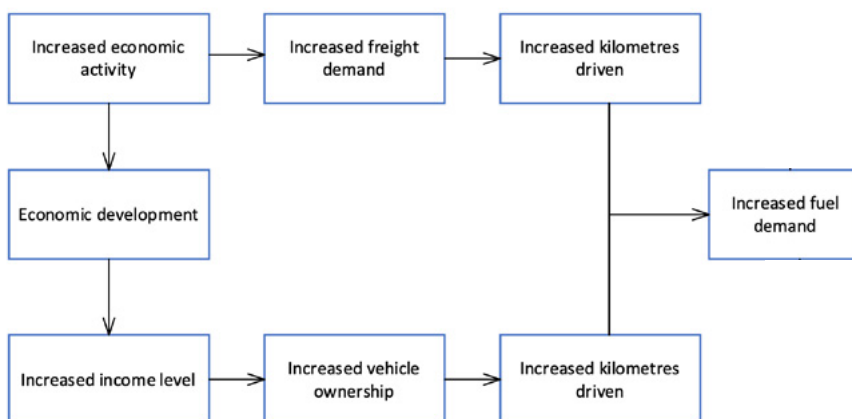


*Source: elaboration by the author*

9

# **References** - Module 1

[1] World Energy Outlook, 2021. International Energy Agency, www.iea.org/weo

[2] Mehaffy, M., Rogat, J., Litman, T., Gutierres B. Munshi, T. The Road Forward.

[3] https://onlinepubs.trb.org/onlinepubs/archive/conferences/sustainability/black.pdf

[4] TDM Encyclopedia, Victoria Transport Policy Institute (VTPI). Updated February, 2017

[5] Rassafi, A.A., Vaziri, M. Sustainable transport indicators: Definition and integration. Int. J. Environ. Sci. Technol. 2, 83–96 (2005). https://doi.org/10.1007/BF03325861A.A.

[6] https://www.vtpi.org/sus_iss.pdf

[7] Munshi, T., M. Sankar, and D. Kothari, Out-of-Home Mobility of Senior Citizens in Kochi, India, in Geographies of Transport and Ageing. 2018, Springer. p. 153-170.

[8] Brussel, M.Z., Mark; van den Bosch, Frans; Munshi, Talat; Van Maarseveen, Martin, Can the ur-ban poor reach their jobs? Evaluating equity effects of relocation and public transport projects in Ahmedabad, India (accepted for publication), in Measuring Transport Equity, K.M. Lucas, K.; Di Ciommo, F.; & Dupont-Kieffer, A., Editor. 2018 Elsevier Publishing.

[9] Will, M.-E., Y. Cornet, and T. Munshi, Measuring road space consumption by transport modes: Toward a standard spatial efficiency assessment method and an application to the development scenarios of Rajkot City, India. Journal of Transport and Land Use, 2020. 13(1): p. 651-669.

[10] Will, M.-E., Y. Cornet, and T. Munshi, Assessment of Physical and Ecological Space Consumed by Transport Modes: a Case of Rajkot City, India. 2018.

[11] Ilhamdaniah, T. Munshi, and S. Amer. Evaluating the planning for social infrastructure in Ah-medabad city, India. in Computers in Urban Planning and Urban Management (CUPUM), 2005 conference. 2005. UCL, London.

[12] Munshi, T., Z. Haque, and Y. Joseph, Examining Equity in Spatial Distribution of Recreational and Social Infrastructure in Delhi, in Marginalization in Globalizing Delhi: Issues of Land, Livelihoods and Health. 2017, Springer. p. 97-113.

[13] Munshi, T., W. Belal, and M. Dijst, Public transport provision in Ahmedabad, India: accessibility to work place, in Urban Transport X: Urban Transport and the Environment in the 21st Century, L.C. Wadhwa, Editor. 2004, Wit Press: South-ampton. p. 343-353.

[14] Jorge Rogat. The Value of Improved Air Quality in Santiago de Chile. Ekonomiska Studier, Handelshöskolan vid Göte-borg Universitet, 1998.

# Module 2. Technical options

## 2.1 FUEL SWITCHING

Fuel switching from petrol or diesel to alternative fuels is required, if the climate targets set in the Paris agreement are to be met. This is due to two main factors. Firstly, the rate of energy efficiency improvement has slowed. For example, the average fuel consumption of light-duty vehicles decreased by only 0.7 % between 2016 and 2017, slower than the 1.8 % improvement achieved, per year between 2005 and 2016 [1]. Secondly, alternative vehicles that can move us away from fossil fuels are still not ready to completely replace fossil-fuelled vehicles. Several countries have announced plans to stop sales of petrol and diesel engine vehicles from 2030 onwards. However, many developing countries are not ready to entirely go on that path and many countries have not even announced such targets. Therefore, overall, this means there will be a significant demand for petrol and diesel even after 2030. The IEA's Net Zero Scenario thus has a substantial share of oil, even in 2050 (Figure 2.1).

**Figure 2.1** Demand for Primary Energy in the IEA's Net Zero Scenario
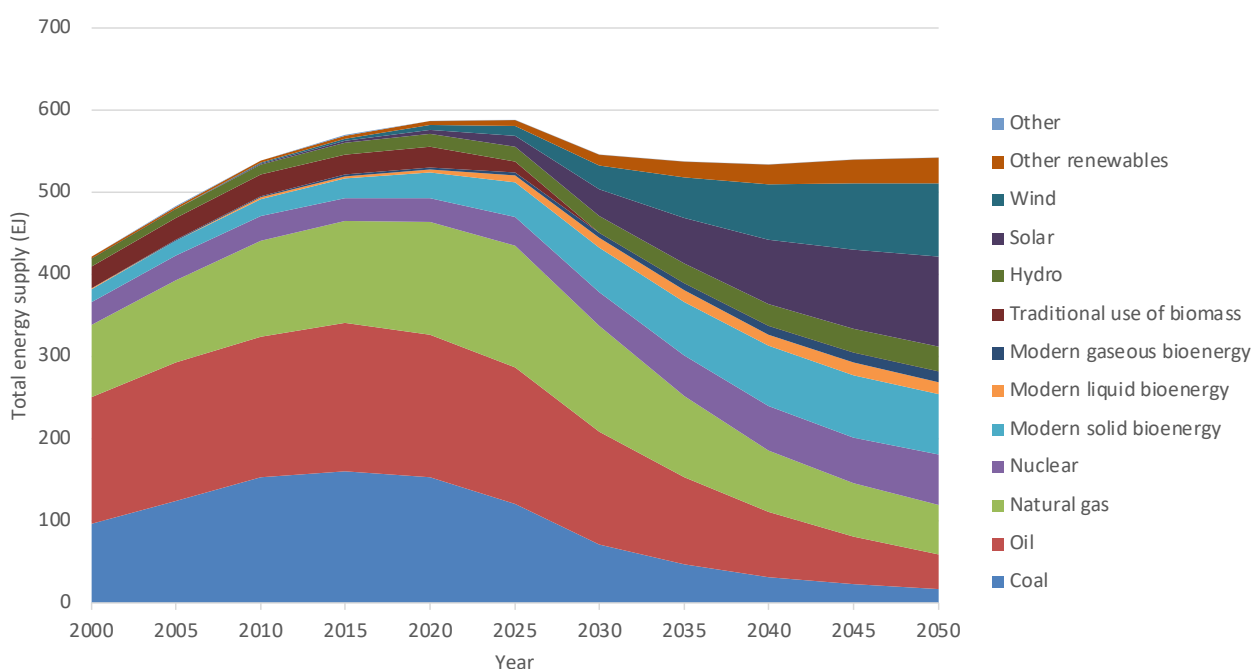


*Source: (2)*

Fuel switching to alternative fuels with lower or zero $CO_2$ emissions is essential to decarbonisation and to improving local air quality, especially in urban areas. Petrol and diesel engines are also responsible for a significant share of local pollution in particulates (PM10, PM2.5), NOx and SOx pollution. This is especially the case in developing countries, where the fuel standards are still many years behind those of most developed countries. There are three different categories of alternative fuels that can be used in place of petrol and diesel, i) Natural gas, ii) Biofuels and Synthetic fuels.

### *Natural Gas*

Natural gas from fossil fuels has been used as compressed natural gas (CNG) in vehicles, and the technology has a high level of readiness. CNG is particularly suitable for light- to medium-duty vehicles [3]. As a result, CNG vehicles have been widely deployed in some regions, particularly in Asia. For example, there are about 6 million CNG vehicles in China [4]. It is also easy to convert petrol-fuelled vehicles to run on CNG [5].

CNG vehicles have certain advantages over petrol and diesel vehicles. For example, they have lower emissions of air pollutants and moderate noise [6]. On the flip side, methane emissions during transportation and $CO_2$ emissions during combustion make them a less attractive option from a GHG mitigation standpoint [7].

In place of CNG coming from fossil fuels, biomethane can be used, which has all the advantages of CNG but has zero GHG emissions. Biomethane can be produced from organic matter such as crop residues, animal manure, municipal waste and woody biomass and the technical potential at the global level is put around 730 Mtoe, whereas the production in 2018 was only about 35 Mtoe [8]. However, the costs of biomethane are mostly above US $ 5 per MBtu [8], making it difficult to compete with Natural Gas, for which the prices are generally below the US $ 5 per MBtu. Overall, CNG can help in the short-term transition, while biomethane can be used for the longer-term transition to net-zero carbon emissions. However, for this to happen, a carbon tax on fossil fuels would be needed to make the business case for investment in biomethane production and consumption.

### Biofuels

An essential advantage of biofuels is that they are compatible with existing engine technologies for vehicles and refuelling systems. Therefore, despite the rapid expansion of electromobility, biofuels are seen as a possible option for mitigation action [9]. Furthermore, from the standpoint of national governments, biofuels help improve energy self-sufficiency and strengthen the agriculture sector [10].

The use of biofuels as a mitigation strategy will depend on the availability and costs of biomass feedstock and alternative mitigation options. For example, ethanol from corn and sugarcane is commercially available in Brazil and the United States, and biodiesel from oil crops and fatty acids are commercially available in Europe [9]. However, the production of biofuels using corn, sugarcane, and oil crops has been sometimes criticised because it takes away land for food and/or leads to deforestation.

To address these concerns, there has been a focus on developing advanced biofuels from lignocellulosic feedstocks, thus minimising the agricultural sector trade-offs. However, technology development has been slow and has not achieved full commercial scale. There are, however, several commercial-scale advanced biofuels projects in the pipeline [9], and

their success will be vital if biofuels are to offer a viable and large-scale impact on emissions reductions. The production of biofuels also involves costs in collecting, storing, and transporting crop residues [11], limiting the size of bio-refineries. Overall, the long-term sustainable path is based on advanced biofuels; however, costs need to come down, and a carbon tax on fossil fuels can help in improving the business case for biofuels. In addition, Biofuels will be competitive in heavy-duty vehicles such as trucks and buses where EVs have not been able to achieve commercial success.

### Synthetic fuels

Synthetic fuels have similar properties compared to petrol and diesel and therefore can be used in existing vehicles or in places where electrification of vehicles is not easy. Synthetic fuels can be produced from green hydrogen and $CO_2$. Green hydrogen is produced via electrolysis, where electricity produced from renewables is used to separate the hydrogen that is bonded to oxygen in water [12]. $CO_2$ can come from a CCS plant associated with a fossil fuel or biomass gasification facility. Technologies for green hydrogen and CCS are well advanced; however, low-carbon synthetic fuel production is still at the demonstration stage.

Cost is the main barrier to the production of synthetic fuels. The cost of producing green hydrogen is USD 5.50/kg H2, and if we consider the cost of $CO_2$ as USD 100 per ton of $CO_2$ and a cost of 0.05 per litre in the production of synthetic diesel from H2 and $CO_2$ [12] then the cost of a litre of synthetic diesel will be USD 1.70. In addition, synthetic fuels, in contrast to EVs, have a much lower total energy efficiency [13]. Therefore, synthetic fuels are not seen as an option for road transport in the coming future since it is more efficient to go for electrification.

## 2.2 ELECTRIFICATION OF VEHICLES

Electrification has been recognised as a critical technology for decarbonising Light-Duty Vehicles [14]. However, large-scale diffusion of EVs for other road transport modes such as heavy-duty vehicles will depend on improvements in energy density (energy stored per unit volume), specific energy (energy stored per unit weight), and costs [15]. Several countries have already achieved more than a 2% share in Electric Vehicles (EVs) sales, with many countries having even crossed a 10% share of new car sales (Figures 2.2a and 2.2b).

**Figure 2.2** Share of EV sold across countries
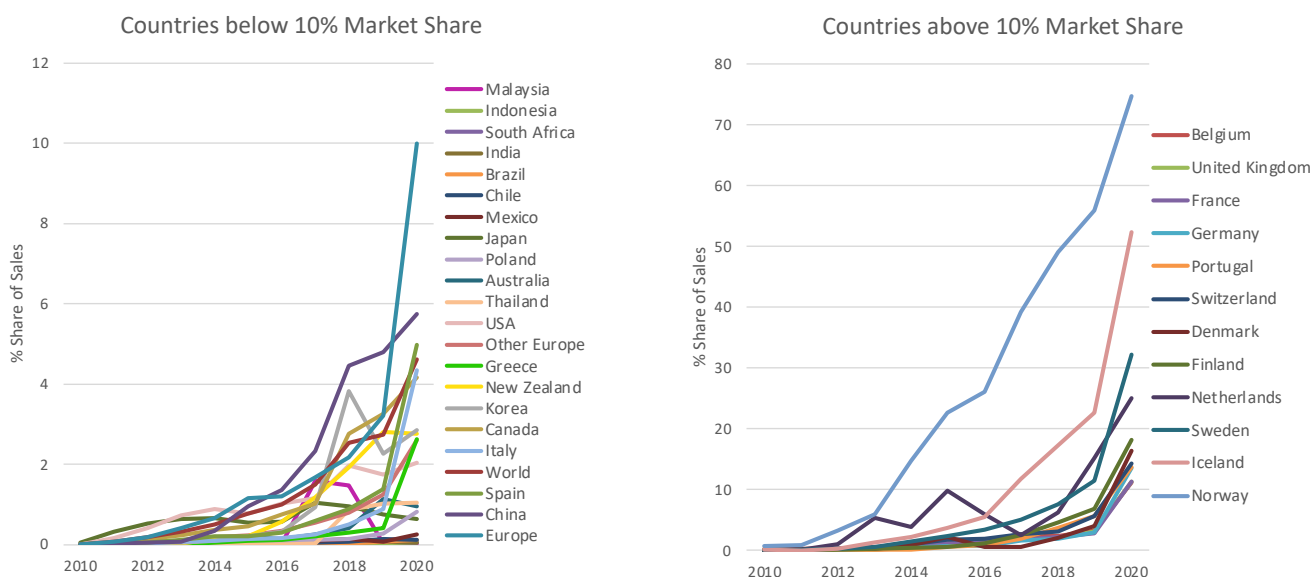
EVs have zero local pollution and are therefore a good solution for cities trying to improve their air quality. Moreover, EVs offer a significant mitigation option if electricity generation is decarbonised. Since an increasing share of renewables is central to most NDCs for countries, assuming progressive decarbonisation of electricity across countries is safe.

A major cost of EVs is batteries, though several battery technologies can be used for EVs. Historically, lead-acid batteries, nickel batteries, high-temperature sodium batteries, and redox flow batteries were used [16]. However, these battery technolo-

gies have not gained much traction for large-scale applications for EVs either due to their low energy density, low cycle life, or high costs. Lithium-ion batteries (LIB) started to be used for commercial applications around 2000 and have, relative to others, e.g., lead-acid batteries, very high energy density and higher cycle lives. Further, LIBs have witnessed a continuous reduction in costs of more than 10% per year, bringing the battery prices very close to the US $100 per Kwh mark (Figure 2.3). $100/Kwh is considered a price level where EVs will become commercially viable for LDVs with little need for incentives from the government. Therefore, most EVs currently use LIBs.

**Figure 2.3** Battery Pack Prices (LIBs)
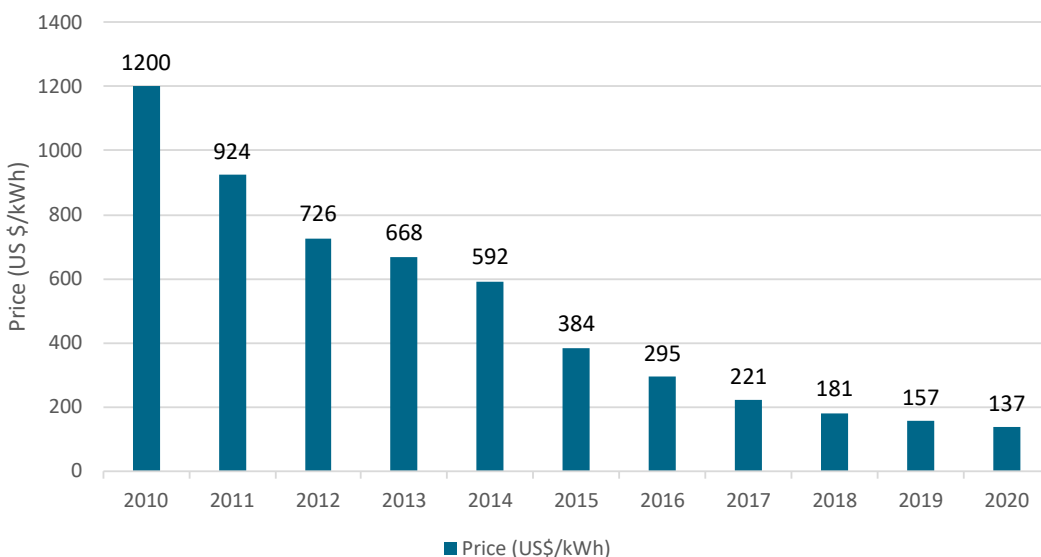
In cities, vehicles can be broadly categorised as private or public. Private vehicles are typically owned and operated by an individual for their use and are taxed differently from vehicles for public use. Public vehicles can be owned privately or publicly, but they will be used for public purposes, where individuals pay a fare for using the transport. In terms of vehicles, two-wheelers and cars are commonly used as private vehicles whereas buses, three-wheelers, rickshaws, and taxis are considered public. There has also been a rapid growth of micro-mobility in public vehicles, including e-bikes and e-scooters. Private vehicles, compared to public vehicles, are used less intensively, which has various implications in terms of owning and operating costs, charging and battery sizes.

### a) Private vehicles

Studies focused on private vehicles show that despite a decline in EV prices, the up-front costs continue to be a significant barrier to EV uptake in developing countries [17][18]. In countries where EVs make up >2% of the market (Figure 2.2), they have received either a purchase subsidy on the upfront price of cars or a reduction in taxes and registration fees, e.g., in Norway, EVs are exempt from paying VAT (25%) and three other purchase taxes levied on non-EVs. EVs have lower operating costs than petrol cars; however, since private vehicles run fewer kilometres in a month, it takes much longer to achieve financial break-even.

The driving range, defined as the distance an EV can drive before it needs to be recharged again, is a significant barrier for EVs [17][18]. Typically, the driving range is related to the size of batteries, and a larger battery can give a longer range, however, since batteries are expensive, there is a fundamental trade-off. The existence of 'range anxiety' is also related to the availability of charging points and time required for recharging. Easily available and reliable charging infrastructure can help overcome driving range anxiety [19]. Charging can happen for private vehicles at the home, office, shopping centre, etc. Since most people spend a large part of their time at home, most charging (varies between 75-90%) has been reported to take place at or near homes [20][21]. Charging at home can happen using home charging or public chargers, e.g., for apartment dwellers where having an individual charger is not feasible. Public charging can occur using AC (slower) and DC (fast) charging, and of late, the share of DC chargers has shown a quicker increase [22]. Public charging, despite having a smaller percentage of overall charging demand, plays a significant role in alleviating the range anxiety of users. Public charging locations should be strategically located, e.g., at workplace parking and transit stations. The creation of public charging requires collaboration between automakers, utilities, and policymakers. Policy support is needed for planning policy, building regulations, and financial support.

An essential aspect of the policy is to harmonise the charging standards to achieve interoperability between charging stations, enable smart charging and provide data to the consumers on their charging sessions [23]. Currently, there are different charging standards available across countries, e.g., CCS2 in Europe [24] and GB/T in China [25].

Electric vehicle charging can put an additional demand on electric grids; however, if properly planned and integrated EV charging can help in supporting the grid if used in combination with 'smart' demand-management technologies. EVs are charged as soon as they are connected to the grid irrespective of grid condition, if there is no planning and integration. This can cause problems if the grid is overloaded. However, two concepts are increasingly used within the broad umbrella of smart charging. The first is 'managed charging', whereby EVs are charged only when high levels of renewable power are supplying the grid, or when demand is low. Managed charging also allows utilities to regulate the rate of charging. The second is Vehicle to Grid (V2G), where vehicles can both receive and provide electricity back to the grid [26]. Smart charging is expected to place transport systems at the centre stage of energy storage and grid balancing [27].

### b) Public vehicles

Among public vehicles, micro-mobility modes such as e-bikes and e-scooters, there was a surge in 2020, with around 650 cities having some micro-mobility initiative in 2021 [22]. The growth in these initiatives has been facilitated by the construction of bike lanes and other city policy initiatives. E-rickshaws are mainly popular in Asia, where they have either replaced cycle rickshaws (run manually) or three-wheelers that run on petrol/diesel. However, the exact number of rickshaws is unknown since vehicle registration authorities have not registered many. However, many vendors supply them at prices below those of petrol/diesel three-wheelers.

E-bus registrations have not shown the growth witnessed in other vehicle segments, and more than 95% of the bus registrations are in China (Figure 2.4). In China, the demand for e-buses is mainly due to initiatives by municipalities aimed at reducing air pollution [22]. However, the capital costs for the e-buses are the main barrier. An upfront capital subsidy of USD 100,000 is needed at current prices to achieve price parity with conventional diesel buses.

**Figure 2.4** Electric Bus registrations across regions



Number of Buses

2010  2011  2012  2013  2014  2015  2016  2017  2018  2019  2020

■ China  ■ Europe  ■ Rest of Asia  ■ Rest of World
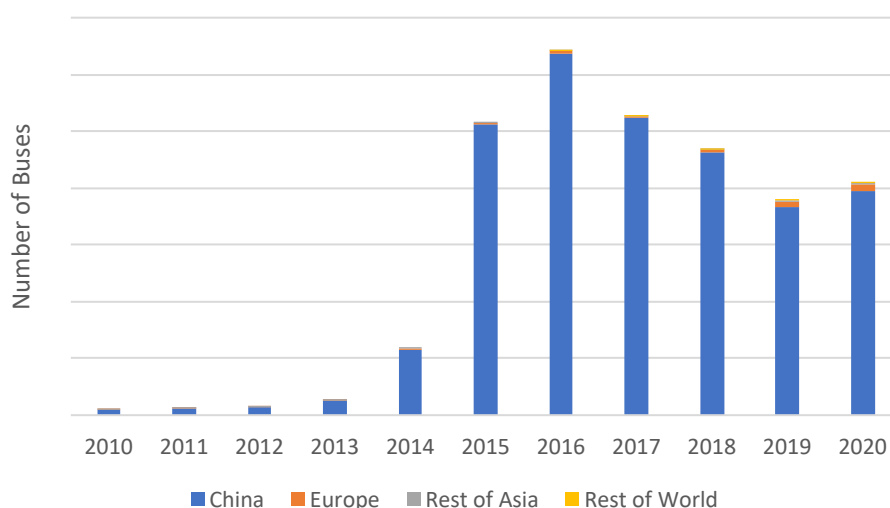
*Source: IEA, 2021*

Charging needs for public vehicles are quite different and, in some cases, may require their own charging solutions. Since public vehicle use is more intensive, they require more frequent charging (at least once a day). For most micro-mobility initiatives, charging is provided by the service provider itself, e.g., for eBikes the company also builds docking stations where these e-bikes can be charged. For e-rickshaws there is the option of charging the rickshaw at night using a simple AC charger or swapping the battery. Either way, the reliance is not much on public charging solutions.

The charging can be done for the bus fleet either at the depot or at the bus stops during operation. However, due to the large battery size (typically more than 150 kWh), fast charging is necessary. These can be pretty expensive, e.g., fast-charging hardware can vary from USD 45,000 to 200,000 per charger, depending on the charging rate, the number of chargers per site, and other site conditions [28][29].

## 2.3  MODAL SHIFT, PUBLIC TRANSPORTATION, BUS RAPID TRANSIT (BRT) AND THE 15-MINUTE CITIES

From an energy-efficiency perspective, the choice of transport mode is probably one of the essential aspects of transport planning. This is because of the key role of public transport and non-motorised transport in reducing the energy used by transport modes. Travelling in public and non-motorised modes uses less per-capita fossil fuel than using a private car. Furthermore, as they are space efficient, they do not contribute to road congestion thereby increasing efficiency gains. Therefore, the issue of mode choice is important and probably the most critical element in transport planning and policy-making. It affects the general efficiency of travelling in urban

areas, the amount of urban space devoted to transport functions, and whether a range of choices is available to travellers.

The factors influencing mode choice may be classified into three groups:

Characteristics of the trip maker: The trip maker's socio-demographic can influence the choice of mode. The availability of a vehicle and possession of a driving license affects a person's access to a private automobile and, therefore, its choice. The household structure (young couple, couple with children, retired, singles, etc.) often put the need for an individual to use particular modes. For example, the need to use a car at work, take children to school, etc. Income is probably the most important driver of mode choice, and it is generally found that the higher incomes determine the use of private automobiles.

Characteristics of the journey. Mode choice is strongly influenced by the purpose for which the trips is being made. For example, the journey to work is normally easier to undertake by public transport than other journeys because of its regularity and the adjustment possible in the long run. The time of the day when the trip is made can also have an influence on mode choice; late trips are more difficult to accommodate by public transport as there can be scheduling and safety-related issues. Individuals are also faced with coupling constraints, whether the trip is undertaken alone or with others, which affects mode choice.

Characteristics of the transport facility. Travel time: in-vehicle, waiting and walking times by each mode and components of monetary costs (fares, tolls, fuel, and other operating costs)

which affect the generalised cost of travel are affected by characteristics of the transport facility. The availability and cost of parking, reliability of travel time, and regularity of service. The comfort and convenience, safety, protection, security; the driving task demands; opportunities to undertake other activities during travel (use the phone, read, etc.) profoundly affect the choice of transport mode.

Build environment: How land use changes over time, the intensity of land use, and land-use mix all affect travel behaviour. Thus, it is important to review and benchmark urban growth, population-employment densities (intensity of land-use) and land-use mix.

The bus has been the main public transport in cities in the developing world. Chen et. al. [30] have shown that a modal shift from personal vehicles to the bus will increase the introduction of bus priority measures like an exclusive bus lane on Indian city roads. Variables such as walking time to bus stop and trip purpose are considered and significantly affect the choice and mode shift towards bus. In countries like China, studies [31] has shown that due to the implementation of BRT, modal shift to BRT in Chinese cities has increased significantly. The reason why BRT modes have been attractive is due to shorter travel times, reduced congestion, fewer traffic accidents and positive socioeconomic effects.

*"Bus Rapid Transit (BRT) is a high-quality bus-based transit system that delivers fast, comfortable, and cost-effective services at metro-level capacities. It does this through the provision of dedicated lanes, with busways and iconic stations typically aligned to the center of the road, off-board fare collection, and fast and frequent operations.*

*Because BRT contains features similar to a light rail or metro system, it is much more reliable, convenient, and faster than regular bus services. With the right features, BRT is able to avoid the causes of delay that typically slow regular bus services, like being stuck in traffic and queuing to pay on board."*

**Figure 2.5** BRTS Quito, Ecuador



*Source: https://www.itdp.org/library/standards-and-guides/the-bus-rapid-transit-standard/what-is-brt/*

The quantity and accuracy of the vehicle schedule have a significant impact on how much energy is used in public transportation. However, one cannot simply reduce the number of trips to minimise emissions. This could cause individuals to move to less efficient transportation methods and have an impact on the level of service and appeal of public transportation. As a result, public transportation providers will encounter significant difficulties in modifying their current dispatching procedures to conserve energy. A smart scheduling plan should consider both the operators' and passengers' perspectives on the cost and quality of bus operation. Therefore, optimising the BRT dispatching method is crucial to raising the level of service and lowering energy usage.

**Figure 2.6** Average Energy per Passenger vs. BRTS Daily Ridership



Average Energy Per Passenger (000'Kj/pax) — Daily Ridership (00' trips/day)
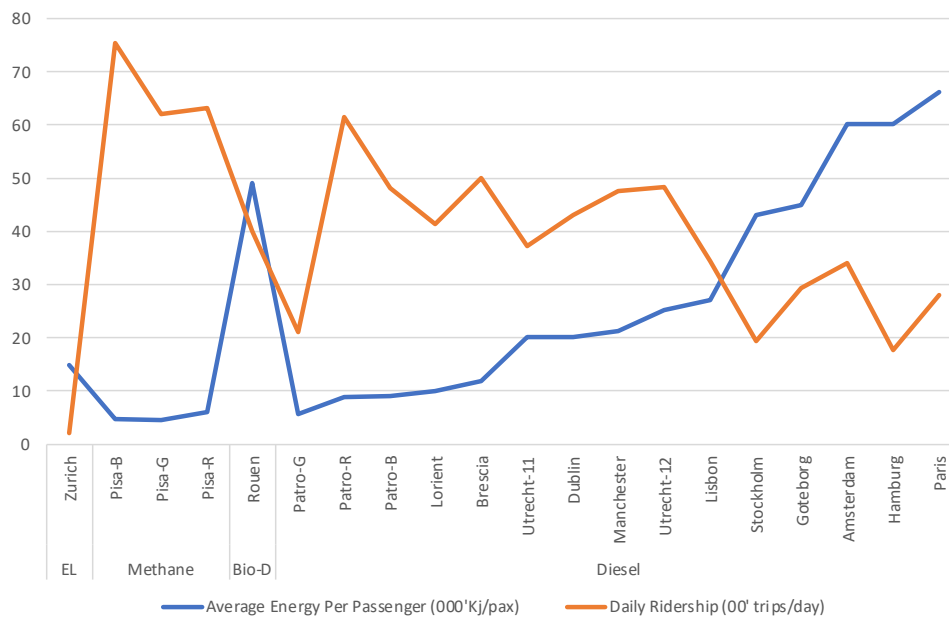
Increased ridership of the BRTS system leads to significantly lower average energy use per passenger, as can be seen from Figure 2.6, which is a plot of the average energy consumption per passenger (in kJ) versus the daily ridership for all the BRT systems investigated. The systems studied use four different energy sources: diesel, biodiesel, methane, and electric energy. The graph follows the general trend of a lower energy per passenger for the higher capacity systems (greater than 30,000 trips/day).

In many countries, the implementation of BRTS (as its ridership is so much dependent upon access and egress time) is integrated with the 15 minutes city concept. The 15-minute city integrates a set of four complementary, overlapping principles for people-centred urban development. It ties together and builds on equitable urban climate action strands to create a model that helps build more liveable, human-scale cities – prioritising the most underserved neighbourhoods and disadvantaged groups. Already, cities are adopting this approach worldwide; every city can join them.

The major advantage of 15-minute city neighbourhoods is that they offer convenience and quality of life. A 'complete neighbourhood' gives personal time back to people by reducing the frequency and length of unwanted trips, but physical and digital connectivity must be at the heart of any 15-minute city strategy, prioritising equitable access to social and economic opportunities. The 15-minute cities try to overcome the current urban paradigm where private vehicle plays an es-

sential role. To this situation will inevitably be added the consequences that COVID-19 will have on the conception of our society and with it, our cities. Among the most innovative and interesting proposals present in the urban debate in recent years is the idea of chrono-urbanism and the 15 minutes-city that Anne Hidalgo has proposed as can be seen in figure 2.7.

**Figure 2.7** 15-Minutes city Paris-A conceptual proposal



*Source: Paris en Commun, 2020*

While residents of a 15-minute city should not have to travel far to meet their basic daily needs, access to public transit, which can be used as connections to the rest of the city is critical to facilitate longer commutes, social trips and other cross-city travel. Efficient BRTS improve the ease and quality of longer trips, reducing the use of private vehicles and traffic in neighbourhoods across the city.

A 15-minute city integrated with BRTS has good walking and cycling connections to existing transport stops and stations. Transit stations, interchanges, and bus routes have enough secure bike parking, with quality pedestrian space in the surrounding area, and stations and stops are connected to the walking and cycling street infrastructure network. The quality of public transport connection frequency is good across the city, especially in poorly connected neighbourhoods. This might mean adding connecting bus routes through underserved neighbourhoods, improving the density of bus stops, and increasing the speed and frequency of service, including by upgrading bus systems to Bus Rapid Transit (BRT). The design of bus stops should ensure that all residents, including people with disabilities and caregiving responsibilities, can use the service. Low-income residents should be prioritised for any transit subsidies. Disability Inclusive Public Transport gives practical advice and low-cost solutions, focusing on African and Asian cities. Cities should also ensure that street space reallocation schemes and walkability improvements are designed with vulnerable users in mind. Use of digital technology like the MaaS application to integrate between different modes, especially the modes providing last mile connectivity in the 15 minutes neighbourhoods.

## 2.4 TRANSPORT INFRASTRUCTURE PROVISION AND EQUITY OF SPACE

Transport infrastructure provides the means for residents to access their desired activity locations, which in turn shapes spatial patterns of development [32], [33], [34], [35], [36]. The efficient use of road space and the reallocation of space to other uses are seen as crucial interventions in the global debate about the role of transport in low-carbon transitions. This is because road-based transportation infrastructure networks (highways, collector roads, urban arteries, and parking lots) typically account for a significant portion of urban space. [37], [38], [39], [40]. In practice, infrastructure choices can lead to long-term lock-ins in terms of transport choices [41], [42]. For example, adapting road supply to accommodate an increase in car traffic can lead to more vehicles on the road and

create more traffic in the long term [33], [43]. Increased individual motorised vehicle ownership trends encourage greater car-oriented transportation planning, stigmatise alternative means of transportation, and discourage their usage. This leads to suburbanization, car-based land use planning, urban sprawl, and ultimately, additional increases in motorised vehicle ownership. Public transportation and non-motorised transportation can be up to 20 times more space-efficient per passenger than a conventional car, according to studies on the spatial footprint of different transportation modes. [44]. A shift from car to public transport (PT) and non-motorised transport (NMT) can therefore theoretically contribute to freeing up precious city space [45].

In developing countries, a significant portion of the lower-income population depends on public transport and non-motorised transport. Typical for many other developing countries, India has traditionally been known for limited transport infrastructure provision, with demand levels often overwhelming the transport infrastructure supply [46], [47]. Transport planners have mainly focused on reducing road congestion and on accommodating the ever-increasing number of motorised vehicles. Thus far, transport planning has favoured the use of cars [47]. There has been a general failure to incorporate NMT in the transport planning process, and PT plans and provisions are inadequate and not comprehensive [48]. Walking, bicycling, rickshaws, public transportation, and motorised paratransit continue to dominate urban transportation in India despite the lack of adequate infrastructure. The majority of NMT and PT users, however, are captive customers who cannot afford to use alternative modes. The National Urban Transport Policy [49] stresses the relevance of promoting NMT and PT modes to retain the existing users and possibly entice present private motorised vehicle users to shift to NMT and PT modes. Providing safe and dedicated infrastructures for NMT and PT modes is crucial in bringing individuals to deliberately choose these modes [50], [51].

**Figure 2.8** Space-time demand, an example of Raiya Road in Rajkot

A demonstrative case is shown in Figure 2.8 using Raiya Road, one of Rajkot's main axes heading west in the city. Since demand changes depending on the time of day, space utilization on Raiya Road is displayed daily and during the morning peak, when there is the most traffic (9:30 a.m. to 10:30 a.m.). According to the development scenarios, a one km-long road stretch with a width of 13 m for 2011 and 24 m for 2031 was chosen (road sections are illustrated in Figure 2.8). There are 13 000 m2 of space available on the stretch in an hour and 312 000 m2 daily in 2011 [53].

For the peak hour analysis, a congested speed of 10 km/h is used, in accordance with the speed-flow graph for Raiya road's capacity. The results for this case are given in $m^2.hr$ to fit with the smaller overall scale. With those parameters, the daily space consumption on the stretch stays below the daily space supply for all transport development scenarios, with consumption rates varying between 15% and 38% depending on the scenario. With those parameters, for all transport development scenarios, the daily space consumption on the length remains below the daily space supply, with consumption rates varying between 15% and 38% depending on the scenario.

However, during busy times the pressure in space increases. In 2011, the stretch's space consumption during peak hour traffic was 65% of the entire amount of space on the route. Even though it is reasonable to anticipate that practically all the available road space will be utilised in congested conditions, elements like mixed traffic and unutilised intersection space help to reduce the rate of space-time consumption. Comparatively, [44] discovered that over the entire city of Paris, the average road space usage during peak hours was around 20%, which is possibly lower than what one may have heuristically predicted [53].

The peak hour space demand would be 100% greater than the supply if development were to occur according to the BAU scenario, notwithstanding the projected road widening from 13 to 24 meters. This demand is mostly driven by cars and motorised two-wheelers. According to these figures, city planners may need to account for 200% more space which will be reserved for road traffic in order to reduce congestion.

Peak-hour demand would still be strong, accounting for 88% of the anticipated supply, if the LCMP scenario were to be put into action. By giving priority to space-efficient modes like buses, this rate is still more than two times lower than in the BAU scenario while maintaining a similar level of passenger kilometres.

Raiya Road is simply an example; a comparable circumstance: a similar situation can be expected across the city, indicating the need for incorporating measures that encourage mobility solutions that utilize less urban space.

# **References** - Module 2

[1] GFEI, "Vehicle Efficiency and Electrification: A Global Status Report:," 2020.

[2] IEA, "Net Zero by 2050: A Roadmap for the Global Energy Sector," Paris, 2021.

[3] W. Yaïci and H. Ribberink, "Feasibility Study of Medium- and Heavy-Duty Compressed Renewable/Natural Gas Vehicles in Canada," J. Energy Resour. Technol., vol. 143, no. 9, Jan. 2021, doi: 10.1115/1.4049455.

[4] X. Qin, L. Liang, X. Zhang, G. Deng, and H. Liang, "Structural Design and Stress Analysis of a Fully-Wrapped Composite CNG Gas Cylinder With Nominal Working Pressure of 30 MPa." Aug. 2020. doi: 10.1115/PVP2020-21521.

[5] G. T. Chala, A. R. Abd Aziz, and F. Y. Hagos, "Natural Gas Engine Technologies: Challenges and Energy Sustainability Issue," Energies , vol. 11, no. 11. 2018. doi: 10.3390/en11112934.

[6] Y. Bayat and M. Ghazikhani, "Experimental investigation of compressed natural gas using in an indirect injection diesel engine at different conditions," J. Clean. Prod., vol. 271, p. 122450, 2020, doi: https://doi.org/10.1016/j.jclepro.2020.122450.

[7] S. Trivedi, R. Prasad, A. Mishra, A. Kalam, and P. Yadav, "Current scenario of CNG vehicular pollution and their possible abatement technologies: an overview," Environ. Sci. Pollut. Res., vol. 27, no. 32, pp. 39977–40000, 2020, doi: 10.1007/s11356-020-10361-7.

[8] IEA, "Outlook for biogas and biomethane: Prospects for organic growth. Paris: International Energy Agency," Paris, 2020.

[9] IEA, "Energy Technology Perspectives 2020," Paris, 2021.

[10] S. Puricelli, G. Cardellini, S. Casadei, D. Faedo, A. E. M. van den Oever, and M. Grosso, "A review on biofuels for light-duty vehicles in Europe," Renew. Sustain. Energy Rev., vol. 137, p. 110398, 2021, doi: https://doi.org/10.1016/j.rser.2020.110398.

[11] P. Purohit and S. Dhar, "Lignocellulosic biofuels in India: Current perspectives, potential issues and future prospects," AIMS Energy, vol. 6, no. 3, 2018, doi: 10.3934/energy.2018.3.453.

[12] C. Graves, S. D. Ebbesen, M. Mogensen, and K. S. Lackner, "Sustainable hydrocarbon fuels by recycling $CO_2$ and $H_2O$ with renewable or nuclear energy," Renew. Sustain. Energy Rev., vol. 15, no. 1, pp. 1–23, 2011, doi: https://doi.org/10.1016/j.rser.2010.07.014.

[13] A. Soler, "A look into the role of e-fuels in the transport system in Europe (2030-2050) (literature review)," 2019.

[14] IPCC, "Climate Change 2022: Mitigation of Climate Change: Working Group III Contribution to the IPCC Sixth Assessment Report," Intergovernmental Panel on Climate Change, 2022.

[15] Z. P. Cano et al., "Batteries and fuel cells for emerging electric vehicle markets," Nat. Energy, vol. 3, no. 4, pp. 279–289, 2018, doi: 10.1038/s41560-018-0108-1.

[16] T. Placke, R. Kloepsch, S. Dühnen, and M. Winter, "Lithium ion, lithium metal, and alternative rechargeable battery technologies: the odyssey for high energy density," J. Solid State Electrochem., vol. 21, no. 7, pp. 1939–1964, 2017, doi: 10.1007/s10008-017-3610-7.

[17] S. Goel, R. Sharma, and A. K. Rathore, "A review on barrier and challenges of electric vehicle in India and vehicle to grid optimisation," Transp. Eng., vol. 4, p. 100057, 2021, doi: https://doi.org/10.1016/j.treng.2021.100057.

[18] P. K. Tarei, P. Chand, and H. Gupta, "Barriers to the adoption of electric vehicles: Evidence from India," J. Clean. Prod., vol. 291, p. 125847, 2021, doi: https://doi.org/10.1016/j.jclepro.2021.125847.

[19] Z.-Y. She, Qing Sun, J.-J. Ma, and B.-C. Xie, "What are the barriers to widespread adoption of battery electric vehicles? A survey of public perception in Tianjin, China," Transp. Policy, vol. 56, pp. 29–40, May 2017, doi: 10.1016/J.TRANPOL.2017.03.001.

[20] J. Webb, J. Whitehead, and C. Wilson, "Chapter 18 - Who Will Fuel Your Electric Vehicle in the Future? You or Your Utility?," F. B. T.-C. Sioshansi Prosumer, Prosumager, Ed. Academic Press, 2019, pp. 407–429. doi: https://doi.org/10.1016/B978-0-12-816835-6.00018-8.

[21] J. Wenig, M. Sodenkamp, and T. Staake, "Battery versus infrastructure: Tradeoffs between battery capacity and charging infrastructure for plug-in hybrid electric vehicles," Appl. Energy, vol. 255, p. 113787, 2019, doi: https://doi.org/10.1016/j.apenergy.2019.113787.

[22] IEA, "Global EV Outlook 2021," Paris, 2021.

[23] M. van der Kam and R. Bekkers, "Comparative analysis of standardized protocols for EV roaming," https://pure.tue.nl/ws/portalfiles/portal/151709855/D6.1_Comparative_analysis_of_standardized_protocols_for_EV_roaming.pdf, May 2020.

[24] ECA, "Infrastructure for charging electric vehicles: more charging stations but uneven deployment makes travel across the EU complicated.," 2021.

[25] A. Hove and D. Sandalow, "Electric vehicle charging in China and the United States.," 2019.

[26] P. E. P. Jochem, J. Whitehead, and E. Dutschke, "The Impact of Electric Vehicles on Energy Systems International Encyclopedia of Transportation," in International Encyclopedia of Transportation, R. Vickerman, Ed. Oxford: Elsevier, 2021, pp. 560–565.

[27] J. Després, S. Mima, A. Kitous, P. Criqui, N. Hadjsaid, and I. Noirot, "Storage as a flexibility option in power systems with high shares of variable renewable energy sources: a POLES-based analysis," Energy Econ., vol. 64, pp. 638–650, 2017, doi: https://doi.org/10.1016/j.eneco.2016.03.006.

[28] M. Nicholas, "Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas.," 2019.

[29] C. Nelder and E. Rogers, "Reducing EV Charging Infrastructure Costs," 2019.

[30] W. L. Chee and J. L. Fernandez, "Factors that influence the choice of mode of transport in Penang: A preliminary analysis," Procedia-Social Behav. Sci., vol. 91, pp. 120–127, 2013.

[31] Y. Wang, Z. Wang, Z. Li, S. R. Staley, A. T. Moore, and Y. Gao, "Study of modal shifts to bus rapid transit in Chinese cities," J. Transp. Eng., vol. 139, no. 5, pp. 515–523, 2013.

[32] G. Banjo and H. Dimitriou, "Urban Transport Problems Third World Cities: the Third Generation," Habitat Int., vol. 7, no. 3/4, pp. 99–110, 1983.

[33] H. T. H. T. Dimitriou, "Towards a generic sustainable urban transport strategy for middle-sized cities in Asia: Lessons from Ningbo, Kanpur and Solo," Habitat Int., vol. 30, no. 4, pp. 1082–1099, 2006, doi: 10.1016/j.habitatint.2006.02.001.

[34] T. Munshi and M. Brussel, "Use of geo-information to determine the workplace accessibility using public transport in Ahmedabad city, India," pp. 1–14, 2004.

[35] K. T. Geurs, Accessibility, land use and transport, Uitgeverij. Delft: Uitgeverij Eburon, 2006.

[36] M. Wegener and F. Fürst, "Land-use transport interaction: state of the art," 1999. doi: 10.2139/ssrn.1434678.

[37] D. Banister, "The sustainable mobility paradigm," Transp. Policy, vol. 15, no. 2, pp. 73–80, 2008, doi: 10.1016/j.tranpol.2007.10.005.

[38] R. Hickman, O. Ashiru, and D. Banister, "Transitions to low carbon transport futures: strategic conversations from London and Delhi," J. Transp. Geogr., vol. 19, no. 6, pp. 1553–1562, 2011.

[39] P. Kivimaa and V. Virkamäki, "Policy mixes, policy interplay and low carbon transitions: the case of passenger transport in Finland," Environ. Policy Gov., vol. 24, no. 1, pp. 28–41, 2014.

[40] K. C. von Schönfeld and L. Bertolini, "Urban streets: Epitomes of planning challenges and opportunities at the interface of public space and mobility," Cities, vol. 68, no. April, pp. 48–55, 2017, doi: 10.1016/j.cities.2017.04.012.

[41] G. C. Unruh and J. Carrillo-Hermosilla, "Globalizing carbon lock-in," Energy Policy, vol. 34, no. 10, pp. 1185–1197, 2006.

[42] T. Munshi, Zia-ul-Haque, and Y. Joseph, Examining equity in spatial distribution of recreational and social infrastructure in Delhi. 2016. doi: 10.1007/978-81-322-3583-5_6.

[43] D. Metz, "The Myth of Travel Time Saving," Transp. Rev., vol. 28, no. 3, pp. 321–336, May 2008, doi: 10.1080/01441640701642348.

[44] F. Héran and E. Ravalet, "La consommation d'espace-temps des divers modes de déplacement en milieu urbain Application au cas de l'Ile de France," pp. 1–188, 2008.

[45] S. Gössling et al., "Urban Space Distribution and Sustainable Transport," Transp. Rev., vol. 0, no. 0, pp. 1–21, 2016, doi: 10.1080/01441647.2016.1147101.

[46] J. Pucher, N. Korattyswaropam, N. Mittal, and N. Ittyerah, "Urban transport crisis in India," Transp. Policy, vol. 12, no. 3, pp. 185–198, 2005, [Online]. Available: http://www.sciencedirect.com/science/article/B6VGG-4G0M3KX-1/2/802cee-ae1b575687766f3957fe4fea35

[47] G. Tiwari, "Key mobility challenges in Indian cities," 2011.

[48] T. Munshi, "Built Form, Travel Behaviour and Low Carbon Development in Ahmedabad, India," University of Twente, 2013.

[49] MOUD, National Urban Transport Policy, Government of India. India, 2006. [Online]. Available: http://urbanindia.nic.in/moud/programme/ut/TransportPolicy.pdf

[50] T. Munshi, M. F. A. M. van Maarseveen, and M. H. P. Zuidgeest, "Built form, Travel Behaviour and Low Carbon Development in Ahmedabad, India," University of Twente, Enschede, the Netherlands, 2013.

[51] R. Oldenziel and A. Albert de la Bruhèze, "Contested Spaces," Transfers, vol. 1, no. 2, pp. 29–49, 2011, doi: 10.3167/trans.2011.010203.

[52] M. R. Rahimi, "Estimation of Capacity and Level of Service for Four Lane divided Urban Arterial Road," Int. J. Res. Appl. Sci. Eng. Technol., vol. 6, no. 4, pp. 452–459, 2018, doi: 10.22214/ijraset.2018.4079.

[53] Will, M.E., Munshi, T. and Cornet, Y., 2020. Measuring road space consumption by transport modes. Journal of Transport and Land Use, 13(1), pp.651-669.

# Module 3. Non-technical options

There are several non-technical options (e.g., policy measures, and regulations), that can be applied to achieve improved fuel efficiency in the road transport sector, and thereby, decreased fuel consumption and both local and global emissions. Non-technical options (NTOs) can also be applied to achieve more sustainable and equitable urban transport systems. Many of these NTOs are, in contrast to some expensive technological options, low-cost and therefore affordable for cities and municipalities in developing countries. These low-cost, or no-cost measures can be also adopted by transport users themselves, for instance by following the A-S-I approach (avoid, shift, improve). Following this approach may generate several benefits, such as decreased congestion and as mentioned above, lower levels of emissions. The A-S-I approach is explained in detail in Module 6, section 6.2.

One of the measures that individual transport users can implement is to follow the A-S-I approach, for example, by switching from a private car to a bicycle. Besides the benefits mentioned above, this modal shift generates several co-benefits such as improved health, and both time and economic savings, thus being a win-win measure. Studies have shown that the bicycle is the fastest mode of transportation for short distances of up to 5 kilometres, which is very often the distance people travel within cities. A study about this was conducted in New York in 2014, in which taxi services were compared to bike-shared systems. The study shows that the bicycle is either faster or equally fast as the taxi [1].

Improving fuel efficiency in public transport vehicles (e.g., buses and taxis) and private cars, is another way of following the A-S-I approach. Improved fuel efficiency can be obtained through non-technical measures such as eco-driving training. The principle of eco-driving is to drive in a more relaxed and friendlier way. The eco-driving technique will be explained more in detail later in this module.

Essentially, all this is about influencing all relevant transport stakeholders, namely, public transport operators, public transport users, and private car drivers to make the necessary change of behaviour. However, to achieve these behavioural changes in the various stakeholders mentioned above, the necessary environmental awareness must be created. Unfortunately, NTOs have not been implemented to the required extent, sometimes not even considered by politicians and decision-makers, simply because there is a lack of knowledge among these stakeholders about the positive effects the suggested measures may have on themselves, as well as on the environment, and how easily they can be implemented. Therefore, information through awareness-raising campaigns can be an effective way of influencing all these stakeholders.

## 3.1 AWARENESS-RAISING CAMPAIGNS

The implementation of awareness-raising campaigns directed to politicians, decision-makers, and the public in general, is an effective and low-cost measure leading to increased environmental awareness, and thereby, to the desired behavioural change. There are examples showing the results of successfully implemented awareness-raising campaigns in several cities that have led to the introduction of environmentally friendlier policies by politicians, and to a modal shift with increased use of bicycles among transport users. Some examples are Bogotá (Colombia), Quito (Ecuador), Ecuador and Concepción (Chile).

The lack of awareness about the negative impacts unsustainable motorised transport systems may have on the local and global environment, and the lack of knowledge about the available low-cost NTOs that could lead to more sustainable and equitable urban transport, have been some of the main barriers hindering the implementation of more sustainable policies and policy measures for this sector. It is, therefore, of paramount importance that information about the negative impacts of unsustainable transportation, as well as the correct information about existing policies and low-cost measures with a significant emissions reduction potential and their associated benefits, is conveyed to relevant target groups in a convincing way. It is also very important that information about the various public transport and other sustainable travel alternatives that are available is conveyed to all citizens.

Evidence shows that a well-designed awareness-raising campaign containing information about the environmental and health benefits of biking can be a very effective way of influencing modal shifts. This is a very cost-effective way of creating the necessary awareness among politicians and decision-makers, and ultimately to behavioural change among transport users, at the same time. Authorities at both the national and local level can arrange public campaigns aimed to influence and promote changes in transport users' behaviour.

Important aspects to take into consideration when designing a campaign are: 1) the objective of the campaign (what is to be achieved); 2) the target audience (whom the campaign is addressing); 3) what are the messages to be conveyed (e.g., negative impacts of unsustainable transport on the environment); 4) the

channels of communication to be used (newspapers, television and others) and; 5) the type of activity (public events, gatherings, etc,). For example, if the purpose is to promote a modal shift from private motorisation to public transport or non-motorised transport (NMT), i.e., biking or/and walking, the campaign must be addressed to private car owners, but also, to those who do not yet own a car. As it is well known, it is easier to prevent somebody from starting to drive a car than to get somebody out of the car.

How effective an awareness-raising campaign is will depend on its design and implementation. There are various strategies that can be considered. In a guidebook on "Planning and Implementation of Campaigns to Promote Bicycle Use in Latin American Countries", four crucial elements to be taken into consideration for a successful campaign are mentioned. These are "1) affective; 2) rational; 3) movement and 4) community social" [2].

The first element refers to strategies addressed to people's emotions. The objective of this is to invoke happiness, a feeling of freedom, and all other positive feelings related to the fact of using an environmentally friendly and sustainable mode of transportation, e.g., the bicycle. This should be preferably accompanied by emotionally convincing activities. The affective element could be shown in advertisements or/and street activities, which do not require the presence of citizens.

The second element refers to the use of facts, i.e., technical, statistical, and numerical. Here, it is important to present accurate information about the transportation mode being suggested and its associated benefits, e.g., less road space used, decreased or zero emissions when used, shorter travel times, lower cost, etc. These arguments should be presented by citizens who stand for high credibility, in conferences or other media platforms.

The third element refers to strategies that require the participation of citizens. One strategy often used is that citizens undertake together a journey by foot, bicycle, or public transport through the city, preferably with a clear objective for the journey, e.g., a trip to a working place, school or for a recreational purpose. Good examples of this strategy are the Sunday bicycle rides like the ones im-plemented in cities like Bogotá and Quito

The fourth element refers to the implementation of promotional activities organised by a team, with the objective of promoting sustainable transportation such as bicycling. This strategy should be implemented in a stepwise process; however, some steps could be implemented in parallel. For the implementation of this strategy, it is advised that both representatives from relevant authorities and citizens are involved. This will create a synergy between the government, citizens, and other stakeholders.

These four aspects also apply to other types of campaigns having the objective of producing behavioural change among car drivers and transport users. Some examples are campaigns against anti-idling, where posters and leaflets are used to describe the negative impacts of idling in inner-city areas.

Although awareness-raising campaigns may not give the expected results in terms of radical changes in the short term, they will most likely, have an impact in the long term. The bicycle is an environmentally friendly, healthy, and efficient mode of transportation. It can be faster than cars when it comes to short-distance travelling in inner-city areas. Another advantage of the bicycle is that it takes considerably less road space than cars take. Figure 3.1 shows the difference in urban space taken by three different modes of transportation

**Figure 3.1** Urban space taken by mode of transportation.
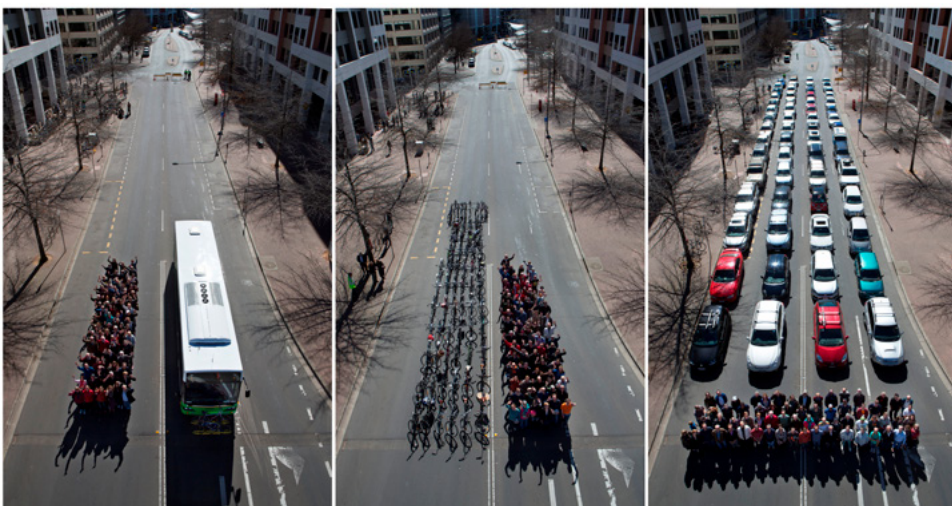


*Source: CPF, Cycling Promotion Fund. ©WeRide Australia*

## 3.2 ECO-DRIVING

Introducing eco-driving training is a low-cost and effective way of improving and changing driving styles among drivers, which can lead to more sustainable urban transport. This measure is low-cost because eco-driving can be incorporated as an extra learning component in already existing driving courses, as it has been already done in many places around the world. Eco-driving is increasingly recognised as an effective measure to achieve fuel consumption reductions thanks to a friendlier and more energy-efficient driving style. Besides, by adopting a friendlier and more relaxed driving style, the driver reduces fuel consumption and thereby expenses on fuel, something which is of great concern due to today's very high fuel prices.

The technique also contributes to reductions in $CO_2$ emissions with corresponding benefits for both the local and global environment. Evidence shows that savings of between 2 and 15% can be achieved due to eco-driving programmes. This may obviously vary depending on the programme and drivers [4].

The principles of Eco-driving are quite simple and can be implemented by any driver of a vehicle, whether it is a car, a bus, a light, or a heavy-duty vehicle. Eco-driving is mainly about various measures that can be implemented by the driver such as maintaining a constant speed, shifting gears at the right time thus optimising the RPM (revolutions per minute) of the engine. High speeds will undoubtedly increase fuel consumption and it is, therefore, important to maintain a low speed. Optimal gear shifting is especially important for cars with manual transmission. A majority of today's new vehicles show in the front panel when it is the right time for a lower or higher gear. "Block changing" is another technique that leads to a decrease in fuel consumption by reducing sequential gear shifting, i.e., the driver can skip the next gear and jump directly to a higher gear instead [5]. This technique gives rise to benefits such as increased fuel efficiency, preserving the life of the car's clutch at the same time.

Eco-driving programmes have been introduced in several EU countries showing they have generated multiple benefits for the environment as well as for car owners, the last mainly due to savings in fuel consumption, which in many cases it represents a significant share of the household's budget. Another benefit generated by Eco-driving is improved public health due to reduced exposure to pollutants like NOx, Sox and PM, pollutants that may have severe impacts on public health. The main benefit for the global environment is the one related to the reductions of $CO_2$ emissions, this be-cause the level of $CO_2$ emissions is directly proportional to the amount of fuel combustion. Another benefits that can be mentioned is reduced number of car accidents, which leads in turn to benefits such as a reduced need for health care and the costs associated with it.

All the benefits mentioned above can be attributed to a more friendly and relaxed driving style. One example of an eco-driving programme introduced in the European Union (EU), is the ECOWILL (Widespread Implementation for Learner Driver and Licensed Drivers) project. The programme was supported by the European Commission Intelligent Energy Programme and was implemented in 13 EU countries between 2010 and 2013 [6]. Among the results that could be observed is an average reduction in fuel consumption of between 9.2 and 18 % among drivers that attended the short-duration course, which resulted in an average decrease in fuel consumption of 14 % in the 13 countries that participated in the ECOWILL programme.

Today, more economic and friendly driving styles are supported by recently developed technological devices that can guide drivers while driving how to do it, thus achieving the expected benefits of eco-driving. A study using the Eco-driving device Eco-Way was conducted in the Riverside area, Cali-fornia, USA in 2010. In the study, 20 drivers were monitored in their daily commuting for a period of 2 weeks. The study found an improvement in fuel economy of 6 % on city streets and 1 % on highways [7].

Today there are several eco-driving applications for mobile phones, which can be downloaded for free. The app tells the driver about your performance as a driver by collecting information like speed, harsh braking, etc. and the application will tell you immediately your eco-driving score.
Real-time normalised indicators such as the one specifically developed for this purpose by Deutsche Telekom AG (Figure 3.2), represent a useful tool to, in real-time, guide the driver to achieve a more economic, secure, and environmentally friendly driving style. This communication device provides immediate feedback to the driver who can adjust to a more economic and friendly style during the trip itself. It can also provide a post-driving summary showing drivers' actual costs incurred by driving on a trip-by-trip basis, thus proposing changes to their way of driving.

**Figure 3.2** Communication of Eco-driving results, conceptual framework.
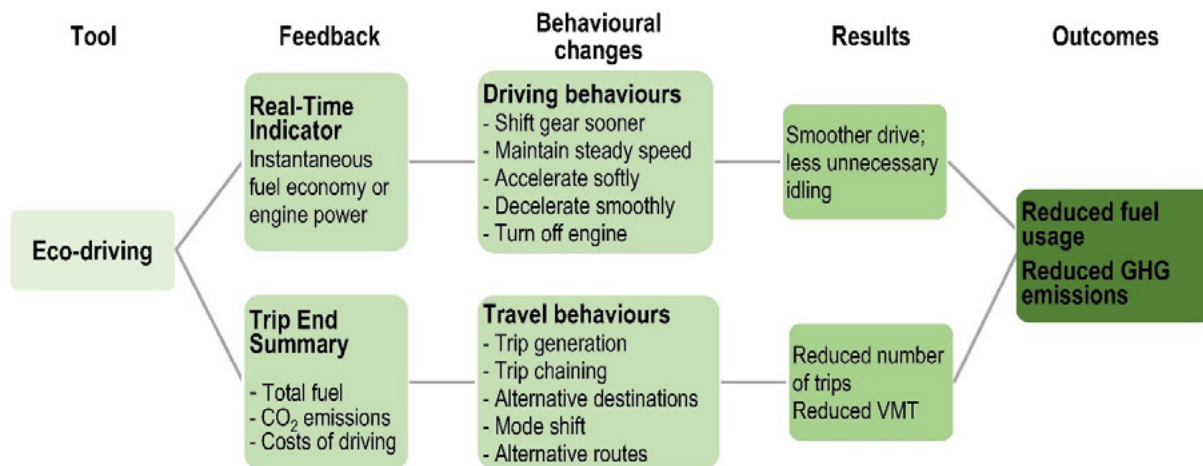


*Source: Transportation Research*

Other ways of improving both the lifespan of a vehicle and fuel efficiency suggested in eco-driving courses are good maintenance, periodic checks of the vehicle such as tyre pressure, reduction of unnecessary vehicle weight, and avoiding unnecessary idling. Anti-idling regulations will be further discussed in the next section.

### 3.3  ANTI-IDLING

Anti-idling regulations can be introduced by corresponding authorities at a very low cost, and be implemented by the driver, not only at zero cost but even obtaining savings in terms of decreased fuel consumption. This policy measure effectively reduces road transport emissions in inner-city areas. In a similar way to eco-driving programmes, it generates several benefits like improved local air quality and decreased global emissions such as CO₂. Another benefit is improved economy for car owners due to fuel savings and decreased engine wear.

An idling vehicle generates considerably more emissions than when it is driven at a constant speed. Furthermore, the air pollutants from idling vehicles are most of the time emitted in inner-city areas, and therefore, their impacts on human health are of greater severity, particularly on children, pregnant women, and the elderly. Anti-idling regulations have been introduced in many countries, including European countries and the USA. Nevertheless, compliance has been low since drivers are not following the rules as expected, which depends most likely to the fact the existing monitoring and enforcement mechanisms are ineffective.

One likely reason for the lack of compliance with anti-idling regulations is the existing misconception among car owners regarding anti-idling, based on the belief that turning the engine off and on will consume more fuel than leaving it idling, a misconception that may have been true for old cars but not for today's modern cars equipped with ignition systems that are much more efficient and that require less fuel to switch the engine on. Another likely reason is the lack of knowledge about the negative impacts idling has on the environment and their economy. An idling car generates several negative impacts on the environment besides the ones already known. It pollutes the local environment, as well as and the engine due to incomplete combustion, leading thereby to an increased level of pollution and fuel consumption of approximately 4-5 per cent [28].

A concern associated with the development of recently developed more advanced technologies, is that these technologies are not used optimally, and are therefore, not generating the expected benefits. One example is that despite the fact most of today's new vehicles are equipped with an auto-stop and start technology, this function can be turned off by the driver and thus not being utilised to the full. Often, car drivers are found sitting in idling cars in crowded urban areas, emitting air pollutants such as PM, SOx, and NOx, that as mentioned earlier, may have severe impacts on human health. This can be also observed in cities where anti-idling regulations have been introduced. It is therefore, very important that monitoring and enforcement is enhanced; without the required monitoring and enforcement mechanisms in place, compliance will remain an issue. Furthermore, the technology being provided must be accompanied with adequate instructions about how to use it optimally, but also information about the benefits the technology can provide, if used correctly.

## 3.4 FUEL ECONOMY AND CO₂ EMISSION STANDARDS

Mandatory fuel economy and $CO_2$ emission standards on vehicles have been much more effective than voluntary targets set by the auto industry. Mandatory standards can achieve annual $CO_2$ reductions of 2-3% per year, compared to 0-1 % average reductions per year achieved through voluntary targets [7]. Mandatory emission standards on passenger cars, light-duty vehicles and trucks have also been an effective instrument to push carmakers in the EU to improve vehicles' fuel efficiency, thereby, achieving reductions in the level of $CO_2$ emissions from the road transport sector. For instance, in 2009, a regulation on $CO_2$ emission standards on new cars was adopted by the European Commission by setting a 130 g/km target by 2015 [8]. The regulation adopted by the European Commission was due to the fact that the voluntary target set by carmakers of reducing $CO_2$ emissions from 186 g/km to 140 g/km by 2005 was not met [9]. This shows that without regulations, no, or very few fuel efficiency targets and $CO_2$ emissions reduction targets would have been achieved. In 2013 a new $CO_2$ target of 95 g/km to be met by 2021 was set by EU policymakers. This target resulted in an annual $CO_2$ emissions reduction rate after 2015 of 5.1%, which was significantly greater than both the car makers' early voluntary targets and the first EU $CO_2$ regulation on cars' emissions. The current EU policy has helped to reduce the average new car's real-world $CO_2$ level by 18% since 2001, from about 200 g/km to 165 g/km.

Nevertheless, the $CO_2$ emission levels could, if an effective enforcement mechanism had been in place, have been 127 g/km, compared to a baseline scenario without mandatory $CO_2$ standards. This means a 33% reduction, almost double the 18% that has been achieved [10]. This shows the important role appropriate monitoring and enforcement mechanisms can play.

Regulations of this kind represent a low-cost measure for transport authorities, but also for car owners since the burden is posed on carmakers and normally not on car owners. However, for these regulations to be effective, rigorous monitoring and enforcement mechanisms must be put in place. This can be done locally at the city level as well as the municipality level. At the local level, the enforcement can be applied in a similar way to the regulations of compliance with the EU5 and EU6 standards for cars that have been applied in several cities, in particular in European cities.

For example, in the Swedish cities Gothenburg and Malmö, the local authorities introduced so-called "miljö zones" (environmental zones or low emissions zones) in which cars not complying with these standards are banned from inner-city areas. Environmental zones were subsequently introduced in Stockholm, Sweden's capital, and other cities in the country.

From 1 July 2022, the regulation will be restricted further on diesel-driven cars, where only those complying with the EU6 standard are allowed to enter the inner-city area so-called Zone 2 [11]. The environmental zones were first introduced in Sweden in 1996 and can be the first low-emission zones (LEZs) program put in place. Following the Swedish example, LEZ were introduced in several cities in Germany, the Netherlands, north Italy and London, the last during 2007-2008. In the last decade, the number of LEZ has been steadily increasing and they are in place now in many EU countries [12]. Currently, there is a variety of regulations restricting the levels of emissions are in place in a number of European cities. For instance, in Germany, cars must have a decal on the windshield showing the car complies with emissions under a certain level. In Barcelona, Spain, old cars are completely banned from inner-city areas. In several cities in Italy, signs levelled with "Zona Traffico Limitato" (limited traffic zone) are found, and the ban applies during specific hours and days.

Fuel economy standards (FES) can also be found in other regions of the world. Chile, with its innovative feebate program to promote passenger-vehicle efficiency, is one of the examples. The programme, which is a mix of taxes and incentives, was approved by the Chilean congress in September 2014 and introduced a carbon tax on new car purchases based on Nitrogen oxide (NOx) (heavy) and Field Electron (FE) (lighter) emissions, according to Fuel Economy labelling information [13]. Fuel economy standards aimed at reducing emissions from road transportation have been introduced also in other Latin American countries like Argentina, Brazil, Costa Rica, and Mexico. In Africa, South Africa included fuel economy standards in their Green Transport Strategy (GTS). In this programme, new vehicle fuel-efficiency standards, which are equivalent to $CO_2$ emission standards, constitute one of the pillar programs that make up the GTS action plan [14]. The introduction of both mandatory (FES) and LEZ has meant significant improvements for both the local and global environment. FES has helped to reduce $CO_2$ emissions which are the main precursors of climate change, while LEZ have helped to significantly reduce the levels of local emissions such as PM10 and NOx and other local pollutants, and this has improved public health.

As mentioned earlier, the levels of both global and local emissions could have been reduced further if the monitoring and enforcement mechanisms had been more effective. This needs to be considered by local authorities in developing country cities by the time FES and LEZ are being gradually introduced. It is only by putting in place the right monitoring and enforcement mechanisms from the beginning that FES and LEZ will provide the expected results.

## 3.5 DEMAND-SIDE MANAGEMENT

Transportation Demand Management (TDM) has traditionally involved strategies to induce commuters and other travellers to shift to green transport modes, which can be high occupancy modes such as carpooling, public transport etc. or non-motorised transport modes [15]. For sustainable mobility globally, transport managers search for innovative and ambitious urban transport solutions to arrive at a situation where towns and cities are less polluted and more accessible and traffic flows more freely. According to ITDP [15] demand-side management strategies seek to do two things: 1) promote efficient travel modes (those that consume less roadway space per passenger-kilometre) to increase the effective capacity of existing infrastructure; and 2) shift travel by inefficient modes to off-peak periods to reduce congestion.

Demand-side management is also recognised internationally as a supportive tool for improving energy efficiency from transport and for mitigating the impacts of greenhouse gas (GHG) emissions. With the transport sector contributing almost a quarter of energy-related GHG emissions (with around three-quarters of that coming from road vehicles), TDM is essential for reducing private car use and promoting more energy-efficient travel modes.

TDM also seeks to reduce auto trips—and hopefully, overall vehicle kilometres travelled—by increasing travel options, providing incentives and information to encourage and help individuals modify their travel behaviour, and/or reducing the physical need to travel through transportation-efficient land uses. Overall, TDM strategies tend to be far more cost-effective in relieving regional congestion than expanding roadway and parking infrastructure.

The typical demand-side management measure include:

### Operational Measures

These measures enhance choices and traveller information about those choices. Traffic management centres use real-time, dynamic information to manage the system and provide users with route choices during their trips. The modern-day navigation systems that help travellers with travel time prediction, route selection and coping with extreme events and congestion based on recent (the past few hours) or archived (historical) data are also operational measures. Operational measures also include strategies for managing demand during disruptions like construction activities or a major event [16].

### Physical Measures

Physical measures that restrict the use of personal automobiles in certain areas or during certain times of the day or involve strategic improvements to the transportation network to enhance system efficiency or provide new capacity for public transport. This can be achieved with physical barriers restricting vehicles into specific areas, such as the historic core during certain portions of the day or for even more extended periods. Likewise, by improving their public transport systems by building extensive park-and-ride facilities and providing high occupancy vehicle lanes to encourage public transport high capacity bus systems like BRT / carpooling and carsharing [16].

### Financial and Pricing Measures

Financial and pricing measures like congestion pricing schemes are being implemented to reduce congestion (London) and emissions (Stockholm, Sweden, and Rome), not primarily to raise funds for transport or other uses. Financial incentives are also being used as a demand management strategy. As part of a highway construction project near Amsterdam, free monthly transit passes were distributed to area residents and workers to complement transit service improvements and employer-based TDM initiatives [16].

### Institutional Measures

Demand management requires new partnerships, planning processes, and approaches to addressing traffic congestion. The ability to institutionalise a demand management philosophy in supply-oriented organisations is a key factor in the endeavour's success [2].

**Figure 3.3** Shared Mobility Service Models (Adapted from Shaheen, Cohen [20])
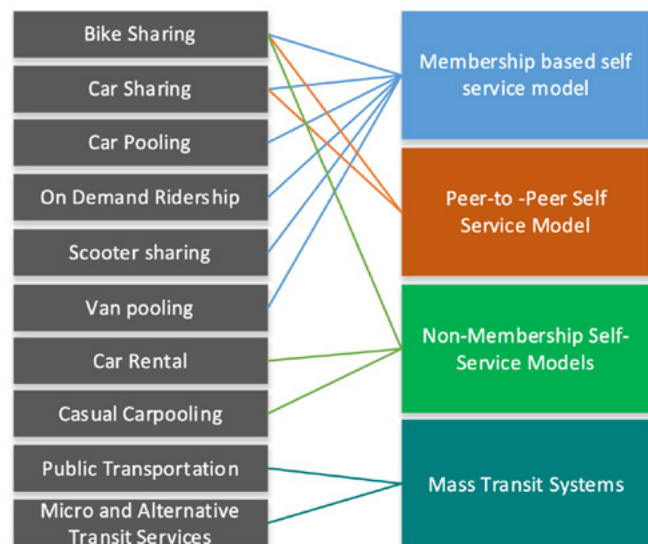
## 3.6 VEHICLE SHARING AND THE SHARING ECONOMY

The term sharing economy is used to describe the act of sharing consumption through online platforms[1]. Most were startups developed from social media platforms where people share ideas, information and insights [17]. The increased use of smartphones and internet-based technologies facilitates their use. The foundation of the sharing economy is shaped by the intention to utilise existing capacities better. While the use of cars and other mobility options is carried out according to peak-load requirements or cannot be divided at will, the sharing economy provides mechanisms to use the available capacities better and thus the fixed costs with mostly low variable costs - in extreme cases, marginal costs of zero. Average costs are reduced by using economies of scale against the background of different individual preferences [18].

Shared mobility is transforming transport systems in many cities across the world. The advent of shared mobility options has increased multimodality and improved accessibility. Above all, it provides mobility options to sections of the population who choose not to own a personalised automobile, making shared mobility an integral part of transport systems in many countries. The most acknowledged sharing economy application has arisen in personal mobility through shared mobility which involves a bicycle, scooter, car or any other mode sharing[19]. It can also include alternative transit services, such as paratransit, shuttles, and private transit services, which can supplement fixed-route bus and rail services. Shared mobility options can be categorised into five groups[6].

---

1 https://www.pwc.co.uk/issues/megatrends/collisions/sharingeconomy/future-of-the-sharing-economy-in-europe-2016.html

1) The membership-based self-service model
2) P2P self-service model
3) non-membership self-service models
4) for-hire service models and
5) mass transit systems.

**Membership based self-service models**

According to Shaheen, Cohen [6], the membership-based self-service models have five common characteristics. That is, there should be an organised group of participants, one or more shared vehicles mentioned in figure 3.7.1., it should have a decentralised network of stations with flexible boarding in and boarding out, should allow short term access (typically one hour or less) and lastly it should provide self-service access. Some examples are given bellow

Bike-sharing (developing world)
1) Mi bici tu bici, Argentina
2) Bike Itaú , Brazil
3) Jo Bike, Bangladesh
4) Mobike, China
5) MyByk, India
6) Bike2Work, Indonesia

Bike-sharing users access bicycles on an as-needed basis. Trips can be point-to-point, roundtrip, or both, allowing the bikes to be used for one-way transport and for multimodal connectivity (first-and-last mile trips, many-mile trips, or both). Station-based bike-sharing ki-osks are typically unattended, concentrated in urban settings, and offer one-way station-based services (bicycles can be returned to any docking location). Free-floating bike sharing offers users the ability to check out a bicycle and return it to any location within a predefined geographic region. Bike sharing provides a variety of pickup and drop-off locations, enabling an on-demand, very low emission form of mobility[20].

**Figure 3.4** Rental bikes in Beijing, China



Markus Winkler, Unsplash

Car sharing

1. ZoomCar, India
2. Zazcar, Brazil
3. Algita, Mobilizim and YoYo, Turkey
4. eHi, China

Individuals typically access vehicles by joining an organisation that maintains a fleet of cars deployed in the urban area, mostly in core and important locations. Typically, the car-sharing operator provides insurance, gasoline, parking, and maintenance, and the participants pay a fee each time they use a vehicle.



**Figure 3.5** Car Sharing ShareNow, Amsterdam

Share Now, Unsplash

Peer-to-Peer (P2P) service models

1. Drivemate, Thailand
2. RentmyRide, South Africa
3. Turo, Drivy USA
4. BlocVehicle, South Korea
5. Darenta, Russia

Advances in ICT technology and increased use of social media platforms enable vehicle owners to share their bicycles or cars with others when they are not using them. Online platforms broker these deals between owners and users and provide organisational support needed for such transactions (online platform, customer support, safety certificates, insurance, and technology).



**Figure 3.6** Auto-Rickshaw, India

Malhar Garud, Unsplash

Non-Membership Self-Service Models

Rental cars and carpooling where no membership is required fall under the category of non-membership self-service models. For example, India's traditional bike-sharing or renting system, where individuals could rent a bike from a bike shop and return it back at the same location, would fall under this category. Car rental like Europcar etc., would also fall under this category.

Carpooling is when one car is shared amongst many people, this is done based on common origin and common destination or have origin or destination along the route. Several carpooling apps allow riders to combine their journeys. These include Blablacar, Trees of cars, Zimride, RideScout etc.

Mass Transit Services

Mass transit systems include public transportation and alternative transit services. The traditional public transport system, bus-based/rail-based/any other that operates on fixed routes and charges fares based on set procedure, falls under the public transport system.

Many countries also have informal transport systems which operate as shuttles, paratransit etc., and micro transit solutions offered by the private sector. These can operate on fixed routes or flexible routes depending upon regulations.

## 3.7 NON-MOTORISED TRANSPORT (NMT): WALKING AND BIKING

Non-motorised transport plays an important role in urban sustainability, especially from the energy efficiency point of view. A wide range of non-motorised modes can be used, starting from pedestrian movement to bicycles, skateboards, push scooters, etc.

From an energy efficiency perspective, NMT modes are desirable as there is no energy use involved, and therefore, any shift from modes using fossil fuel only improves the system's overall energy efficiency. Traditionally, walking, and other non-motorised transport have been dominant modes, even from the time before industrialisation, as automobiles were not available. Therefore, the land use and transport traditional core of many cities are still designed to favour pedestrian and non-motorised movement. In modern-day transport, non-motorised transport is considered the primary mode of transport that should be encouraged for short-distance trips and for accessing public transport modes that can be used for long-distance travel.

Non-motorised modes use very little space compared to private automobiles and provide mobility to a large section of the population, especially those who do not have access to private automobiles (children, elderly, women, poor, etc.). In a study done for Rajkot [21] in India, results of which are presented in Figure 3.7, it was found that NMT modes account for around half of the total trips made in the city. However, only 2% of dedicated space is allocated for these modes. The analysis also revealed that if these modes were supported with adequate infrastructure, they would still consume only 11% of total space transport space used by all modes in the city.

**Figure 3.7** Road space used in Rajkot, India
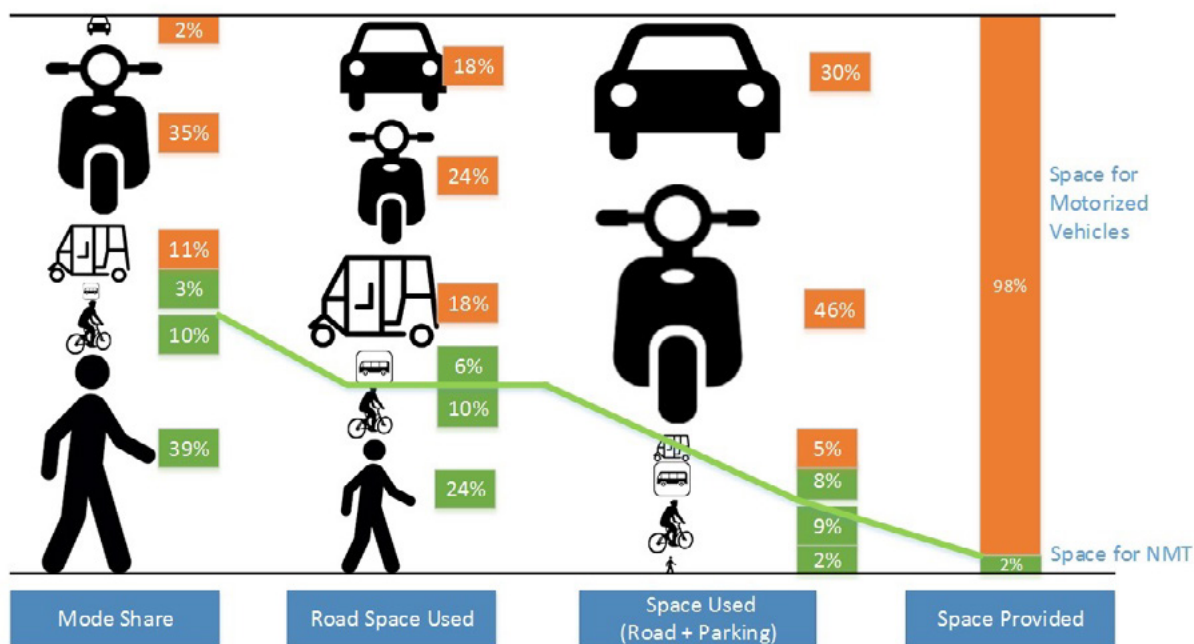


In the same study, it was also found that if adequate policies and measures are put in place to promote non-motorised transport, a large percentage of the population can be attracted towards non-motorised transport.

# **References** - Module 3

[1] Ahmadreza Faghih-Imani, Sabreena Anowar, Eric J. Miller, Naveen Eluru. Hail a cab or ride a bike? A travel time comparison of taxi and bicycle-sharing systems in New York City. Transportation Research Part A 101 (2017) 11–21.

[2] Jorge Rogat, Ed. "Planning and Implementation of Campaigns to Promote Bicycle Use in Latin American countries – guide for decision makers". UNEP Risoe Centre, 2010.

[3] https://www.ctc-n.org/technologies/promotion-non-motorised-transport

[4] Yuhan Huang et.al. "Eco-driving technology for sustainable road transport: A review". Renewable and Sustainable Energy Reviews, journal homepage: www.elsevier.com/locate/rser.

[5] Online: https://cartreatments.com/gear-shifting-tips-for-car/

[6] Online: www.ecodrive.org/en/home/ecowill_the_project/

[7] Paper: Proc IMechE Part D: J Automobile Engineering 2018, Vol. 232(14) 1865–1882 Cairns S, Sloman L, Newson C, Anable J, Kirkbride A & Goodwin P (2004) Travel awareness 'Smarter Choices – Changing the Way We Travel'

[8] https://www.globalfueleconomy.org/transport/gfei/autotool/approaches/regulatory_policy/fuel_economy.asp

[9, 10] https://theicct.org/sites/default/files/publications/Role_of_EU-CO2_Standard_20180212.pdf

[11] https://www.miljofordon.se/bilar/vad-aer-miljoebil/miljoeklasser/

[12] https://dieselnet.com/standards/eu/lez.php

[13] https://www.thegef.org/news/chile-puts-carbon-tax-vehicles-promotes-efficiency

[14] https://www.globalfueleconomy.org/blog/2019/april/south-africa-includes-fuel-economy-standards-in-green-transport-strategy#:~:text=South%20Africa%20includes%20fuel%20economy%20standards%20in%20Green%20Transport%20Strategy,-April%2015%2C%202019&text=GFEI%20partner%20the%20ICCT%20have,explore%20fuel%20economy%20policy%20options.&text=This%20study%20shows%20that%20annual,4.1%20billion%20litres%20by%202050

[15] ITDP, Transprot Demand Management, in The Online BRT Planning Guide. 2017, ITDP.

[16] Black, C.S. and E.N. Schreffler, Understanding transport demand management and its role in delivery of sustainable urban transport. Transportation research record, 2010. 2163(1): p. 81-88.

[17] Cusumano, M.A., How traditional firms must compete in the sharing economy. Communica-tions of the ACM, 2014. 58(1): p. 32-34.

[18] Theurl, T., et al., Ökonomie des Teilens—nachhaltig und innovativ? Wirtschaftsdienst, 2015. 95(2): p. 87-105.

[19] Novikova, O., The sharing economy and the future of personal mobility: New models based on car sharing. Technology innovation management review, 2017. 7(8).

[20] Shaheen, S., A. Cohen, and I. Zohdy, Shared mobility: current practices and guiding principles. 2016, United States. Federal Highway Administration.

[21] Munshi, T., et al., Low carbon comprehensive mobility plan, Rajkot. Unpublished Report, UNEP Risoe Centre on Energy, Climate and Sustainable Development, Technical University of Denmark, Roskilde, 2014.

# Module 4. Barriers to the implementation of sustainable urban transport policy measures

## 4.1 INTRODUCTION

The transport sector stands for approximately a third of the global $CO_2$ emissions of which approximately 80% originates from the road transport sector [1]. This sector represents thus a considerable emissions reduction potential. Despite this, a significant share of the potential remains untapped. Many of the available transport policy measures, which could have contributed to achieving emissions reductions, have not been implemented - sometimes not even considered by decision-makers and transport authorities. A likely reason for this is the existence of several barriers that, in one way or another, are hindering the implementation of various transport policy measures that, if implemented, could have led to the development of a more sustainable and equitable urban transport. There are also barriers that are hindering public transport and non-motorised transport (NMT) users from increased use of the existing services and infrastructure facilities.

The barriers can be of different types and have different degrees of influence on decision-makers, transport authorities, public transport and NMT users. It is, therefore, crucial to identify and analyse these barriers so the appropriate measures to overcome them can be taken, thus facilitating the transition to a more sustainable urban transport.

Barriers hindering the implementation of more sustainable transport policy measures apply to the whole transport sector; road transport (passenger and freight). However, this module focuses on barriers associated with urban transport. The barriers encountered in the urban transport sector could be divided into two categories; those faced by decision-makers and transport authorities on the one hand, and those faced by individual users of public transport services and NMT transport modes on the other hand.

The first category refers to the barriers faced by decision-makers and transport authorities when designing and trying to introduce new policy measures. The second category is associated with how public transport users perceive the way public services are provided (e.g., quality, reliability, and safety). Specifically, the quality, reliability, and safety perceived by passengers when using buses, the metro and other public transport modes. This applies also to NMT transport users when using the existing infrastructure such as bicycle lanes and walking paths. Users of public transport services often have a negative perception about what these services can deliver, and the quality with which these are delivered; a perception that is not always justified. Nevertheless, a negative perception, justified or not, will deter public transport users from its use, thus constituting a barrier.

In order to be able to address these barriers in the best possible way, it is very important to identify them and understand the reasons behind their existence. Without identifying and understanding the reasons behind them, it is very difficult to design and implement effective measures to address them.

This module suggests a four-step process through which the required steps are organised and undertaken in sequence. This is because the input from previous steps is used in the analysis for the next steps (Figure 4.1). The four-step process starts with the identification and categorisation of the barriers and continues until the design of the measures to be applied to overcome these barriers. The four steps are described in detail in section 4.2. For the whole process, it is recommended that all relevant transport-related stakeholders, from both the public and private sector, are involved from the beginning of the process. The advantage of this is that it can benefit from the experience and insights of experts, but also from the perceptions of public transport users. Involving all relevant stakeholders will increase the process's acceptability and legitimacy. Also, engaging them from the very beginning will make them feel more ownership, and thereby, a greater level of commitment. The stakeholder involvement process is covered later in section 4.4.

## 4.2 IDENTIFICATION, ANALYSIS, AND PRIORITISATION OF THE BARRIERS: A FOUR-STEP PROCESS

As mentioned earlier, it is very important that the 4 steps are undertaken in sequence. It is also crucial that the identification and categorisation of the different types of barriers are correctly done since different categories of barriers will most likely require different measures to be taken to overcome them effectively. In some cases, a combination of measures could be the most effective way of removing a barrier.

Categories such as institutional barriers, may be more difficult to address because they are likely to require approval or endorsement at a certain political level. Other initiatives such as awareness-raising campaigns about the benefits of investing in more sustainable transport alternatives, or dissemination campaigns to promote increased use of NMT may be less dependent on political acceptance. However, they may certainly need the endorsement and approval of the local authorities.

Figure 4.1 shows the suggested four-step process to be conducted for the identification, analysis, and prioritisation of the barriers, but also for the identification of measures that could be taken to overcome the different types of barriers.

As mentioned earlier, it is important that the 4 steps suggested for the barrier analysis process are followed and undertaken in sequence. This is because the information derived from one step will inform the analysis in subsequent steps. The first step will help to identify and categorise the prevailing barriers to policy implementers and users of public transport and NMT modes that need to be addressed. Understanding the reasons behind the barriers will help to understand which of the identified barriers are more likely to be overcome and which are not likely to be overcome, thus prioritising accordingly.

Table 4.1 shows a list of potential barriers applying to decision-makers, public transport users, and users of NMT modes. The barriers are divided into categories and sub-categories. The rationale for dividing the main barriers into sub-categories is that it will provide more detailed information about the reasons why they constitute a barrier (what causes it). In this way, it will also help to understand better the reasons behind them, which makes it easier to identify measures to overcome the barriers.

**Figure 4.1** Barrier analysis: the four-step process



*Source: Elaborated by the author*

**TABLE 4.1** Categories and sub-categories of barriers to decision-makers and public transport and NMT modes users.

| Category | Sub-category/reason | Decision-makers | Public transport service and NMT users |
|---|---|---|---|
| **Economic and Financial** | • Lack of financial resources or budgetary constraints<br>• Need for large upfront capital for infrastructure interventions<br>• High cost of capital (high-interest rate) | X<br>X<br>X | |
| **Institutional** | • Lack of managerial and organisational skills<br>• Lack of clear policy guidance<br>• Lack of available competent staff | X<br>X<br>X | |
| **Legal and Regulatory** | • Ineffective or lack of regulatory frameworks<br>• Bureaucracy<br>• Political instability<br>• Lack of political will<br>• Absence of monitoring and enforcement mechanisms | X<br>X<br>X<br>X<br>X | |
| **Technical capacity** | • Lack of capacity to assess the potential impacts of different policies<br>• Lack of capacity to operate and maintain new transport systems | X<br>X | |
| **Awareness** | • Lack of awareness about the negative impacts of pollution<br>• Lack of knowledge of the benefits (e.g., environmental, and health-related) of biking and walking<br>• Distorted information about the performance of public transport systems | X<br><br><br>X | X<br>X<br><br>X |
| **Safety** | • Insecurity when using public transport systems (inside buses/ metro and shelters)<br>• Insecurity when biking or walking (lack of dedicated lanes/paths and lighting) | | X<br><br>X |
| **Cultural** | • Aversion to new technologies<br>• Prestige | X | X<br>X |
| **Usability** | • Long distance to access bus and metro stops<br>• Lack of integrated tariffs between different transport modes<br>• Lack of information regarding timetables and routes | | X<br>X<br>X |

*Source: Elaborated by the author*

Table 4.1 shows some of the most common barriers both policy implementers and users of public transport and NMT modes face. In this context, it is very important that policy-makers and decision-makers are aware and understand not only the barriers they face, but also those faced by users of public transport and NMT modes, so they can design the transport policies in a way that promotes and facilitates the use of both public transport and NMT modes. For instance, if the policy is to promote an increase in the use of bicycles and walking, it is crucial to understand the barriers people are facing in terms of safety, e.g., bike lanes and walking paths which may be perceived as too narrow, with poor lighting, or in bad conditions. This will help them to take this into consideration at the time of designing the policy measures.

## 4.3 MEASURES TO OVERCOME THE BARRIERS

The information about different types of barriers affecting decision-makers, and users of public transport and NMT modes are shown in table 4.2, which emanate from step 1, need subsequently to be analysed in step 2. Step 2 will allow for a more in-depth analysis of the reasons behind the existence of the barriers. Consequently, having a better understanding of the reasons behind the barriers will make it easier to. Table 4.2 shows potential measures applicable to the different types of barriers.

**TABLE 4.2** Potential measures to be taken to overcome the transport barriers

| Category | Measure |
|---|---|
| Economic and Financial | <ul><li>Introduction of investment subsidies</li><li>Grants and loans</li><li>Loan guarantees</li><li>Taxation</li><li>Congestion charges</li><li>Public-private partnerships</li></ul> |
| Institutional | <ul><li>Relevant capacity building to decision-makers and transport authorities</li><li>Relevant capacity building to staff in transport authorities</li><li>Establishment of formal organisational structures and provision of the required authority to decision-makers</li></ul> |
| Legal and Regulatory | <ul><li>Introduction of regulations (e.g., to comply with anti-idling regulations, maximum speeds, parking, etc.)</li><li>Establishment of monitoring and enforcement mechanisms</li></ul> |
| Technical capacity | <ul><li>Technical training related to public transport systems to decision-makers and transport authorities (better understanding of which measures are possible or not)</li><li>Technical training to operators and those that maintain transport systems</li></ul> |
| Awareness | <ul><li>Awareness-raising campaigns to inform decision-makers and transport authorities of the multiple benefits (economic, social and environmental) of sustainable transport</li><li>Dissemination campaigns among public transport and NMT users of the benefits of biking and walking (health, economic and environmental)</li></ul> |
| Safety | <ul><li>Improved safety for the use of bicycles and walking (better allocation of road space, e.g., widening of both bike lanes and walking paths)</li><li>Improved lighting on bicycle lanes and walking paths</li></ul> |
| Cultural | <ul><li>Behavioural change through the dissemination of the benefits (economic, social, and environmental) of the shift from private cars to NMT</li><li>Improved public transport services (bus/metro) information, (e.g., timetables, stops, routes, etc.)</li></ul> |
| Usability | <ul><li>Decrease the distance between bus and metro stops</li><li>Introduce intelligent payment systems between different transport modes</li><li>Introduce passenger real-time information</li></ul> |

*Source: author compilation*

As mentioned earlier, some of the measures designed to overcome some of the barriers may be implemented in combination with complementary measures. For instance, to have a better impact from a campaign to promote a shift from private cars to public transport or to NMT modes (biking or walking) introducing economic incentives or disincentives could be a good option. For example, a reduced bus/metro tariff and the introduction of congestion charges could be effective complementary measures. It will incentivise private car owners to either shift to public transport or to NMT modes. This way, the effectiveness of the measure taken to promote the mode shift will be reinforced by the complementary measures. If the objective is promotional, it is crucial that the campaign is designed in a way so the message is conveyed in such a way that it can achieve the intended objective, namely, to overcome the barrier.

Similarly, if the designed measure is intended to overcome a safety-related barrier faced by users of NMT modes, infrastructure improvements aimed to increase security will be needed. Investments, such as widened bicycle lanes or improved lighting during dark hours, could be financed by establishing a private-public partnership, or as previously mentioned, by the revenues from congestion charges.

## 4.4 STAKEHOLDER INVOLVEMENT IN THE BARRIER IDENTIFICATION AND ANALYSIS PROCESS

The identification and analysis of the barriers facing decision-makers, transport authorities, public transport users and NMT users, is a process that should be conducted in consultation with all relevant stakeholders from the start. Engaging stakeholders in the process from the beginning will make them feel ownership and thus be more willing and committed to participate and contribute with ideas and feedback. Relevant stakeholders are those that may be affected by, have a direct or indirect interest in; or that are in one way or another, affected by the situation or problem either positively or negatively.

To achieve the best possible stakeholder representation, it is suggested to conduct a mapping of all relevant stakeholders and from there select the ones that should be invited to participate in the consultation workshops. For the mapping exercise, a reduced number of stakeholders, i.e., a core group, should be composed. This core group could be composed of decision-makers, policymakers and implementers, transport authorities, municipality and civil society representatives and relevant actors from the private sector. It is recommended that the core group does not exceed 8-10 participants, thus allowing for more structured and fruitful discussions. This core group shall map, categorise and select a wider group of stakeholders, which are directly or indirectly associated with urban transport that will be, later on, invited to participate in the consultation workshops, where a more comprehensive analysis will be conducted.

**Figure 4.2** Core group stakeholder mapping



Christina@wocintechchat.com, Unsplash

**Figure 4.3** Relevant stakeholders
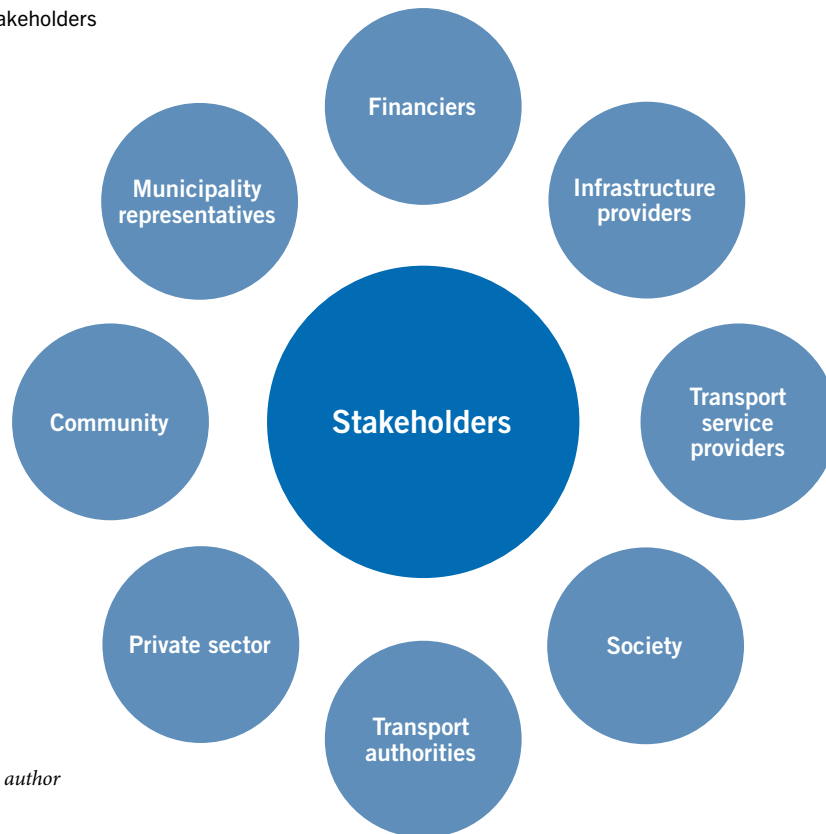


*Source: Elaborated by the author*

Involving all relevant stakeholders has several advantages since the various experts and relevant stakeholders will contribute with expertise and insights, which may lead to the design and implementation of more sound, sustainable and widely accepted transport policies. Another advantage is that stakeholder participation will give more legitimacy to the process, and the transport policies emanating from the process will more easily get the acceptance and endorsement of politicians and other transport authorities.

The input and feedback from the selected stakeholders can be obtained, as we will see below, in various ways, for example, through online surveys. For instance, in a study by McTigue

et al., undertaken in Great Britain to identify barriers to the implementation of local transport policies, online surveys and follow-up interviews were used. In the survey, it was revealed that the greatest challenges faced by local authorities were the availability of financial and staff resources [2].

Involving representatives from local communities (public transport and NMT users) will help to collect relevant information about the way the barriers are perceived by citizens on the ground, which is an important input to the process. Figure 4.4 shows the 4 steps of the process and the methodology that could be used to obtain the needed information.

**Figure 4.4** Barrier analysis: four-step process with stakeholder involvement
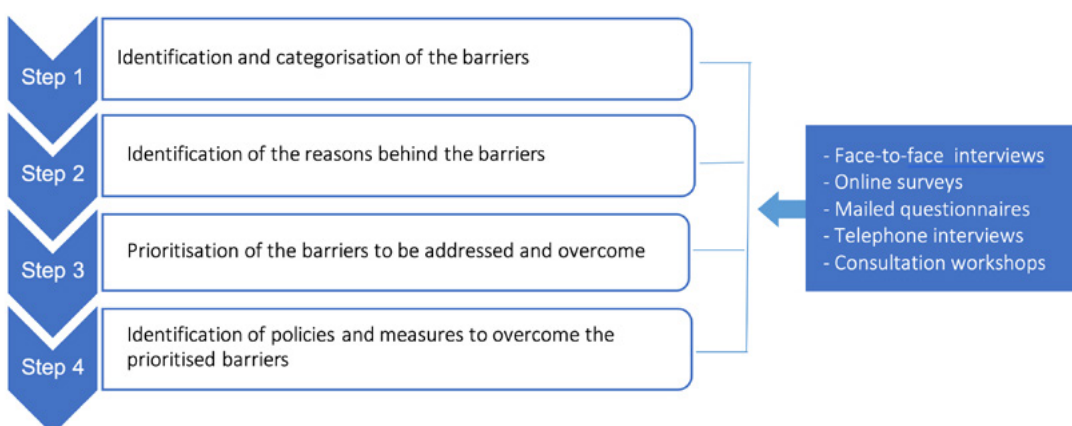


*Source: author compilation*

To obtain the best possible results from the stakeholder consultations, it is important to identify and make a list of the most relevant stakeholders to be interviewed or invited to participate in the consultation workshops. As shown in Figure 4.4 the methodology for the elicitation of information can vary depending on a number of factors such as availability to participate (very busy stakeholders or stakeholders that are not allowed to participate), or prevailing policies at their working place. Therefore, mailed questionnaires or telephone interviews may make their participation more likely. The design of questionnaires, as well as telephone interviews, need to be designed in such a way so they don't include any biases which can affect or influence the answers. In that sense, open-ended questions are recommended. Similarly, a screening of the stakeholders to be invited to participate in the consultation workshops is suggested. This is mainly because different stakeholders will have different levels of understanding, different interests, and even different degrees of influence on the institutional system but also on other stakeholders. Having information previous to the invitation to participate being sent will make it possible to compensate for the bigger influence some of the stakeholders may have.

Eventually, the elicited information obtained through the barrier analysis process must be analysed by policymakers and implementers and the costs and benefits of their implementation should be carefully assessed. Module 3. Non-technical options

# **References** - Module 4

[1] ENERDATA, 2018

[2] Clare McTigue, Jason Monios and Tom Rye. "Identifying barriers to implementation of Local Transport Policy: an Analysis of Bus Policy in Great Britain".

[3] Aaltonen, S., & Kreutz, E. (2009). Engage your Stakeholders - Stakeholders Involvement Toolkit for Local Authorities. Union of the Baltic Cities Commission on Environment (EnvCom) co-funded by European Union.

# Module 5. Business Models and Financial Instruments for Sustainable Urban Transport

## INTRODUCTION

The increasing demand for individualised and flexible urban transportation, with the use of new technologies and shared transport modes, is skewing the long trajectory of conventional transportation towards new patterns of urban mobility. Likewise, the ongoing COVID-19 pandemic has led to increased use of private vehicles due to recommendations by many health authorities around the world not to use public transportation. The shift from public transport to private cars will, most likely, persist for some years to come. This is mainly because we are prone to adopt increased comfort and flexibility, not willing to give it up afterwards. As mentioned in Module 4, the lack of economic resources is one of the main barriers to policymakers and policy implementers who aim to achieve more sustainable urban transport. Therefore, there is a need for appropriate business models (BMs) and financial instruments (FIs) that can make these interventions possible. In a world characterised by dynamic urban settings and ways of travelling, these can play a crucial role, help secure the required resources.

This module presents various BMs, for example, the Peer-to-Peer (P2P) model, within the shared mobility and micro-mobility modes (i.e., car sharing, bike sharing, and others) for the urban transport sector. The study of BMs in this module will build on the concepts of shared mobility service models already introduced in module 3. In this regard, the introduction of the Business Model Canvas for Sustainability (BMCS) will support the analysis of the selected BMs. The BMCS will pay attention to the burdens and benefits of these BMs, and it will suggest recommendations and examples to reduce the associated costs to implement different BMs. This module also describes and suggests potential FIs that can be used to fund the necessary investments to uptake shared mobility and micro-mobility services.

## 5.1 THE ROLE OF BUSINESS MODELS

Traditional modes of transportation are being significantly replaced by new mobility services and the BMs that support them. In this sense, organisations that want to be ahead of the curve use design thinking, strategy, and an openness to changing their BMs. Customers nowadays are looking for businesses that have disrupted the status quo by reimagining their BMs and delivering value to them. Furthermore, distinct, and innovative BMs are required to develop sustainable and profitable solutions. A BM traditionally defines how an organisation develops, delivers, and collects value in economic, social, cultural, or other contexts. However, BMs are frequently focused on creating value through financial gains,

sometimes ignoring environmental and social considerations - this needs to be addressed.

With the COVID-19 crisis, the development of innovative BMs and some assistance are key for operating in the black [1]. Simultaneously, consumer behaviour and mobility patterns are changing. The pandemic of COVID-19 has expedited these changes, which are facilitated by digital solutions and the shared and collaborative mobility services [2]. All these factors are increasing the demand for better, more sustainable, and more efficient BMs. Numerous studies demonstrate that businesses that redesign their BMs are more likely to prosper [3], [4], [5], [6].

The development of new BMs will be essential for expanding the mobility industry because advances in this field pose a challenge to established BMs [7], [8], [9]. Transportation firms need to develop a sustainable business plan to succeed in today's competitive environment. It is about the value a company can provide to consumers, how it will structure to do so, and how it will regain a percentage of that value [10]. Well-defined BMs allow organisations to identify what customers want and need, and how organisations may best meet and pay for those demands [11].

## 5.2 SUSTAINABLE BUSINESS MODELS FOR URBAN TRANSPORT

Today, businesses need to operate more sustainably and consider the three main sustainability pillars, economic, environmental, and social, in the logic behind their business practices to create value for their stakeholders. This also applies to the transport sector and, in particular, to the road transport sector, due to the sector's multiple negative environmental impacts, both local and global. However, within BM innovation, the idea of sustainability, which encompasses all three dimensions mentioned above, is gaining popularity and is now a major topic in academic research [12].

This section introduces the new Business Model Canvas for sustainability (BMCS) developed by Cardeal et al. [13]. The BMCS focuses on integrating the three pillars of sustainability in one BM.

Thus, the BMCS preserves the original point of the original Canvas model of Osterwalder and Pigneur [14], focusing on the value of a product, process, or organisational innovation, while integrating the three pillars of sustainability as we see in Figure 5.1.

**Figure 5.1** Business Model Canvas for Sustainability.



*Source: adapted by the author using information from A. Osterwalder and Y. Pigneur [14] and S. Sarasini and O. Langeland [15]. The figure has been designed using Miro (online whiteboard & visual collaboration platform).*

Analysis to show the potential of the selected BMs depicted in sections 5.3. to 5.4. of being sustainable and low-cost options are conducted below using the BMCS. This section will mainly focus on the burdens and benefits while considering the three pillars of sustainability. In addition, the BMCS will also include a section for recommendations and examples of improvement for each of the different BM presented below.

## 5.3 SHARED MOBILITY (CAR-SHARING, RIDE-SOURCING AND RIDESHARING) BUSINESS MODELS

Car-sharing is centered on changes in travel behaviour as a practice, new markets, and business model innovation while being powered by new mobile technology and applications. More people believe that car sharing will lead to a more environmentally friendly transportation system. Among other advantages, they are connected to improved urban management and energy efficiency [15].

**TABLE 5.1** BMCS for the Car-Sharing Business Model.

**Analysis of Car Sharing Business Models**

| | Integrator | Public transport service and NMT users |
|---|---|---|
| **Key partnerships** | The network of suppliers and partners that make the BM work. | Direct contact with individuals. |
| **Key activities** | Customer support and marketing. | Customer research and co-creation. |
| **Key resources** | Mix of internal combustion engine (ICE) and electric vehicle technologies. | Physical: Existing vehicle stock. |
| **Value propositions** | Station-based (i.e. Ubeeqo) or Free floating (i.e. Car2go & Zipcar). | Rental from peers' homes. |
| **Customer relationships** | Looser ties based on digital surveys and feedback. | Close ties based on continuous interaction. |
| **Channels** | • Smartphone apps<br>• Website | • Smartphone apps<br>• Website<br>• Social media<br>• SMS |
| **Customer segments** | • Smartphone apps<br>• Website<br>• Social media<br>• SMS | P2P (i.e. Dégage) |
| **Benefits** — Revenue Streams | • Monthly subscription payments Hourly fees<br>• Kilometre fees | Provisional fees |
| **Benefits** — Eco-Social Benefits | • Car-sharing improves the use of resources by redistributing, sharing, and utilising excess capacity.<br>• It increases economic output by enabling job seekers who cannot afford a car to utilise one if they need one for job hunting and employment purposes.<br>• Additionally, car-sharing can serve specific market segments. For instance, small firms could use car-sharing as a more efficient and flexible alternative to owning automobiles that are only used on an as-needed basis if there is no local conventional vehicle rental service;<br>• Social inclusion. | |
| **Burdens** — Cost structure | • Vehicle fleet maintenance and operations<br>• Parking fees<br>• Congestion charges<br>• Employees | • Employees |
| **Burdens** — Eco-Social costs | • The social costs of car-sharing are moderate.<br>• Car-sharing allows drivers to pay as they go, incurring small fixed expenses but significantly greater variable costs. | |
| **Recommendations** | **1.** The success factors listed below, according to Deloitte (2017), are crucial for free-floating providers (Deloitte, 2017):<br>• Location. Dense populations will attract enough clients per car.<br>• Time-based pricing.<br>• Collaboration with municipal governments to receive parking spaces/permits, and<br>• Convenience and widespread accessibility of (small) vehicles in urban areas.<br>Moreover, for P2P car-sharing, the following aspects must be considered:<br>• Improve user-friendliness in technology and<br>• A broad and diverse network that ensures the best possible match for all customers.<br>**2.** Integrators also advocated for policymakers to prioritize developing electric vehicles (EV) charging stations.<br>**3.** Finally, other key takeaways of the current state of the market of car sharing includes:<br>• Partnerships with public transport operators and Original Equipment Manufacturer (OEMs).<br>• Multi-modal flexibility. | |
| **Real cases examples** | **1.** One option is to lower free-floating service costs, like one Nordic provider that created a novel pricing structure that rewards users who relocate their vehicles. By not hiring workers to redistribute vehicles, the operator saves money.<br>**2.** Some integrators provide lower usage charges with a monthly membership, while others do not, allowing members to register without obligation. This lets users to pay as they go for services, offering convenient and flexible access to those who like to experience them before adoption. Integrators regularly test price packages with differing degrees of coverage using BMI to optimize value. | |

*Source: compiled by author using data from S. Sarasini and O. Langeland; T. Litman; V. Roblek, M. Meško, and I. Podbregar; T. Schiller, J. Scheidl, and T. Pottebaum; and S. B. Suzi Tart, Peter Wells [15]–[19].*

**TABLE 5.2** BMCS for the Ride-Sourcing Business Model.

**Analysis of Ride-sourcing/Ride-hailing (i.e., Uber) Business Models**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Key partnerships** | • The drivers (the supply side of Uber) can join or leave, as they like. It is essential to have a sufficient number of them to give the consumer proposition (timely pick-up at low cost). <br>• Investors. <br>• Technological partners. | | | | | |
| **Key activities** | Commuters can use rideshare apps while at home to identify the nearest pickup spot. Transit vehicles only stop in prefixed locations. Rideshare apps offer dynamic stations while remaining within the radius of operation. It also provides the freedom to move when public transportation is not operating. | | | | | |
| **Key resources** | • Network | • Data and Analytics | • Skilled staff | • Apps, Architecture | • Venture capital | • Brand |
| **Value propositions** | • For the Driver: Income generation; Flexible Work Hours; ease of joining; low idle times. <br>• For the Rider: Fast pick up; lower cost; convenience; easy transaction; rating/ feedback. <br>• Cheaper and faster than taxis and social networking. | | | | | |
| **Customer relationships** | Close ties based on continuous interaction. | | | | | |
| **Channels** | • Private vehicles and drivers <br>• Smartphones applications with location-based service | | | | | |
| **Customer segments** | P2P | | | | | |
| | • Drivers: <br>Demographic - Socio-economic - Micro geographic - Behavioural - Situational | | | • Customers/riders: <br>Usage patterns - Type of usage - Demographic - Socio-economic - Micro-geographic | | |

| | | |
|---|---|---|
| **Benefits** | Revenue Streams | The primary source of revenue production is provided by 20% of the fare charged to the customer, with the remaining 80 percent going to the driver as compensation. |
| | Eco-Social Benefits | • Reduce the environmental impact of local transportation by lowering car use and fossil fuel consumption. <br>• Resources and supply chains that are underutilised. The vehicles used are personal vehicles owned by individuals who wish to share their vehicles. <br>• Interaction with peers and with customers. |
| **Burdens** | Cost structure | • The main costs involve: sales, marketing & promotion cost <br>• Also, there are various more costs to consider, for instance: (1) infrastructure cost, (2) research and development, (3) platform maintenance, (4) legal and settlement costs, (5) insurance costs. |
| | Eco-Social costs | Srnicek (2017) describes the new sharing economy phenomena as "a sort of platform capitalism" that illustrates Uber's so-called social costs. Uber's international operations, many of which are banned, include: (1) violation of the labour legislation (primarily because employees do not recognise drivers' status, irrespective of the amount of job they are carrying out), and (2) infringement of legislation setting the safety of the road/workplace. |
| **Recommendations** | | 1. Cohen & Kietzmann (2014) advised shared mobility service providers to collaborate with local governments to secure active city support and maximise public and environmental goals. Riders might save money if these P2P networks were incorporated into transportation apps, such as shared mobility data. <br>2. By considering shared transportation as a merit good and minimizing the traditional agency conflicts typically seen in strictly private business models, access and environmental impact can be maximized. <br>3. Therefore, to reduce the costs (both economic and social) from ride-sharing business models, merit good BMs for sustainability (BMfS) could play an important role. For doing so, promoting public-private partnerships (PPP) is cru-cial. More details about PPP will follow in section 5.6.1.. More details about PPP will follow in section 5.6.1. |

*Source: compiled by the author using data from B. Cohen and J. Kietzmann [7], S. Sarasini and O. Langeland [15], S. Sarasini and O. Langeland [17], S. Satti; A. Asirin and D. Azhari; AppsRhino; and G. Fisher, J. E. Wisneski, and R. M. Bakker [20]– [23].*

**TABLE 5.3** BMCS for the Ride-Sharing Business Model

**Analysis of Ridesharing (i.e. carpooling) Business Models**

As mentioned in Module 3, Blablacar is an example of carpooling services with non-membership self-service model.
Below an illustration of its BM using BMCS.

| | | | |
|---|---|---|---|
| **Key partnerships** | • The venture capital funds that have facilitated the company its development and expansion | • Insurance company | • Hosting and architecture providers, to handle the platform´s data |
| **Key activities** | Blablacar's major activity as an intermediary between drivers and passengers is the development, maintenance, and promotion of its web platform and apps. | | |
| **Key resources** | • The user community<br>• Blablacar brand<br>• The web platform and apps<br>• The cash provided by venture capital funds<br>• Staff | | |
| **Value propositions** | Provide a less expensive mode of transportation than the bus or train on long-distance routes that are tailored to your schedule and needs. | | |
| **Customer relationships** | • The self-regulation of the user community before, during and after each trip.<br>• The rating and review system, which helps create a digital reputation for each user. | | |
| **Channels** | • Ads on Facebook.<br>• The delivery of the value proposition occurs between the users themselves. | | |
| **Customer segments** | It is a two-sided market in the sense that it must recruit drivers who offer car journeys on the platform and passengers who come into touch with those drivers. | | |
| **Benefits** | Revenue Streams | • Commission per trip | • Fixed cost |
| | Eco-Social Benefits | • Carpooling protects the environment. Less traffic implies less greenhouse gas emissions and better air quality.<br>• It's good for your health. Carpooling can lower health hazards for everyone. Carpooling may also be less stressful than solo commuting. | |
| **Burdens** | Cost structure | • Advertising | • Personal | • Apps + Web |
| | Eco-Social costs | N/A | | |
| **Recommendations** | Carpooling is an adaptable model that can also take place in different settings. Some studies analyse various carpooling schemes in the work environment or academic settings. In this regard, Transport for Ireland (TFI) has established some guidelines to advise on good practices when running carpooling schemes. It provides recommendations concerning etiquette, safety issues, operations, license, insurance, tax, and shared costs, together with some practical case studies. More information can be found **here.** | | |

*Source: compiled by author using data from Sergio Rodriguez; Anonymous; and Daniel Spence [24]–[26].*

## 5.4 MICRO-MOBILITY (BIKE SHARING AND SCOOTER SHARING)

Car parks, vast highways, and multi-tiered bridges occupy public space in metropolitan areas. Most developed cities have micro-mobility targeted toward commuters. This business concept saves customers money while simultaneously providing a cost-effective source of revenue for service providers.

Micro mobility services are provided by the micro mobility industry. The industry is known for selling to consumers (B2C), but it may also supply to groups (B2G) or other businesses (B2B). Most of the vehicles produced by the industry are electric, such as scooters, bicycles, and automobiles.

The majority of shared micro mobility consists of station-based bike-sharing (bicycles can be taken up and dropped off at any station or kiosk) and dock less bike-sharing and scooter-sharing (a bicycle or scooter picked up and returned to any location).

For the purpose of this study, the analysis will be done for e-scooter sharing and bike-sharing business models.

**TABLE 5.4** BMCS for the Bicycle sharing Business Model

| | | | | |
|---|---|---|---|---|
| **Key partnerships** | • Municipalities | • Public transport | • IT technology providers | • Component/material providers |
| **Key activities** | • Development and production | • Platform and fleet maintenance | • Rental terminal maintenance | • Marketing |
| **Key resources** | • Production facilities and materials | • Platform   • Terminals | • (e-)Bicycle fleet | • IT and customer support employees |
| **Value propositions** | • (e-)Bike-sharing service | • Bike-sharing solution | | • Advertising space (on bicycles and mobile apps) |
| **Customer relationships** | • Automated & self-service; | • Tailored business customer service; | | • Active online communities |
| **Channels** | • Website/platform Apps (iOS, Android, Microsoft) | • Terminals Bicycles | | • Social media profiles |
| **Customer relationships** | • Universities | • Municipalities | • Individual bike riders | • Companies |
| | B2C/B2B/B2G (Aasebø, 2019). | | | |

| **Benefits** | Revenue Streams | • Subscription fees | • Usage fee (time-based) | • Sponsorship | • Advertising |
|---|---|---|---|---|---|
| | Eco-Social Benefits | Bike-sharing programs must be used in big numbers in order to provide the greatest possible benefits. Bike-sharing programs provide the following eco-social benefits:<br>• They provide cities with flexible mobility, decrease congestion, and serve as a "first/last-mile" connection to boost public transportation.<br>• A recent study revealed that the health advantages of the 12 major Bike-sharing systems bike-sharing systems (BSS) in Europe outweigh the hazards of increased air pollution and road traffic deaths. If all bicycle sharing journeys in these cities replaced car trips, 73 deaths per year could be averted.<br>• Nonetheless, the environmental advantages of bicycle sharing appear to be related to increased cycling rather than reduced resource usage. BSS members own more private bicycles than non-members, according to research. | | | |

| **Burdens** | Cost structure | • Marketing | • Platform maintenance and customer relations | • Bike fleet and terminal maintenance |
|---|---|---|---|---|
| | Eco-Social costs | • Bicycle maintenance and management. | | |

| **Recommendations** | 1. Key takeaways:<br>   • Cities shall actively promote shared micro-mobility to maximise market potential and mileage commercialisation.<br>   • Cities might create intermodal hubs for micro-mobility and public transportation.<br>   • Some cities are unwilling to employ the service due to safety concerns;<br>   • The low entry barriers allow competitors to acquire a player's consumer base by investing a little more (McKinsey, 2019).<br>2. Assess public preferences. A study carried out for the city of Mashhad in Iran regarding public preferences towards bicycle sharing system (BSS) suggests that certain variables have a significant impact on the likelihood of choosing BSS as the primary mode of transportation in Mashhad. These variables are employment status, gender, bicycle fare, dedicated bicycle lane, bicycle quality, pavement quality, proximity of BSS stations to bus stops, and bicycle training programs.<br>3. Good telecoms and Internet of Things (IoT)-based systems. According to a study on cost-effective and eco-friendly bicycle sharing systems for developing countries, it is feasible for individuals to travel more by bicycle and use less public or private transportation in cities around the world with a lower budget. However, an efficient way to establish good telecoms and IoT-based systems are needed. Furthermore, NFC cards for payments and a lock/unlock verification system will help increase efficiency and security in the future. |
|---|---|
| **Real case example** | There are several kinds of bike-sharing, with hybrid bike-sharing taking a unique approach that maximizes flexibility while minimising turmoil. In this regard, Urban Sharing (a Norwegian software platform for micro-mobility) has developed a better bike-sharing system. Its hybrid lock works with both physical and virtual bike-share stations. The method works by locking the bike "to itself" or returning it to a physical dock. This paradigm allows for user flexibility while maintaining urban order. |

*Source: compiled by author using data from E. Vitkauskaite and E. Vaiciukynaite; H. K. W. Aasebø; P. DeMaio; E. Fishman, S. Wash-ington, and N. Haworth; E. Fishman, S. Washington, and N. Haworth; Y. Zhang and Z. Huang; S. Shaheen, S. Guzman and H. Zhang; L. Caggiani and R. Camporeale; L. Abolhassani, A. P. Afghari, and H. M. Borzadaran; and L. Bajracharya, T. Mulya, A. Purbasari, and M. Hwang [27]–[35].*

**TABLE 5.5** BMCS for the Scooter sharing Business Model

| | | | | | |
|---|---|---|---|---|---|
| **Key partnerships** | • Scooter producer | • City authorities | • Operator for picking up and charging scooters | • Insurance (AXA) | • Investors |
| **Key activities** | • Scooter & App maintenance.<br>• Communication with authorities.<br>• Customer experience optimisation. | | | | |
| **Key resources** | • Electrical scooters<br>• GPS tracker system and the App<br>• Human resources: sales and marketing team, mechanics;<br>• Depot for maintenance<br>• Financial resources | | | | |
| **Value propositions** | • Improved end-to-end short-distance transport experience with a shared electric scooter.<br>• More cost effective than owning a scooter. | | | | |
| **Customer relationships** | Automated and self-services, as well as personalised support in some scenarios. | | | | |
| **Channels** | • App based channel | | • Website based channel | | • Physical scooter presents in cities |
| **Customer segments** | • Commuters in cities | | • Users of public transports who travel their 'last-mile' | | |

| **Benefits** | Revenue Streams | • Fixed fee per scooter trip.<br>• An additional fee for each minute spent on the scooter. |
|---|---|---|
| | Eco-Social Benefits | • Better community cohesion.<br>• Less traffic congestion (for short trips).<br>• Lower emissions, thereby contributing to better air quality.<br>• Because e-scooters are smaller than other modes of transportation and easier to ride on sidewalks than bicycles, women may feel safer riding them than men may. Women may also be more distance-sensitive than men, making it easier to stand on an e-scooter than a bicycle. |
| **Burdens** | Cost structure | • Scooters acquisition, maintenance, collection and charging.<br>• Maintenance of the app. |
| | Eco-Social costs | • A major source of GHG emissions from shared e-scooter use is materials, manufacturing, and automotive use for the collection of e-scooter for charging.<br>• Recycling is essential since electric scooters consist of rare elements that are possibly polluting. The batteries (and the cell itself), which makes them responsible for a large amount of pollution from which it cannot be escaped, have to be taken care of, at least until the battery recycling industry is better developed.<br>• Customers abandoning damaged or outdated scooters on the street are difficulties, as are safety concerns. |
| **Recommendations** | | 1. BMs for e-scooters should address the following to optimize use and promote its cost-efficiency:<br>• Use e-scooters for the last mile and ride them carefully to extend their life.<br>• Improve the charging infrastructure and<br>• Not to be used to replace low-carbon travel options like walking, taking public transportation, or cycling.<br>2. But how to hold firms accountable and modify consumer behaviour? Possible solutions include:<br>• Dedicated on-street parking.<br>• Docks and parking zones. Multiple dockless services should share a universal dock rather than having separate docks for each company. Bonus parking zones could be introduced to encourage people to park away from entrances and key paths.<br>• Parking penalties and off-limits areas. Leaving a bike or scooter on the street may result in a fee for the user, and the operator may be charged for failing to remove bikes or scooters that pose a safety concern or obstruct access. |
| **Examples for Improvements** | | 1. The leading smart commercial bike parking provider in the world, Bikeep, provides parking lots with the uniqueness that it allows all e-scooters to be locked and loaded, regardless of manufacturer or service provider. Scooters are easily accessible yet securely locked in their parking lots to prevent vandalism and do not require daily loading.<br>2. Grin (a Mexican electric scooter company) is trying to support with parking issues. It has partnered with restaurants, businesses, and corner stores to provide scooter parking. It created "grin zones" in front of establishments that shoppers can find in its app. The businesses receive publicity and potentially more foot traffic. Grin pays merchants to charge scooters overnight in-store backs to avoid building an independent charging network. Also, Grin encourages customers who return scooters to "grin zones" in front of establishments with discounts on rides or neighbouring stores. Also, Grin encourages customers who return scooters to "grin zones" in front of establish-ments with discounts on rides or neighbouring stores.<br>However, Grin had to cease its City of Mexico activities when its scooters were stolen and sold online, notably on Facebook. Grin is now obliged to cease operations owing to COVID-19. |

## 5.5 REMARKS AND RECOMMENDATIONS FOR BUSINESS MODELS WITHIN THE SUSTAINABLE URBAN TRANSPORT LANDSCAPE

After exploring the different BMs depicted from sections 5.3. to 5.4., it can be concluded that they provide several eco-social benefits and some challenging cost structures. Both public and private actors can investigate novel synergies that might pave the way for new disruptive BMs. Of course, the circumstances of each country, investment opportunities, and potential consumers' willingness to pay will all influence these developments.

Nonetheless, COVID-19 emphasizes how the "old mobility normal" was already damaging local economies through traffic congestion, overpaying on roads and parking, and drivers harming and killing too many people through crashes and air pollution. Our transportation infrastructure was previously inadequate and is now in decay [1].

The pandemic has impacted urban transportation, which has also impacted the idea of smart cities as a sustainable city model for 2020. Cities began accelerating initiatives including pedestrians, bicyclists, and new vehicle or bike-sharing programs with private partners. In 2020, the COVID -19 pandemic prompted car-sharing companies to close. For example, businesses emphasise cutting-edge mobile solutions that give customers more affordable options (like the introduction of "pay-as-you-go") and increase payment through applications. Micro-mobility solutions may be on the increase as a result of a pandemic (sharing scooters, bicycles, and scooters) [17].

According to UNECE (2021), a variety of enabling factors might spur public support for environmentally friendly and sustainable transportation [42]:
- Increase efforts by government agencies to address public worries about the future of sustainable mobility.
- Strong partnerships between local government entities, transportation providers, the general public, and the commercial sector are required.
- Informational initiatives that illustrate how active commuting, better public transit, and effective spatial design may ease such worries.
- A constant information and outreach initiative equivalent to the anti-smoking campaign.

Implementing BMCS enables viewing various sustainable transportation BMs in a broader context and locating possible advantages and disadvantages. It may act as a foundation for investment opportunities and decision-making processes. However, further study is required to assess the burdens and benefits of the BMCS quantitatively.

## 5.6. FINANCIAL INSTRUMENTS AND RISK-MITIGATION MECHANISMS FOR SUSTAINABLE URBAN TRANSPORT

Typically, the primary source of financing for urban mobility systems are general city budgets and transfer payments from the national level.

However, the procurement and operation of new products and services and the adaptation of existing infrastructure add to the cost of urban mobility transformation. Public funds are limited, and private investors are typically unwilling to engage in sustainable transportation initiatives. Thus, cities must seek more funds and build business models to attract private sector participation in urban transport development. In this regard, this section won't focus on local revenue streams linked to sustainable urban mobility but on external financing and financial instruments (FI) that can boost the funding for the expansion and delivery of urban services.

Financial instruments that allow project-generated revenues or cost reductions to cover the debt during the operating term are required to re-finance upfront investments using expected future returns [43].

A FI is a contract that generates both a financial asset and an equity instrument for two different businesses [44]. Financial assets are defined as "cash, contractual rights to obtain cash or another type of financial asset, or equity instruments" provided by other businesses. Financial liabilities, on the other hand, are contractual agreements to transfer cash or other financial assets or "to interchange financial instruments with another business under potentially unfavourable terms." A government, public institution, or any private organisation may employ various tools to finance its expenditures. Commonly, financing instruments are categorised as either debt or equity [45]. The investing or borrowing entity may define a wide range of rights, privileges, and constraints within these two broad categories.

In this section, the classification of FIs will follow a broader categorisation suggested by the European Investment Bank (EIB) in 2018 [46]. Thus, financial instruments can be classified as follows:
- **Equity instruments**. According to Alexopoulos and Wyrowski [45], equity instruments, including private equity and venture capital, comprise ownership interests subject to divi-dend payments when declared but do not have a right to a return on capital. Equity in-struments are used at all phases of a company's development, with venture/growth capital and private equity being more common in later stages. Common stock is the most funda-mental kind of equity instrument.

- **Debt instruments or debt financing**. Alexopoulos and Wy-rowski describe debt in-struments or debt financing as generally characterised as a fixed obligation to repay a particular sum at a specified future date plus interest [45], which includes senior debt, project financing, and asset-backed debt. This section will concentrate on loans and other financial instruments like the issuance of green bonds [43]. They are used to fund businesses in their late stages of development and profitability, when they have solid business models, a strong balance sheet, recurring revenues, and stable, consistent cash flows to fund interest and principal repayments.
- **Hybrid instruments**, such as venture debt, mezzanine, and quasi-equity, combine debt and equity elements, such as mezzanine financing, venture debt, shareholder loans, and preferred shares. During a company's growth phase, hybrid instruments are generally used to secure finance and assure expansion without jeopardizing the founders' and current owners' equity.
- **Public and risk-mitigation tools**, including grants, government-backed loans and guarantees, and public-private partnerships (PPPs), are designed to assist businesses in ex-panding and accessing the funding often provided by national and EU-level public entities. They enable companies to invest in research and development (R&D) and expansion by completing private market instruments.

There are several factors to consider when determining which type of FI to use to finance transpor-tation infrastructure and services. The planner should analyse the various instruments that may be employed, and compare their advantages and disadvantages. Moreover, using alternate forms of finance for public transportation, such as green bonds, PPPs, and enabling local businesses to invest in public transport [47], will allow them to reap the benefits of increased usage.

As urbanisation and car ownership show rising levels, there is a crucial need for a stable and robust financing framework of urban mobility [48].

In this regard, the following section will analyse different FI and risk-sharing arrangements available in the market and comment on the adequacy of each of these tools regarding the urban service models depicted in the section above. The focus will be on each selected FI's advantages and disadvantages, together with some actual case examples, with recommendations. The following are the selected financial instruments and risk-sharing mechanisms that seek to facilitate the execution of both private and public projects:
- Public-private partnerships (PPPs);
- Loans;
- Grants;
- Loan guarantees and;
- Green bonds

## 5.6.1. PUBLIC PRIVATE PARTNERSHIPS (PPPS)

**TABLE 5.6** Analysing the PPP as a risk-mitigation mechanism

| | |
|---|---|
| **Description** | PPPs are procurement methods that help private sector participation and risk sharing. They must provide adequate "value for money" compared to traditional public procurement to be effective. In addition, the proper institutional capacities and processes must be in place. |
| **Advantages** | Transportation PPP initiatives may deliver infrastructure and services promptly and reliably and set criteria without needing substantial government capital expenditures. Private providers are not in danger of contract termination if the infrastructure is developed and services are supplied following objective standards. |
| **Disadvantages/Barriers** | 1. In the transportation industry, the drawbacks of a PPP program are generally related to poorly designed or implemented contracts. A lack of flexibility, inefficient risk transfer, or a low return on investment can all lead to this scenario.<br>2. Following Polis (European network for local transport):<br>&bull; Cities are demanding more information. There has been little research into the optimal ways to integrate mobility into the transportation environment;<br>&bull; Technical difficulties. Cities have experienced difficulties in creating technology solu-tions for regulating operators, particularly in the parking area. |
| **Recommendations** | 1. Effective city-private sector collaboration is critical to maximise new innovative mobility options. PPP frameworks are vital for attracting investment in this area. Following Polis, this mechanism still encounters several challenges:<br>&bull; Having a clear sidewalk is critical to building better connections with those who rely on shared micro-mobility;<br>&bull; Hybrid systems. People demand flexibility; thus, the best way to offer micro-mobility servic-es is to combine free-floating and docked services. Better parking and user educa-tion are also needed.<br>2. Below are some final remarks based on the outcomes of the POLIS' Working Group Governance & Integration:<br>&bull; When new mobility services are introduced, new governance models are needed, and outdated models must be examined to ensure their long-term viability;<br>&bull; The private sector also influences individual mobility behaviors. Reacting to regulatory reforms: As mobility regulations (such as data sharing) change, agreements must be examined and amended.<br>&bull; As new services emerged, COVID-19 experienced the creation of new collaborations.<br>&bull; SDGS. Stournaras argues that PPPs can help achieve the UN's Sustainable Development Goals. |
| **Examples** | 1. On car-sharing, parking is a crucial subject as well. According to Dowling & Kent, several challenging conversations between public and private partners are essential to the success of car-sharing. The authors' research paper emphasised the need for a designated parking area accommodating car sharing. For instance, using behavior-change techniques and launch-ing public awareness campaigns may persuade locals to start carpooling. Parking is a crucial component of car sharing's sustainability strategy. Dowling and Kent used various car-shar-ing examples from their research to illustrate the potential for a private supply of sustainable transportation.<br>2. On ride-hailing. A 2018 survey of 44 public transit agencies in 22 states was examined by Kortum (2021). The study concentrated on the nature of coordination efforts made by transit agencies with ride-hailing companies. More information on the results of the study here [53].<br>3. On micro-mobility. The previous author suggested that the Transit Cooperative Research Program (TCRP) is studying pilot projects by transit agencies to collaborate with cities and micromobility providers to promote first/last-mile linkages to transit. |

*Source: compiled by the author using data from UNECE [45], G. Ang and V. Marchal [49], Polis; Y. Stournaras; and K. Kortum [50]–[53].*

**Figure 5.6** Types of Public-Private Partnerships
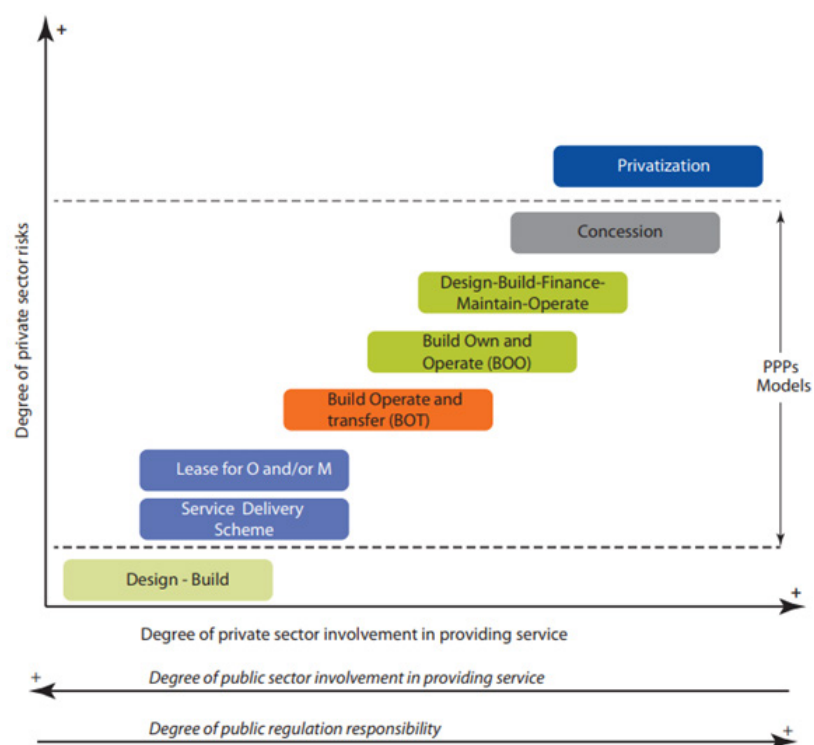


*Source: (Ardila-Gomez & Ortegon-Sanchez, 2016, p. 80) [54]*

## 5.6.2. DIRECT LOANS (SENIOR DEBT)

**TABLE 5.7** Analysing direct loans as a FI for urban transport services

| | |
|---|---|
| **Description** | Loans are defined by Fi-compass, a platform for advising services on financial instruments under the European Structural and Investment Funds (ESIF), as an agreement wherein the lender pledges to make a certain sum of money available to the borrower. This sum of money is designed for a set duration of time. The borrower promises to repay the amount within the period specified in the loan agreement. |
| **Advantages** | In some instances, the loan can finance the entirety of the desired investment, while in others, the loan can be leveraged through other mechanisms (equity, leasing, etc.). |
| **Disadvantages/ Financial Barriers** | 1. The primary financial impediments to direct lending are the high interest rates in some coun-tries and the lack of a flexible repayment schedule.<br>2. Creditworthiness, collaterals, and borrowing capacity of the municipality. |
| **Recommendations** | 1. In line with the EIB, grants and public loans are critical in enabling the business to take off and supporting R&D and development across all models [46]. When business models are established, and companies generate consistent, positive operating cash flows throughout the profit phase, public debt instruments become essential, including intermediated loans, direct loans, and project finance.<br>2. Long-term loans should not be taken out in hard currency due to the high costs associated with potential exchange rate fluctuations.<br>3. Cities must improve the access and strengthen local credit markets. |
| **Real case examples** | 1. The EIB outlines in its research the suitability of public loans and subsidies for creating vari-ous Innovative Transport business models, such as the Usage-Based Payment business model. In this context, service providers are primarily focused on the Usage-Based Payment business model, which includes a wide range of mobility services. With businesses like Uber, Lyft, and BlaBlaCar, they are highly active in the sector of ride-sharing and ride-pooling.<br>2. Another example is the EIB's specialized programs focusing on climate-friendly transport, sustainable and safe mobility, and innovative solutions. The EIB provides long-term invest-ment financing for significant transportation projects worth at least €50 million. EIB loans can pay up to 50% of project expenses, or €25m. However, smaller projects may be bundled under one framework loan to meet the requirement.<br>3. The European Fund for Strategic Investments (EFSI) aims to raise private financing for high-risk projects, such as transportation. The EFSI offers loans and guarantees, among other FIs. |

*Source: compiled by author using data from European Investment Bank; V. T. Stephanie Nour and Pierre Langlois of Econoler, Bruce Hedman; X. Zhu, C. C. Hernando, and R. R. Dusa [55]–[57], European Investment Bank [46], T. H. Daniel Platz and S. S. Vito Intini [58], S. Werland and F. Rudolph [43].*

## 5.6.3. LOAN GUARANTEES

**TABLE 5.8** Analysing loan guarantees as a FI for urban transport services

| | |
|---|---|
| **Description** | A guarantee is defined as a formal agreement to assume whole or partial responsibility for a third party's debt or obligation. Alternatively, if an event, such as a loan default, occurs that triggers such a guarantee for the effective processing of those third parties' obligations. |
| **Advantages** | According to the European Commission, guarantees (issued by governmental, commercial, or mutual guarantee organisations) can compensate for the lack of collateral or creditworthiness by reducing the risk to the bank and helping small businesses secure loans from banks. |
| **Disadvantages/Barriers** | Criteria used by commercial banks to assess creditworthiness |
| **Recommendations** | In line with the EIB, grants and public loans are critical in enabling the business to take off and supporting R&D and development across all models[46]. 66 % of the firms interviewed have used or plan to use grants, primarily at the seed stage and, to a lesser extent, in the growth stage. Seed-stage businesses are usually supported by public grants and guarantees from the European Commission or state programs, seed money and angel investments. |
| **Real case examples** | 1. The Connecting Europe Facility (CEF) is a fund for pan-European infrastructure investment in transport, energy, and digital initiatives. Grants, financial guarantees, and project bonds are used for financing.<br>2. The Cleaner Transport Facility was launched in December 2016 by the European Commission and the EIB. The Facility supports investments in alternative fuel public transportation fleets and infrastructure. It combines lending, funds, guarantees, advisory services. |

*Source: compiled by author using data from European Investment Bank [55], European Commission [59], X. Zhu, C. C. Hernando, and R. R. Dusa [57], European Investment Bank [46], S. Werland and F. Rudolph [43].*

**Figure 5.7** Example of a Partial Loan guarantee for an Energy Efficiency (EE) project
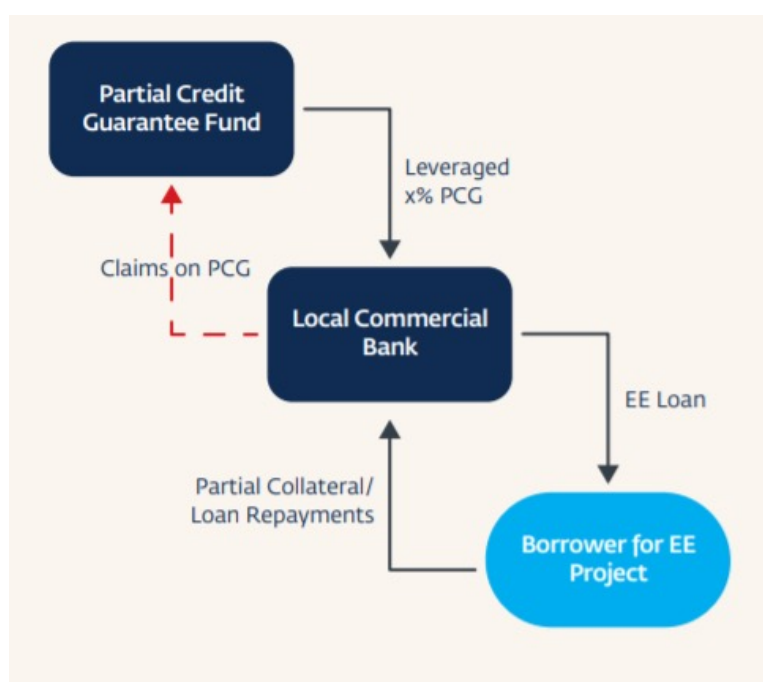
## 5.6.4. GRANTS

**TABLE 5.9** Analysing grants as a FI for urban transport services

| | |
|---|---|
| **Description** | According to the literature, grants are donations from one entity (usually a business, foundation, or government) to another organisation (usually the grant recipient). |
| **Advantages** | 1. They are non-repayable.<br>2. They boost credibility. |
| **Disadvantages/Barriers** | 1. Public grants and other public financing exist but they are often not geared towards the fast-paced and often service-based Innovative Transport sector.<br>2. Following EIB (2018), Grants were employed less frequently than in the Product Sales sector, reflecting their frequent inadequacy for mobility services and the Usage-Based Payment industry's rapid expansion objectives. |
| **Recommendations** | 1. It is crucial that grants are adaptable in terms of the project's outcome: mobility service providers, in particular, operate in an ever-changing environment and frequently need to ad-just and adapt their business models or style of operation in response to market feedback and competition.<br>2. Accelerate the development of charging infrastructure by combining grants and flexible debt.<br>3. Seed-stage businesses are usually supported by public grants and guarantees from the Eu-ropean Commission or state programs, seed money and angel investments. |
| **Real case examples** | 1. The European Commission is planning to open (by 2022) a grant scheme for projects con-tributing to the deployment of new and shared mobility services. More information **here**.<br>2. The Global Environment Facility (GEF), a large multilateral trust fund, has lunched the Global Electric Mobility Program in 2019. The program assists over 50 countries in developing ca-pacity, e-mobility strategies, roadmaps, business models, and financing schemes, establish-ing e-mobility policy frameworks, and preparing for the environmental sustainability of elec-tric mobility and piloting electric vehicles on the ground.  More information **here**. |

*Source: compiled by author using data from European Investment Bank [46], T. H. Daniel Platz and S. S. Vito Intini [58].*

## 5.6.5. GREEN BONDS

**TABLE 5.10** Analysing green bonds as a FI for urban transport services

| | |
|---|---|
| **Description** | 1. A green bond is a debt instrument that can be used to finance projects within adaptation and mitigation to climate change. Bond proceeds are allocated to initiatives that, following predetermined criteria, help the environment, such as low-carbon transportation. Any entity that has never issued a bond but has a reasonable prospect of being creditworthy may issue a green bond. <br> 2. The issuer of a bond establishes a fixed annual interest rate and repayment schedule before selling the bonds to creditors. Bondholders obtain a guarantee that interest and principal will be repaid on a timely basis. |
| **Advantages** | 1. Bonds generally have a lower risk profile than equity securities due to their fixed returns and predefined maturity dates. This increases the attractiveness of bonds for institutional investors such as pension funds and insurance companies, who value predictability, consistent payouts, and capital preservation. Bond purchasers benefit from tax exemptions in a number of countries. <br> 2. Green City Bonds can provide cities and municipalities with low-cost money to finance climate-friendly initiatives. Additionally, they can give additional benefits such as a broader and more diversified investment base, more favourable economic terms, stronger branding, media attention, and increased citizen engagement. <br> 3. Investor demand for green bonds is considerable, as they are frequently oversubscribed. |
| **Disadvantages/Barriers** | In line with KPMG, issuers and investors can reduce risks that might otherwise reduce the green bond's financial attractiveness by ensuring that it is properly designed and the right due diligence is in place. Some of the most frequent difficulties in the market for green bonds include the following: <br> 1. The absence of a universal definition of "green." There is no widely acknowledged definition of what constitutes a bond being "green" or "not green." As a result, KPMG specialists advise bond issuers to establish rigorous green criteria in order to maintain investor trust and ob-tain funding; <br> 2. The requirement to understand how bond revenues are used. <br> 3. 'Greenwashing'. Bond issuers incur reputational risks if the expected environmental ad-vantages are not accomplished. If the issuer violates agreed-upon green clauses, investors may demand penalties; <br> 4. The complicated green bond scene. Navigating this environment with so many distinct green bond principles and standards available, ranging from the Green Bond Principles to green bond indexes and sector-specific standards, can be difficult and takes in-depth competence. |
| **Recommendations** | According to Ang and Marchal, this FI can attract institutional investors such as pension funds and insurance companies by tapping into the debt capital markets currently underutilised for green infra-structure investment. Bonds continue to be the most popular asset type in pension funds (50%) and insurance firms' (61%) portfolios throughout OECD nations. |
| **Real case examples** | 1. LeasePlan, a global fleet management company, launched the Green Finance Framework for Clean Transportation on March 2020. This approach enables the issuance of Green Bonds to finance and/or re-finance "Eligible Projects" that fit under the "Eligible Category" of Clean Transportation. Projects including battery electric vehicles (BEVs), particularly micro-mobility vehicles, are referred to as eligible projects. <br> 2. The Community of Madrid is one illustration of a region issuing green bonds. The Community of Madrid, which issued 1,250 million euros worth of sustainable bonds over ten years, occupied the top spot in Spain for sustainable bond issuance in 2020. Therefore, the 700 million euros obtained through the sale of green bonds in 2020 made it easier to execute clean transportation policies, such as the creation and use of electric vehicles and charging stations, as well as the use of bicycles and public transportation. <br> 3. Climate Bonds Standard and Certification Scheme is a bond labelling and certification scheme. Strict scientific criteria ensure that it is compliant with the Paris Agreement's 2 degree Celsius warming limit. <br><br> Projects involving public transportation, such as bicycle transportation and vehicles powered entirely by electric motors or hydrogen fuel cells, are automatically qualified. More Information here: https://www.climatebonds.net/about |

*Source: compiled by author using data from The World Bank; E. Campiglio; KPMG; and Sustainalytics [60]–[63], S. Werland and F. Rudolph [43], G. Ang and V. Marchal [49], LeasePlan; Comunidad de Madrid; and Consejería de Hacienda y Función Pública [64]–[66]*

## 5.7. CONCLUSIONS FOR THE FINANCIAL INSTRUMENTS AND RISK-MITIGATION MECHANISM WITHIN THE SUSTAINABLE URBAN TRANSPORT LANDSCAPE

Prior sections have covered various financial instruments and mechanisms and their associated benefits and drawbacks. Yet, some actions can be made to boost private investment in sustainable urban mobility:

1. Expand the number of investors. Include institutional investors such as pension funds, in-surance companies, and banks, which have limited capacity to provide long-term financing. Climate investors can bring in new funding.
2. **Develop a comprehensive investment portfolio** rather than focusing on individual initiatives. To pique the private sector's interest, establishing a program with scalability in mind is crucial rather than developing a single initiative. [67].

Also, some suggestions to accelerate the access to finance in the urban mobility scene are presented below:

1. In terms of financial instruments, **credit upgrades and guarantees** may reduce eco-nomic and political risks that discourage the private sector. [68];
2. **Public-private partnerships** can promote the sharing of information, resources, and risks;
3. **Competitive advantage** and value proposition act as enablers in attracting strategic in-vestment;
4. Innovation and a readiness to question industry standards to support mobility's future;
5. Incorporate **new technology and business models** to encourage sector transfor-mation.

Nonetheless, external factors such as a weak financial infra-structure or structural and legal issues that have limited the growth of nonbank financial institutions, instruments, and markets may impact access to financing. These elements, however, are not covered in this book.

Finally, to guide the identification of suitable financing methods for municipal services projects, the Annex will provide a decision tree to advise municipal decision-makers. Additionally, any other stakeholder involved in implementing sustainable urban services can also benefit from the decision tree.

## Annex: Decision tree for municipal sustainable urban transport financing

This module has shown that there are many funding and financing options for supporting sustainable urban mobility. Still, there is no one size fits all combination of instruments that are suitable for all projects in all member states. An adequate combination needs to be defined case-by-case, depending on factors such as the size and nature of the project, the municipality's budgetary situation, legal competencies of cities, or the availability of funding sources from the regional, national and European level.

**TABLE 5.11** Decision tree for municipal urban services project financing

| Situation | | | Issues/ challenges | Action | Financing mechanism |
|---|---|---|---|---|---|
| **Does the municipality have enough budget to finance the mobility service project?** | | YES | Allocation of funds from the budget | Prepare grant application | General budget financing |
| **Are grants available from donors or from national governments?** | NO | YES | Grants may not finance entire project | Prepare grant application | Partial budget financing and partial grant |
| **Are funds available from national government?** | NO | YES | Funds may only provide partial financing | Apply for national funds | Budget capture |
| **Does the municipality have access to interna-tional funding programmes?** | NO | YES | Eligibility criteria for the fund | Apply to the selected fund | International /European funds |
| **Are commercial banks willing to offer dedicated loans/or risk-sharing programmes?** | NO | YES | Creditworthiness, collaterals, and borrowing capacity of the municipality | Review eligibility for these mechanisms | Loans or risk guarantee programmes |
| **Does the municipality have margin in the balance sheet to incur in debt?** | | YES | Criteria used by commercial banks to assess creditworthiness | Access credit lines or risk-sharing programmes | Loans or risk guarantee programmes |
| **No options available for financing** | | | | | |
| **You cannot finance the project without externalising the finance from third parties. Do you want to continue and explore this possibility?** | NO | YES | The project value profitability and risk level | Agree on the terms of risk sharing, contractual aspects and duration of the project | PPPs |
| **Does the municipality have the capacity to issue municipal bonds? / Can the bonds be certified with a "green label" by an independent institution?** | NO | YES | The market for such bonds, transaction costs | Develop municipal bond/green bond programme | Green bonds |

*Source: adapted by author from [57].*

# **References** - Module 5

[1] Forbes, "Transportation Business Models Are Broken. It's Time To Fix Them," 2020. https://www.forbes.com/sites/timothypapandreou/2020/05/20/transportation-business-models-are-broken-its-time-to-fix-them/amp/.

[2] European Commission, "Sustainable and Smart Mobility Strategy," 2020. https://eur-lex.europa.eu/legal-content/DE/TXT/?uri=CELEX%3A52020DC0789.

[3] H. Chesbrough, "Business model innovation: Opportunities and barriers," Long Range Plann., vol. 43, no. 2–3, pp. 354–363, 2010, doi: 10.1016/j.lrp.2009.07.010.

[4] R. R. Nelson, Technology, institutions, and economic growth. Harvard University Press, 2005.

[5] D. J. Teece, "Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance," Strateg. Manag. J., vol. 28, no. 13, pp. 1319–1350, 2007, doi: 10.1002/smj.640.

[6] S. C. Voelpel, M. Leibold, and E. B. Tekie, "The wheel of business model reinvention: how to reshape your business model to leapfrog competitors," J. Chang. Manag., vol. 4, no. 3, pp. 259–276, 2004, doi: 10.1080/1469701042000212669.

[7] B. Cohen and J. Kietzmann, "Ride On! Mobility Business Models for the Sharing Economy," Organ. Environ., vol. 27, no. 3, pp. 279–296, 2014, doi: 10.1177/1086026614546199.

[8] M. Kamargianni and M. Matyas, "The business ecosystem of mobility-as-a-service," in 96th Transportation Research Board (TRB) Annual Meeting, Washington DC, 8-12 January 2017, 2017, vol. 96, no. January, pp. 8–12, [Online]. Available: http://discovery.ucl.ac.uk/10037890/1/a2135d_445259f704474f0f8116ccb625bdf7f8.pdf.

[9] T. Vaskelainen, "Sustainable business models-The case of car sharing," 2014.

[10] J. Teece, D., "Business Models, Business Strategy and Innovation," Long Range Plann., vol. 43, no. 2, pp. 172–194, 2010.

[11] Andrea Ovans, "What Is a Business Model?," 2015. https://hbr.org/2015/01/what-is-a-business-model.

[12] J. V. R. de Souza, A. M. de Mello, and R. Marx, "When is an innovative urban mobility business model sustainable? A literature review and analysis," Sustain., vol. 11, no. 6, pp. 1–18, 2019, doi: 10.3390/su11061761.

[13] G. Cardeal, K. Höse, I. Ribeiro, and U. Götze, "Sustainable business models–canvas for sustainability, evaluation method, and their application to additive manufacturing in aircraft maintenance," Sustain., vol. 12, no. 21, pp. 1–22, 2020, doi: 10.3390/su12219130.

[14] A. Osterwalder and Y. Pigneur, Business model generation: a handbook for visionaries, game changers, and challengers, vol. 1. John Wiley & Sons, 2010.

[15] S. Sarasini and O. Langeland, "Business model innovation for car sharing and sustainable urban mobility," Nord. Energy Res., vol. 5, pp. 1–28, 2017, [Online]. Available: http://www.nordicenergy.org/wp-content/uploads/2017/05/IST-2017-Sarasini-Langeland.pdf.

[16] T. Litman, "Evaluating carsharing benefits," Transp. Res. Rec., vol. 1702, no. 1702, pp. 31–35, 2000, doi: 10.3141/1702-04.

[17] V. Roblek, M. Meško, and I. Podbregar, "Impact of car sharing on urban sustainability," Sustain., vol. 13, no. 2, pp. 1–19, 2021, doi: 10.3390/su13020905.

[18] T. Schiller, J. Scheidl, and T. Pottebaum, "Car Sharing in Europe - Business Models, National Variations and Upcoming Disruptions," Monitor Deloitte, 2017. https://www2.deloitte.com/content/dam/Deloitte/de/Documents/consumer-industrial-products/CIP-Automotive-Car-Sharing-in-Europe.pdf.

[19] S. B. Suzi Tart, Peter Wells, "Analysis of business models for car sharing Deliverable D3.1," 2018, [Online]. Available: http://www.lgi-consulting.com/wp-content/uploads/2019/10/STARS-D3.1.pdf.

[20] S. Satti, "Success Factors of Rideshare Business Model and Future Forecasts," 2019. https://cabstartup.com/success-factors-rideshare-business-model-future-forecasts/.

[21] A. Asirin and D. Azhari, "Ride-sharing business model for sustainability in developing country: Case Study Nebengers, Indonesia," in IOP Conference Series: Earth and Environmental Science, 2018, vol. 158, no. 1, p. 12053, doi: 10.1088/1755-1315/158/1/012053.

[22] AppsRhino, "How Uber works and makes Money: Business and revenue model of Uber," 2020. https://www.appsrhino.com/how-uber-works-and-makes-money-business-and-revenue-model-of-uber/.

[23] G. Fisher, J. E. Wisneski, and R. M. Bakker, "Business Model Canvas," Strateg. 3D, pp. 174–184, 2020, doi: 10.1093/oso/9780190081478.003.0019.

[24] Sergio Rodriguez, "El business model canvas o lienzo de modelos de negocio – caso Blablacar," 2016. https://www.theamazingstartup.es/business-model-canvas/.

[25] Anonymous , "CASO DE ESTUDIO: MODELO DE NEGOCIO DE BLABLACAR," 2018. https://estrategialean.com/caso-de-estudio-modelo-de-negocio-de-blablacar.

[26] Daniel Spence, "BENEFITS OF CARPOOLING." https://www.uottawa.ca/parking/carpooling/benefits-of-carpooling.

[27] E. Vitkauskaite and E. Vaiciukynaite, "Comparative study of business models of European micro-mobility online services," Proc. Int. Conf. Electron. Bus., vol. 2020-Decem, pp. 55–62, 2020.

[28] H. K. W. Aasebø, "Shared Micro Mobility: What is happening in our streets? A study on Micro Mobility and Mobility Data." 2019, [Online]. Available: https://www.duo.uio.no/bitstream/handle/10852/69645/7/AaseboHaakon.pdf.

[29] P. DeMaio, "Bike-sharing: History, Impacts, Models of Provision, and Future," J. Public Transp., vol. 12, no. 4, pp. 41–56, 2009, doi: 10.5038/2375-0901.12.4.3.

[30] E. Fishman, S. Washington, and N. Haworth, "Bike Share: A Synthesis of the Literature," Transp. Rev., vol. 33, no. 2, pp. 148–165, 2013, doi: 10.1080/01441647.2013.775612.

[31] Y. Zhang and Z. Huang, "Performance evaluation of bike sharing system in Wuchang area of Wuhan, China," in 2012 6th International Association for China Planning Conference, IACP 2012, 2012, pp. 1–10, doi: 10.1109/IACP.2012.6342972.

[32] S. A. Shaheen, S. (University of C.-B. Guzman, and H. (University of C.-B. Zhang, "Bikesharing in Europe, the Americas, and Asia: Past, Present, and Future," Transp. Res. Rec. J. Transp. Res. Board, vol. 2143, no. 1, pp. 159–167, 2010.

[33] L. Caggiani and R. Camporeale, "Toward Sustainability: Bike-Sharing Systems Design, Simulation and Management." Multidisciplinary Digital Publishing Institute, 2021.

[34] L. Abolhassani, A. P. Afghari, and H. M. Borzadaran, "Public preferences towards bicycle sharing system in developing countries: The case of Mashhad, Iran," Sustain. Cities Soc., vol. 44, no. October 2018, pp. 763–773, 2019, doi: 10.1016/j.scs.2018.10.032.

[35] L. Bajracharya, T. Mulya, A. Purbasari, and M. Hwang, "A study on cost-effective and eco-friendly bicycle sharing system for developing countries," Lect. Notes Electr. Eng., vol. 514, pp. 523–531, 2019, doi: 10.1007/978-981-13-1056-0_52.

[36] P. Kao, C. Busquet, V. Lubello, M. Meta, and C. Van Den Heuvel, "Review of business models for new mobility services," 2019.

[37] S. Boglietti, B. Barabino, and G. Maternini, "Survey on e-powered micro personal mobility vehicles: Exploring current issues towards future developments," Sustain., vol. 13, no. 7, p. 3692, 2021, doi: 10.3390/su13073692.

[38] J. Fong, P. Mcdermott, and M. Lucchi, "Micro-Mobility , E-Scooters and Implications for Higher Education," Upcea, no. May, pp. 1–21, 2019, [Online]. Available: https://upcea.edu/micro-mobility-e-scooters-and-implications-for-higher-education/.

[39] J. Hollingsworth, B. Copeland, and J. X. Johnson, "Are e-scooters polluters? the environmental impacts of shared dockless electric scooters," Environ. Res. Lett., vol. 14, no. 8, p. 84031, 2019, doi: 10.1088/1748-9326/ab2da8.

[40] Paris Marx, "How to Fix the Scooter Parking Problem," 2019. https://medium.com/radical-urbanist/how-to-fix-the-scooter-parking-problem-f124d9747d30.

[41] Oscar Steve, "Grin no quiebra por COVID-19, pero para sobrevivir sí está recortando personal en México y América Latina," 2020. https://www.xataka.com.mx/vehiculos/grin-no-quiebra-covid-19-para-sobrevivir-esta-recortando-person-al-mexico-america-latina.

[42] UNECE, "Recommendations for Green and Healthy Sustainable Transport – 'Building Forward Better,'" Recommendations for Green and Healthy Sustainable Transport – "Building Forward Better," 2021. https://unece.org/sites/default/files/2021-04/2101940_E_PDF_WEB.pdf.

[43] S. Werland and F. Rudolph, "Funding and financing of sustainable urban mobility measures: topic guide," 2019, [Online]. Available: https://epub.wupperinst.org/frontdoor/index/index/docId/7397.

[44] A. Duțescu, "Financial instruments," in Financial Accounting: An IFRS Perspective in Romania, 2019, pp. 241–259.

[45] UNECE, Innovative ways for Financing Transport Infrastructure, no. ECE/TRANS/264. 2017.

[46] European Investment Bank, "Financing innovation in clean and sustainable mobility Study on access to finance for the innovative road transport sector," 2018. https://www.eib.org/en/publications/access-to-finance-for-the-innovative-road-transport-sector.

[47] A. Americo et al., "Recommendations for Green and Healthy Sustainable Transport-" Building Forward Better"," 2021.

[48] E. D. Sclar, M. Lönnroth, and C. Wolmar, Urban access for the 21st century: Finance and governance models for transport infrastructure. Routledge, 2014.

[49] G. Ang and V. Marchal, "Mobilising private investment in sustainable transport: The case of land-based passenger transport infrastructure," 2013.

[50] Polis, "Public Private Partnerships: Shared Micromobility, taking stock," 2021. https://www.polisnetwork.eu/news/public-private-partnerships-shared-micromobility-taking-stock/.

[51] Polis, "Public Private Partnerships: Local & Regional Scales," 2021. https://www.polisnetwork.eu/news/public-private-partnerships-local-regional-scales/.

[52] Y. Stournaras, "Building public-private partnerships," no. October, pp. 1–5, 2019.

[53] K. Kortum, The Role of Transit, Shared Modes, and Public Policy in the New Mobility Landscape, no. 332. 2021.

[54] A. Ardila-Gomez and A. Ortegon-Sanchez, Sustainable Urban Transport Financing from the Sidewalk to the Subway. 2016.

[55] European Investment Bank, "Financial Instrument products Loans, guarantees, equity and quasi-equity," 2015, [Online]. Available: https://www.fi-compass.eu/sites/default/files/publications/ESIF-factsheet-FI-products.pdf.

[56] V. T. Stephanie Nour and Pierre Langlois of Econoler, Bruce Hedman, "Improving Thermal and Electric Energy Efficiency at Cement Plants," Improv. Therm. Electr. Energy Effic. Cem. Plants, 2017, doi: 10.1596/28304.

[57] X. Zhu, C. C. Hernando, and R. R. Dusa, Upscaling Energy-efficiency in Municipalites: Sourcebook on Project Bundling. 2020.

[58] T. H. DANIEL PLATZ and S. S. VITO INTINI, "FINANCING SUSTAINABLE URBAN DEVELOPMENT IN THE LEAST DEVELOPED COUNTRIES," 2017, [Online]. Available: https://www.un.org/esa/ffd/wp-content/uploads/2016/09/Financing-Sustainable-Urban-Development-in-LDCs.pdf.

[59] European Commission, "Loans and guarantees." https://ec.europa.eu/growth/access-to-finance/funding-policies/loans-guarantees_en.

[60] World Bank, "Transition towards sustainable mobility – Where is the financing?," 2021, [Online]. Available: https://blogs.worldbank.org/transport/transition-towards-sustainable-mobility-where-financing.

[61] E. Campiglio, "Beyond carbon pricing: The role of banking and monetary policy in financing the transition to a low-carbon economy," Ecol. Econ., vol. 121, pp. 220–230, 2016, doi: 10.1016/j.ecolecon.2015.03.020.

[62] KMPG, "Issuing green bonds," 2018, [Online]. Available: https://assets.kpmg/content/dam/kpmg/xx/pdf/2018/10/green-bonds-services.pdf.

[63] Sustainalytics, "Most common Questions for Green bond issuance," 2019. https://www.sustainalytics.com/esg-research/resource/corporate-esg-blog/most-frequently-asked-questions-green-bonds.

[64] LeasePlan, "LeasePlan ' s 2020 green bond impact assessment report," 2021, [Online]. Available: https://www.leaseplan.com/corporate/~/media/Files/L/Leaseplan/documents/leaseplan-green-bond-impact-assessment-final-report.pdf.

[65] Comunidad de Madrid, "Lideramos en 2020 el ranking español de emisión de bonos sostenibles," 2021. https://www.comunidad.madrid/noticias/2021/06/02/lideramos-2020-ranking-espanol-emision-bonos-sostenibles.

[66] Consejería de Hacienda y Función Pública , "INAUGURAL 2020 GREEN BOND & Sustainability Mandate of Comunidad de Madrid," no. May, pp. 1–14, 2021.

[67] World Bank, "Maximizing finance for sustainable urban mobility," 2018. https://blogs.worldbank.org/transport/maximizing-finance-sustainable-urban-mobility.

[68] World Bank, "Coming together is the way forward: Maximizing Finance for Development," 2017. https://blogs.worldbank.org/ppps/coming-together-way-forward-maximizing-finance-development.

# Module 6. Demand projections

## 6.1 POPULATION PROJECTIONS AND CITY SPRAWLING

The number of people living in the city or city zones in the study area influences transport demand. Population forecasting is more than just estimating the number of people because the composition of the population in terms of age and sex structure will influence the transport demand. For example, the number of trips to work can depend upon the number of workers in the population, which is a function of the number of economically active people. This varies by age and sex. Consequently, a forecasting method that estimates separately for age and sex groups is likely to be better than one that treats the population in total.

The simplest method is to extrapolate by assuming that the past growth rate (or decline) will apply in the future. Thus:

Trend Extrapolation,
$$P(t+i)=gP(t)$$

*Where P(t) is the population at the time t and g is the growth rate, i is the number of years for which the population is being projected.*

The method could be applied to the whole study area, or separate growth rates could be applied to sub-populations, either by area or by age and sex group. This simplistic can be good for quick population projections; however, the method is unlikely to be very satisfactory because it ignores the effects of changes in the housing pattern and provides no behavioural explanation.

Population projections are made in some countries and can be used as the basis of forecasts in a transport model. For example, in India, the Office of Population Censuses and Surveys makes projections for various spatial disaggregations, including local authority areas. As discussed below, the method used is a form of cohort survival method, using suitable assumptions about birth, death, and migration rates. An accounting model based on the components of population change is commonly used for demographic forecasting. The basic equation is:

$$P(t+i)=P(t)+b(t,t+i)-D(t,t+i)+I(t,t+i)-O(t,t+i)$$

*Where P(t) is the population at time t, B(t,t+i) is the number of births in the period t to t+i, D(t,t+i) is the number of deaths in the period t to t+I. I(t,t+i) is the number of in-migrants in the period t to t+i, O(t,t+i)is the number of out-migrants in the period t to t+i*

Data on births and deaths are available from registration records in most countries and can be used in the form of rates. For example:

*Where b is the birth rate then B(t,t+i) = bP(t)*

The birth rate can be disaggregated into age groups and applied only to females to increase the accuracy of the model. This type of rate is used in the cohort survival model, and only births and deaths are considered. Deaths are considered in terms of survival, that is, not dying. The model is based on the concept of cohorts, which is the population in an age group. If the initial population in each group is known, the number of people surviving in the next group is found using a survival rate:

*P_(n+1) (t+i)=sP_n (t)*

*Where s is the probability that a person of age n at time t will survive to reach age n+i at time t+i.*

*B_n (t,t+i)=b_n P_n (t)*

*Where Bn(t, t+i) is the number of births in the period t to t+i to women aged n at time t.*

The model can be formulated in matrix terms. This model would generally be carried out for males and females separately since only the latter give birth.

## 6.2 INTEGRATED PLANNING FOR GREEN AND ENERGY-EFFICIENT TRANSPORT

The urban planning implications of the built form and travel behaviour relations are key to developing integrated green and energy-efficient transport planning. Urban Planning and management of cities require urban planners to make decisions that can be implemented at different scales and for different time horizons. For urban development and management organisations to undertake informed decisions, the basic information needed will flow from observed ground realities and derived from empirical evidence from studies. This evidence bridges the knowledge gap and provides a key direction that would enable decision-makers to evaluate existing built form policies/plans or formulate new policies/plans. These plans and polices would lead to the desired impact on vehicle distance travelled and modal choices. As shown in Figure 6.1 to formulate policies, the basic information needed is on the interaction between built form and travel behaviour [1].

As shown in figure 6.1, the information derived from empirical studies is converted into specific policy statements, which essentially underline what kind of built form should be promoted for green and energy-efficient transport development. The information leads to overall urban development strategy. In many cases these strategies aim to promote polycentric development, concentrate all other built-form around it, and improve access to the destination with green and energy-efficient transport modes. These are then assigned action by associating the existing planning tools and mechanisms that can be used to achieve these strategies. In the end, these indicators also need to be monitored and regulated.

The green and energy-efficient transport scenario preparation follow a back casting approach where the aim is to achieve low carbon and energy-efficient mobility. Given the ground realities, the task here is to identify options of suitable measures and their integration to get an overview of different options that could contribute to the overall vision.

In the context of developing countries, it is important that the green and energy-efficient scenarios also assume an increase in motorised transport to some extent, which is inevitable given the low level of motorisation. Therefore, emphasis is also placed on improving technology in terms of efficiency and emissions. Based on the empirical evidence and strategies adapted in cities that are more advanced in adopting sustainable transport strategies, the key strategies can be typically classified into four categories, namely:

Green and energy-efficient transport strategies can be based on actions that i). avoid travel, including measures to reduce trip lengths or the number of trips; ii) facilitate the shift to more efficient low carbon modes, including public transport and non-motorised transport and iii) switch to improved and cleaner fuels and modes for, e.g., electric/hybrid vehicles, biofuels, etc. (Figure 6.2). The low carbon scenarios analyse each of these strategies individually and collectively. How these strategies can be incorporated is discussed in the following sections.

**Figure 6.2** Exploring energy efficiency in transport options



| AVOID | SHIFT | IMPROVE |
|---|---|---|
| **Land use and Planning** Mixed Use with Access to Public Transit Development of new areas near transit corridors | **Land use and Planning** Transit oriented development zones Route planning and Rationalising | **Land use and Planning** e-mobility schemes in housing programs, spatial planning and district development |
| **Technology** ICT to reduce travel Restructuring freight logistics | **Infrastructure** Bike lanes and pedestrian facilities Public transport Infrastructure (mass transit, bus systems) | **Infrastructure** Charging infrastructure for Electric/Alternate vehicles |
| **Economic instruments** Parking charges Emissions based road charges | **Economic instruments** Fare structures and Subsidies for public transport Parking charges Tax incentives to developers near public transportation | **Regulations and standards** Full economic standards Biofuel targets Ban on old vehicles Air pollution emissions norms |
|  |  | **Economic instruments** Tax benefits on vehicle registration tax. Free recharging for electric vehicles Subsidies for hybrid/full EVs Vehicle scrappage programs |

*Source: [3]*

## Urban Structure (Land use and planning)

Based on empirical evidence (Ewing and Cervero, 2010, Munshi, 2013), in this scenario, the following aspects are modelled and tested for their impact on transport emissions.

1. Restricting the development area of the city
2. Increasing density of jobs (polycentric development) and population.
3. Improving mixing of land use.
4. Size of development block

The evidence shows that the above-stated measures will help to shorten trip lengths and encourage higher use of public transport and non-motorised modes. The changes in zoning regulations and floor area ratio (FAR) include some planning and regulatory measures, which can help achieve higher density and compact development.

## Non-Motorised Transport Infrastructure

Improvements in NMT user experience by enhancing footpaths and bicycle lanes can improve NMT user experience while also addressing improvement in safety and accessibility for pedestrians and bicycles. Reducing barriers and impediments on roads to improve bicycle safety is another aspect considered. Reduced conflicts between non-motorised and motorised modes on roads can result in a small increase in bus speed.

## Public Transport (Infrastructure)

The public transport scenario includes NMT, as any public transit trip includes a component of NMT for access and egress. Since many cities in developing countries lack a reliable bus service, two kinds of scenarios for public transport may be considered:

## Technology

Technology changes include changes in vehicle technology, including changes in efficiency or alternate vehicle technologies, including biofuel, hybrid, or electric vehicles. Changes in vehicle technologies are influenced by national policies. However, cities can facilitate greater adoption of low carbon and cleaner technologies by providing supporting infrastructure (e.g., EV charging stations), through incentives (free charging, subsidies), and by incorporating these in existing land use plans and regulations (e.g., urban guidelines).

Cities can restrict the use of old polluting vehicles through financial assistance and set up effective emissions monitoring systems.

## Regulatory and Financial Measures

A range of measures can be undertaken to facilitate the shift of people from private transport modes to sustainable urban transport under a regulatory and financial measure scenario. These measures try to internalise the cost of externalities imposed by private vehicles. Such measures include parking policies, congestion pricing, registration tax and carbon tax. These are incorporated in the model in the form of increased generalised cost of travel by private modes. As an example, described below is the approach for modelling parking policies.

## Parking Policies (Economic instruments + regulations)

Parking is generally low-cost, but not free, in most developing cities. As a result, there is no disincentive for owners of private transport modes like cars and motorised two-wheelers to stop using them to get from one place to another. Instead, there are plenty of incentives to keep using them, as they offer a high amount of personal mobility.

In this scenario, infrastructure improvements are made for pedestrians, bicycles, public transport, and increased parking costs. To implement robust on-street parking management and enforcement system, the cities must regulate on-street parking spaces. The existing parking management system, including current earnings and expenditures, operational systems, and public perception, must be documented, assessed and improved. An expanded and improved parking management system can help efficiently allocate road space, generate revenue for sustainable transport projects, and encourage a shift to more sustainable modes. In the four-step model, these should increase the generalised cost of travel of motorised modes compared to NMT and PT modes, favouring the use of NMT and PT modes.

## Demand for transportation and impact on energy demand

The transport sector is one of the fastest-growing contributors to global energy consumption and carbon dioxide ($CO_2$) emissions (IEA, 2017). Even though technology solutions can lead to lower energy consumption, travel behaviour and demand have to be modified or managed concurrently in order to achieve desired energy efficiency in transport. Managing transport demand also becomes important as a problem concerning most urban areas is the constant increase in the number and use of passenger cars, very little or inefficient public transport system, and lack of infrastructure to support non-motorised transport. In many cities, it is very difficult to change the transport supply as specific constraints exist (e.g., limited space for new infrastructure) and budget availability.

Therefore, extensive effort has been made to achieve energy efficiency in transport through the implementation of demand management strategies.

Broad transportation reforms are required to influence travel behaviour and thereby manage transport demand, either in the form of modal share or travel distance, through land use, urban design, planning, and pricing policies. The energy consumed by transport is directly related to the total distance travelled, mode choice, and energy intensity of the chosen transport mode. As discussed in other sections, advanced vehicle technology and alternative transportation fuel can solve a significant part of the problem. However, how total transportation activity is formed, the distance travelled, or certain transport modes are also key to transport energy demand.

Studies have shown that external factors could influence transport demand, such as land-use planning ([4, 5]; while mode choice is often determined by discrete individual preferences that could be shaped through pricing strategies ([6] or governmental regulations. Pricing strategies, for example, vehicle taxation or insurance, fuel types, such as fuel taxation and fee, the use of transportation infrastructures, such as road, toll, and parking pricings, or even distance travelled through VMT taxation can be applied. Other policies and measures include providing transit incentives, employer-based transit and shuttles, the creation of ridesharing programs, encouraging walking, and bicycling, and developing flexible work schedules that include telecommuting. These measures can be categorised as transportation demand management (TDM) measures. Several innovative TDM measures have also been developed over the past few years, focusing on the use of technology to influence travel behaviour by creating mobile phone applications that can provide more information on each mode choice and other travel decisions. Such measures have also created economic incentives to reward less energy-intensive transportation choices, such as transit, carpooling, walking, or bicycling.

Transport demand management measures that are land use intervention, improvement in non-motorised transport infrastructure and improvement in public transport systems were tested for the city of Rajkot in India [7]. The first step was to estimate the mix of vehicles in the business-as-usual scenario for 2031, their use, and energy consumption. The fuel used for the base year and horizon year of 2031 in the BAU scenario is presented in Table 6.1. It was found that there is a significant increase in trip rates and a steep rise in the use of two-wheelers and cars, and the consumption of petrol, diesel, and gas is likely to multiply almost ten times by the year 2031.

**TABLE 6.1** Vehicle type and fuel consumed

| Vehicle type | Fuel consumed (million litres or million kg) 2011 | | | | Fuel consumed (million litres or million kg) 2031 | | | |
|---|---|---|---|---|---|---|---|---|
| | Petrol | Diesel | Gas | Electricity | Petrol | Diesel | Gas | Electricity |
| 2Ws | 9.80 | 0 | 0 | | 96.45 | 0 | 0 | |
| Cars | 5.61 | 4.89 | 2.45 | | 39.34 | 34.34 | 17.17 | |
| MUVs | 0.18 | 0.57 | 0 | | 1.68 | 5.37 | 0 | |
| Taxis | 0 | 0.22 | 0 | | 0 | 1.49 | 0 | |
| 3Ws | 0.04 | 0.46 | 0.81 | | 0 | 0 | 4.07 | |
| Buses | 0 | 3.51 | 0 | | 0 | 41.35 | 0 | |
| HDVs | 0 | 4.25 | 0 | | 0 | 21.94 | 0 | |
| LDVs | 0 | 1.59 | 0 | | 0 | 7.97 | 0 | |
| Total | **15.62** | **15.50** | **3.26** | | **137.47** | **112.46** | **21.24** | |

Analysing the relationship between land use and how individuals travel in Rajkot, it was found that accessibility to jobs, polycentric development, and a balanced jobs-housing ratio encourage individuals to travel and use NMT and PT modes. Thus, a strategy is proposed that ensures increased accessibility to jobs and polycentric development with major and minor nodes. The major nodes would have a Floor Space Index (FSI) of 4 and minor nodes an FSI of 2.5. These nodes will have a good land use mix, ensuring a balanced job-housing ratio. As a result of this strategy, it was projected that the share of the public transport mode would increase to 22 per cent, and the estimated average trip length would drop to 3.9 km from the 6.0 km of the BAU.

In the NMT strategy, it was proposed that on all major roads, and on roads where demand for walking is high, footpaths greater than 2m wide will be provided. By doing so, it is estimated that the NMT share will hold its current share of 48 per cent going into 2031, rather than decrease to 29 per cent as under the BAU scenario. Potential dedicated bicycle routes were identified in areas along all major roads where individuals stated they would prefer using bicycles if dedicated corridors were provided. As a consequence, the bicycle share in LCS is projected to increase from the current five per cent to 12 per cent. Overall, it was found that a significant number of trips (including all short trips, educational trips, and some of the work trips) would shift to NMT, thus decreasing vehicle use and, in turn, reducing $CO_2$ emissions by 41 per cent in comparison to the BAU scenario.

A three-stage approach was adopted for the public transport strategy. This included the use of lower-capacity buses on routes that have low public transport demand, city buses on roads with sufficient demand, and BRT on corridors where the city bus service is unable to cater to demand even if it is run at a higher frequency. But adopting this strategy, it was projected that the combined trip share of public transport, including BRT, would be 29 per cent, and the motorised mode would significantly decrease to 27 per cent. As can be seen in Table 6.2 this strategy results in a 47 per cent drop in $CO_2$ emissions in comparison to the BAU scenario.

**TABLE 6.2** Energy Saving from TDM measures in Rajkot

| Private Auto-mobiles | Fuel consumed (million litres or million kg) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2011 | | | 2031 (BAU) | | | 2031 (Land use) | | | 2031 (Land use+NMT) | | | 2031 (Land use+NMT+PT) | | |
| | Petrol | Diesel | Gas | Petrol | Diesel | Gas | Petrol | Diesel | Gas | Petrol | Diesel | Gas | Petrol | Diesel | Gas |
| 2Ws | 9.80 | 0 | 0 | 96.45 | 0 | 0 | 65.65 | 0 | 0 | 28.10 | 0 | 0 | 25.08 | 0 | 0 |
| Cars | 5.79 | 5.68 | 2.45 | 41.02 | 41.20 | 17.17 | 7.02 | 7.05 | 2.94 | 4.85 | 4.87 | 2.03 | 3.60 | 3.62 | 1.51 |
| Total | **15.59** | **5.68** | **2.45** | **137.47** | **41.20** | **17.17** | **72.66** | **7.05** | **2.94** | **32.95** | **4.87** | **2.03** | **28.68** | **3.62** | **1.51** |
| % of BAU | | | | | | | 52.86 | 17.11 | 17.11 | 23.97 | 11.83 | 11.83 | 20.86 | 8.79 | 8.79 |
| % of 2011 | | | | 881.78 | 725.35 | 700.82 | 466.09 | 124.09 | 119.90 | 211.37 | 85.82 | 82.92 | 183.97 | 63.74 | 61.59 |

# **References** - Module 6

[1]   Munshi, T., Built form , Travel Behaviour and Low Carbon Development in Ahmedabad, India, in Faculty of ITC. 2013, University of Twente: Enschede, the Netherlands.

[2]   Huxhold, W.E., An introduction to urban geographic information systems. OUP Catalogue, 1991.

[3]   Hoornweg, D., L. Sugar, and C.L. Trejos Gómez, Cities and greenhouse gas emissions: mov-ing forward. Environment and urbanization, 2011. 23(1): p. 207-227.

[4]   Cervero, R. and J. Landis, Suburbanization of Jobs and the Journey to Work, in Working Paper. 1991, University of California Transportation Center, Berkeley.

[5]   Munshi, T., Built environment and mode choice relationship for commute travel in the city of Rajkot, India. Transportation Research Part D: Transport and Environment, 2016. 100(44): p. 239-253.

[6]   Pickrell, D., Cars and clean air: a reappraisal. Transportation Research Part A: Policy and Practice, 1999. 33(7/8).

[7]   Munshi, T., et al., Low carbon comprehensive mobility plan, Rajkot. Unpublished Report, UNEP Risoe Centre on Energy, Climate and Sustainable Development, Technical University of Denmark, Roskilde, 2014

# Module 7. Big data, social analytics and Planning energy-efficient transport

"Big data refers to data sets whose size is beyond the capabilities of typical database software tools to capture, store, manage and analyse" [1,2]. Another definition is big data "describes a new generation of technologies and architectures, designed to extract economic value from a very large volume of a wide variety of data, with a high-speed data capture, discovery, and/or analysis, resulting in the 4 V's of Big Data (value, volume, variety and speed)"[3].

These massive datasets are available because of recent advances in information technology. There is an exponential increase in (a) telecommunication bandwidth that connects a network of (b) centralised and decentralised data storage systems, which are processed thanks to (c) digital computational capacities. The digital footprint created by this enormous data exchange has created a plethora of opportunities to find alternative low-cost data sources. These by-products of digital technology have shown immense potential to replace traditional data sources (like surveys) with proxy indicators that correlate with the variable of interest. These data sources can be called by-products and have shown prospects of replacing official statistics. Because the data come from a by-product of some other intended use, the Data sources are not produced as a result of a specific research question, unlike most traditional data sources. As such, Big Data often requires interpretation after the event rather than prior to it. The term big data was first used a couple of decades ago in the corporate world, but it is increasingly used for the benefit of civil society, especially in the transport sector.

Big data related to transport is generally referred to as structured or unstructured data generated naturally due to activities in transportation usage such as transactional, operational, planning, and social activities. According to the literature review, the sources of Big Data in transportation can be identified as traditional or new ones [4]. Traditionally sources include structured (data with fixed formats and schema that have fixed fields) and semi-structured data collected (Data that does not have fixed formats, but does contain labels and other markers), by Intelligent Transportation Systems (ITS): smart cards data, GPS data, videos and images. New potential data sources include such sources of non-structured or semi-structured data as:

- Data collected from social media.
- Open Data.
- Data collected by roadside or car sensors.

## Data collected from social media

Social media are a set of Internet-based applications that are grounded in the idea of Web 2.0 (which allows for dynamic or user-generated content). Ellison and Vitak [5] listed three aspects to define social media that they referred to as "social network sites" as web-based services: Individuals are allowed to create their public or semi-public profile. These individuals can connect to others to form a network. These individuals can view and relate to other users and their activities, which are publicised in their network. The most common big data applications for social media are trend discovery, social media analytics, sentiment analysis, and opinion mining. For instance, social media assists organisations in obtaining customers' feedback regarding their products, which can be used to modify decisions and to obtain value out of their business. In transport planning, this can influence the choice of a particular mode of transport, for example, non-motorised transport or public transport. Most of the existing approaches to social media big data analysis rely on artificial intelligence and use machine learning techniques like clustering and deep learning.

As stated earlier, the data is not collected to answer a particular question. Big data collected from social media are useless until properly utilised to drive decision making by turning a huge amount of social data into meaningful insights. Figure 7.1 shows the processes for data collected from social media sources. Storage technologies that can handle a large amount of data are required. Some examples are HDFS, Hbase, Cassandra. Data collected from social media has a lot of noise (irrelevant information) and can contain a lot of inconsistent data; therefore, a lot of data cleaning and processing are required. This can be done using technologies such as Spark, Hadoop, and Mesos. The processed data is good enough for a transport policymaker to use and analyses for taking decisions to decarbonise transport.

**Figure 7.1** Processing social media big data for decarbonising transport
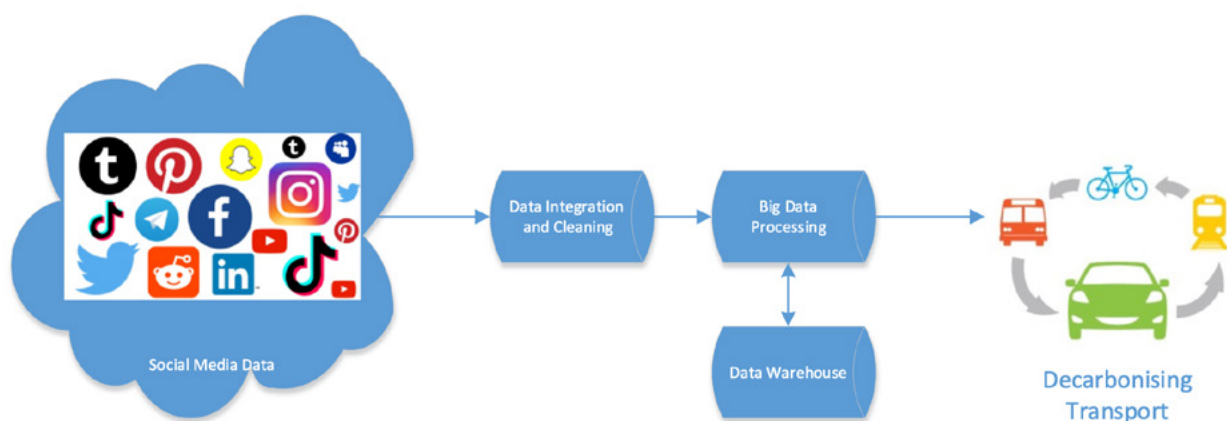


The data from social media can be structured, semi-structured, and unstructured data, such as Microblogging, news articles, blog posts, internet forums, reviews, and Q&A posts. The massive amount of data generated by users is the result of integrating their background details and daily activities on several social media platforms. All the statuses, tweets, comments, posts, and reviews are user-generated content. User-generated content is a type of data that typically refers to images, text, and videos. This content comes from regular people and not necessarily in a standard form. Therefore, various quality distributions of user-generated content occur, which range from high-quality to low-quality things, as the data generated by social media sites are naturally fuzzy and unstructured. All these data may incorporate the users' personal opinions, behaviours, and thoughts, which makes extracting high-quality information from such data increasingly important. This data is processed using machine learning tools and social analytics tools to understand individual preferences towards transport, current use of transport modes, and choice riders who can be targets for low carbon transport strategies leading the implementation of strategies which will result in energy savings.

### Open Data

The purpose of the concept is to make public service data open and accessible to everyone to promote its use without restrictions or other mechanisms of control. Therefore, open data is characterised by how it is stored and for what purpose. Data from various sources can be distributed as Open Data, so long as they are free of barriers to use, access, and cost (as described above). Open Data often consists of large datasets from scientific and governmental sources (including Big Data), although these data only become Open Data if their owner(s) decide to release and distribute them in such a manner. Thus, most data

could be made Open, but that is not always desirable or even legal, given ownership, intellectual property, and privacy considerations. Open Data has three fundamental characteristics. First, it should be accessible over the Internet and be interoperable (having a free license restriction on use and distribution), and capable of being used by computers and reused by various applications or systems, in addition. They are not personal or individual data of the organisations, but rather of the products offered and achievements translated into benefits for the users of those services. They can be stored in electronic sheets (xls, csv, cal, odt, json, and preferably in RDF format) that transformed are exposed, or published on the Internet in a format that generally corresponds to tabular tables grouped in control panels to facilitate their understanding. Once the tables are published, they can be "downloaded" or saved.

Thus, the philosophy of Open Data is defined as information displayed on the Web in a tabular format of numbers, statistics, metrics, micro, and macroeconomic data, geo-referenced or not, on all kinds of topics, without intellectual property restrictions or access control mechanisms.

The initiative to open data to disseminate knowledge, activities, accountability, and transparency was born by the political agendas established in Europe and the United States in 2009 to promote transparency and reuse of Public Sector data In the US, the government of President Obama promoted the opening of data, followed by the UK (http://data.gov.uk/data), then other European countries such as Spain http://datos.gob.es/datos, in Latin America: Chile (http:// datos.gob.cl/), Uruguay (http://datos.gub.uy ), Brazil (http://dados.gov.br ), Colombia ( www.datos.gov.co ), among other countries in the world. A world catalogue of Open Data can be accessed at: http://datacatalogs.org/.

In many countries, there are good examples of open data from public transport and other sources supporting mobility services; these new services now hold journey datasets that can support decision-making about other transport infrastructure and operations, for example, in the UK. However, breaking the barrier of consistency, interoperability, and making transport data open source might still require collaboration and investment across the sector.

### Sensor Data

Sensors constantly monitor the main constituents of a transport system: vehicles, infrastructure, and people. The use of the sensor in vehicles has increased enormously; cars had practically no sensors back in 1970; four decades later, an average car had from sixty to a hundred sensors on board. Typical sensors in a car monitor almost all information possible about the hardware (fuel consumption, engine performance, on-board diagnostics), driving (acceleration, braking, turning, speed), position (GPS), and environment (cameras, ultrasonic and radar/lidar in automation, advanced driver-assistance systems, etc.). In addition to vehicle sensors, there are Infrastructure sensors. Over the years, sensors have become relatively inexpensive. As a result of significant cost reductions and ongoing technological advancements, sensors are now common in the transportation system. They are utilised for parking, weather, road surface pollution, and intelligent traffic control systems (inductive loops, cameras, and radar sensors) (free parking lots, parking management). There are also sensors that individuals carry, like mobile phones, and wearables. Many of the sensors in cellphones and wearable electronics are helpful in the context of mobility (GPS, Accelerometer, Gravity-Motion detection, Gyroscope, Linear Acceleration, Magnetic Field, Orientation, Rotation Vector, etc.).

With the help of this data, researchers have been able to better understand how people choose their modes of transportation on a daily basis or how they use their preferences to provide services like personalised mobility services.

### The potential of big data use for energy efficiency in transport

For the transition from private to public, non-motorised mode choice and adaptation of technologies the following question need to be answered.

1. Are the urban planning strategies of densification (jobs, opportunities and residences) working, and what factors affect residential and commercial location choices
2. Has the demand for public transport increased, which socioeconomic groups are likely to use the public transport system, and what factors affect public transport choice
3. Has the demand for non-motorised transport increased, which socioeconomic groups are likely to bicycle and/or walk, and what factors affect non-motorised vehicle choice
4. Have devices and technology led to substitution, where devices decrease travel
5. Has telecommunication made travel more efficient and influenced the choice of particular modes
6. What socioeconomic groups are likely to purchase electric vehicles, and what are the factors influencing the purchase of electric vehicles
7. What factor will influence the shift of cargo from road to the electric train
8. Consumption of fossil fuel

As mentioned in section 3, parallel to small data (available from conventional sources), the prevalence and rapid rise in ICT technologies have enabled the collection of a massive amount of data, resulting in many studies on human behaviour and movement. Figure 6.2 shows mobile phone and call data records, smart card data (if used to access public transport), and geo-coded social media records that allow an understanding of mobility behaviour to an unprecedented level of detail and help answer the first seven of the eight questions asked above. However, simply observing is not particularly helpful for planning purposes. To allow for prediction in what-if scenarios, we need to understand and contextualise the information contained in such Big Data sources to inform travel behaviour models and adapt them to be useful in modelling frameworks to implement energy efficiency in transport.

**Figure 7.2** Transport attribute data using big data from **mobile phones**

| Data Type | Other data | Transport attribute | Methodology |
|---|---|---|---|
| Event Driven | Geodata | mobility Patterns | Strategical analysis |
| Network Driven | Zip codes | Trip identification | Spaciotemporal clustering/k-means dustering |
| | Traffic counts | Travel mode | Rule based (temporal based - duration) |
| | Traffic network | OD matrices | Frequency based/Probabilistic approach |
| | Census | Accessibility to public transit | Scaling method |
| | | Activity diaries | Spaciotemporal clustering/Frequency based/(ITA) algorithm |
| | | | Georeferencing/Rule based |
| | | | Huff model-based FCA method |

In most countries, mobile penetration is high. Therefore, data from mobile phones can become a potential big data source for extracting mobility-related information that can feed the transport model as input and validate the outputs. As shown in figure 7.2, data types are mainly used by researchers from mobile phone data, these are event-driven data, and second is network-driven data; most research has used event-driven data for transport modelling studies. The transport model requires data on mode choice and travel distances. Researchers have used many rules to extract the origin-destination (OD) matrix. The mode of transport is detected by clustering and rule-based method. A significant advantage of mobile phone data is that it offers large samples and broad spatial and temporal coverage. Lack of social-economic information and their noisy and sparse measurements are their main disadvantages.

**Figure 7.3** Transport attribute data using big data from **social media**

| Data Type | Other data | Transport attribute | Methodology |
|---|---|---|---|
| Check-in | Land uses | mobility Patterns | Statistics |
| Text | Census | Riders option | Machine learning |
| Geotagged | | Individual activity patterns | Probabilistic topic model |
| | | Trip purpose | Sentiment analysis |
| | | OD patterns | Classification |
| | | travel behavior | Hierarchical clustering |
| | | | Latent class analysis/Tobit regression model |
| | | | X-means clustering |

Another source of massive data that is gaining attention is social media as shown in figure 7.3, such as Facebook and Twitter. In the literature, there are various efforts to mine transport information by analysing text, hash-tag(s) or check-in data provided by social networks. Most of them focus on real-time traffic management and detecting incidents or anomalies in the network. However, relevant studies attempt to utilise such data for planning purposes by analysing aggregate or individual mobility patterns, deriving activity locations, estimating OD matrices, and examining commuters' opinions regarding the transport system. Data from social media provides location-based information, which is the most common in extracting transport-related data from users' posts. Almost all studies use check-in and geo-tagged data, while one uses text mining techniques to obtain more information. Among the reviewed studies, the majority examines mobility patterns and travel behaviour. Some recent efforts on estimating OD matrices and trip purposes show that social media can be a helpful supplement for travel demand estimation and activity-based modelling. In such cases, supplementary data such as census data and land uses are often necessary. The main advantages of social media are their free access at low cost and containing many qualitative data, while the main disadvantage is the lack of transport information between two posts.

**Figure 7.4** Transport attribute data using big data from **Automatic Fare Collection System and smart cards**

| Data Type | Other data | Transport attribute | Methodology |
|---|---|---|---|
| Bus | AVL Data | Travel Patterns | Rule based |
| All modes | Land uses | Trip destination (OD estimation) | Trip-Chaining/Users classification |
| Metro | | Transfer patterns | Probabilistic method (multinomial logit model) |
| Train | | Trip/Activity detection | Machine learning (Conditional random fields) |
| Ferry | | Trip, Alighting stops/Activity detection | Unsupervised mascine-learning (continuous hidden Markov model) |
| | | Trip purpose/Activity patterns | Center point based algorithm |
| | | Home location | Bayesian n-gram model |
| | | | Spatial statistical analysis |

Smart card automatic fare collection systems (SC-AFC) as shown in figure 7.4 are increasingly applied in transportation systems worldwide. Since they can store and analyse a variety of information, smart cards are an effective tool for many applications, including identification, localisation, and payment. Smart cards often hold information such as the card ID, the mode of transportation, the boarding times and places, and occasionally the times and locations for alighting. Although fare collection is these systems' primary goal, the information they keep may be used for purposes unrelated to those for which it was originally intended. Smart card data has mostly been used in performance evaluation, public transport modelling, and trip pattern analysis in the context of transportation planning. Since different types of smart cards offer different information about boarding and alighting, most studies concentrate on extracting key qualities for transport modelling. Reconstruction of individual trips is the main goal. The most widely used approach is a trip chaining algorithm with various distance and time limits. Separating transfers from the activity site is a crucial effort. Time-based constraints are the most typical strategy. Using rule-based, machine learning, and probabilistic techniques, more recent studies have sought to extract the trip purpose and analyse activity patterns from smart card data. In the research mentioned above, vehicle GPS or GIS data is a typical supplemental dataset. Last but not least, the majority of studies lacked validation or only contrasted their suggested methodologies with travel journal or survey data. Overall, smart cards contain large volumes of individual trip data, which cover extended periods, while the basic disadvantage is that they provide information only about specific public transport modes.

# **References** - Module 7

[1]   Yin, S. and O. Kaynak, Big data for modern industry: challenges and trends [point of view]. Proceedings of the IEEE, 2015. 103(2): p. 143-146.

[2]   Manyika, J., et al., Big data: The next frontier for innovation, competition. 2011, and productivity. Technical report, McKinsey Global Institute.

[3]   Gantz, J. and D. Reinsel, The digital universe in 2020: Big data, bigger digital shadows, and biggest growth in the far east. IDC iView: IDC Analyze the future, 2012. 2007(2012): p. 1-16.

[4]   Torre-Bastida, A.I., et al., Big Data for transportation and mobility: recent advances, trends and challenges. IET Intelligent Transport Systems, 2018. 12(8): p. 742-755.

[5]   Ellison, N.B. and J. Vitak, Social network site affordances and their relationship to social capital processes. The handbook of the psychology of communication technology, 2015. 32: p. 205-228.

# Module 8. Evaluation of social, economic, and environmental impacts

The different options - technical and non-technical covered in module 2 & 3 will be difficult to implement if we only look at the financial returns. The options are however widely accepted to have substantial mitigation benefits and other social, economic, and environmental benefits. This module briefly introduces two widely used approaches to do an assessment of costs and benefits.

## 8.1 EXTERNALITIES AND VALUATION APPROACHES

Transportation services contribute significantly to economic growth however they also contribute to many negative externalities. Negative Externalities are the costs imposed on society through misuse and pollution of common resources (resources for which no property rights are defined such as air, water, etc.). Individual preferences are the most important indicator of valuing costs imposed on society (externalities). The first best solution is to estimate damage costs. In order to value individual preferences, the following approaches are relevant [1].

- The willingness to pay (WTP) for an improvement.
- The willingness to accept (WTA) compensation for non-improvement.

The value of a benefit can be derived as the amount of money an individual is willing to pay (WTP) to obtain the benefit, and, similarly, the value of a cost element can be derived as the amount of money an individual is willing to accept (WTA) as a compensation. However, these values (WTP/ WTA) are generally not obtained by asking direct questions such as "How much are you be willing to pay for a reduction in air pollution" since the users can answer strategically since they believe they may eventually be asked to pay for it for example through a fuel tax. Therefore, indirect methods such as *stated preference (SP)* or *revealed preference (RP)* can be used.

The stated preference (SP) method which uses a contingent valuation approach to directly measure the WTP is most commonly used. The stated preference approach is useful for the valuation of individual key values such as the statistical value of human life. The values obtained, however, depend on the survey design and the level of information. It also suffers from the fact that it involves hypothetical expenditures only. Indirect methods like revealed preferences (RP) have been used as an alternative. For example, using the hedonic pricing method house price differentials can be used to estimate noise costs.

A major recommended approach for valuation of environmental impacts is the *impact pathway approach* (such as used by the ExternE model specifically developed for air pollution) which follows the dose-response function considering several impact patterns on human health and nature [2]. Sometimes the lack of certain information on the dose-response function renders it necessary to find an alternative model for estimation of the damage level. In this case, the avoidance cost approach (cost to avoid a certain level of pollution) can be used.

## 8.2 NEGATIVE EXTERNALITIES OF TRANSPORT

The transport sector is a significant driver of economic growth but also creates a number of externalities i.e., costs to society that is not borne by the transport users. The major externalities are in terms of noise, air pollution, accidents, congestion, nature and landscape and climate change ([1]).

The different externalities can be measured in different units e.g., noise can be in decibels, air pollution can be in terms of concentration of particulate matter in parts per million, etc. We can also refer to these quantitative values as attribute values. There are two approaches that are commonly used for converting these attribute values into a common unit that allows adding across the indicators or making a comparison across projects. These are the Cost Benefit Analysis (CBA) and Multi Criteria Decision Analysis (MCDA) and are introduced in Section 7.3 and 7.4.

The methods for estimation of external costs vary with the type of externality and involve a number of assumptions that lead to uncertainties. A good discussion of different tools and methods for evaluating social, economic and environmental costs is provided in [1]and here we introduce the main negative externalities from the transport sector of noise, air pollution, accidents, congestion and climate change.

### Noise pollution

Noise pollution is defined as unwanted sounds happening over a period and of a certain intensity that cause physiological or psychological harm to humans [1]. Transport noise is expected to cause two types of negative impacts i) Annoyance and ii) Health. Annoyance is considered when noise can impose social and economic costs e.g., if noise interferes with listening to music. It is however health impacts that receive the most attention. Noise can cause physiological damage to the human body when the noise exceeds 60 decibels [1]. For example, hearing can be damaged at a noise above 85 dB whereas even a lower noise of

60 dB can lead to an increased heart rate. Time of noise is also important and noise at night is more damaging than during the day. For noise costs, the impact pathway approach is broadly acknowledged as the preferred approach, using Values of Statistical Life based on Willingness to Pay [1].

## Air pollution

Road transportation contributes to a wide range of air pollutants such as sulphur dioxide, Nitrogen Oxide, Particulate Matter (measured as PM10, PM2.5 depending on the size of particles), Ozone, etc. Most of these are related to the combustion of fossil fuels within engines though some particulate emissions also come from road dust and wear of tyres. All these air pollutants are also referred to as local pollutants since their impacts are local in contrast to $CO_2$ emissions which have a global impact. A detailed discussions on air pollution is also provided in Module 1 since it is one of the most significant negative externalities of transport. Air pollutants are known to impact human health and therefore WHO has prescribed Air Quality Standards for each of these pollutants [3]. For air pollution the impact pathway approach is broadly acknowledged as the preferred approach, using Values of Statistical Life based on Willingness to Pay [1].

## Climate change

Transportation vehicles produce direct greenhouse gas (GHG) emissions of carbon dioxide ($CO_2$), methane (CH4) and nitrous oxide (N2O) from the combustion and evaporation of fuels used in transport activity. Since the GHG emissions are related to the fuels the emissions can be estimated using default emission coefficients for fuels provided by Intergovernmental Panel on Climate Change [4]. The CH4 and N20 emissions can be converted into equivalent $CO_2$ ($CO_2$eq) emissions using global warming potential values for CH4 and N2O available from IPCC [4].

GHG emissions result in global warming, a global externality and therefore emissions happening in one country affect other countries as well. Global warming results in climate change i.e., changes in surface temperatures, precipitation patterns, sea level rise and extreme events that have impacts on human systems. Since climate change is a long-term problem, the avoidance cost approach is the preferred approach for estimating climate costs. Alternatively, a carbon price can be used to value GHG emission reductions, and this carbon price can be either a market price coming from an emission trading scheme (ETS) or based on a carbon tax put by the government[2].

## Accidents

Road transportation is associated with accidents which result in loss of lives, non-fatal injuries[3], and permanent disabilities. In a year approximately 1.3 million lives are lost and between 20 and 50 million people suffer non-fatal injuries . Injuries caused result in economic losses to individuals, their families, and to nations as a whole. The losses comprise treatment costs, productivity losses for those disabled by injuries, and for dependents who need to take time off work to take care of the injured. Since road transportation requires compulsory insurance therefore a part of these is covered by insurance however a substantial part of the losses is not covered and is an externality.

The marginal accident cost can be estimated by the risk elasticity approach, using Values of Statistical Life [1].

## Congestion effects

Congestion happens when multiple users are competing for a limited transport system capacity and this leads to several effects such as increased travel times, increased vehicle operating costs, increased fuel costs, reduced reliability and dis-amenities for users travelling in congested systems [1]. The estimation of congestion costs is done by i) measuring differences in vehicle speeds during peak and off-peak periods and ii) the difference between traffic volume and usable capacity. The increased travel time costs and disamenities from increased travelling on congested systems are further based on the value of time [1]. The value of time can be in turn estimated using a stated preference survey [5].

## 8.3 OVERVIEW OF COST BENEFIT ANALYSIS (CBA)

Many projects implemented by the city government are of a kind where the revenues from the projects are not sufficient to justify the project. In financial terms, we can say that the Internal Rate of Return  is less than the discount rate. The project may however provide several non-financial benefits. For example, let us consider a Bus Rapid Transit project which besides fare and advertising revenues can deliver improved air quality, lower $CO_2$ emissions, improved access to jobs, improved safety for pedestrians, etc. In such cases, we use Cost-benefit analysis (CBA) which is a widely used tool for evaluating the 'goodness' of public investments. The basic feature of CBA is the comparison of costs and benefits, which are all measured in monetary terms. The benefits, in this case, include both financial and non-financial benefits for any public project. For a project to get approved the benefits should exceed the costs.

---

2  More than 40 countries and 20 cities have introduced carbon pricing mechanisms and you can follow more at https://carbonpricingdashboard.worldbank.org/

3  https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries
IRR is calculated by reducing the discount rate of the net present value (NPV) of all cash flows from a particular project to zero. IRR provides a metric used to estimate the profitability of investments.

The CBA of a public project can be compared with the financial analysis carried out by a private company for its projects. A private company will conduct financial analyses using the product's sales price as a measure of the benefit and the prices of production factors as measures of costs. Hence, market prices are the measurement units in financial analysis [6].

The CBA for a public project in addition to private costs and benefits also look at externalities i.e., costs and benefits that happen from a project to other parts of the society and not just to project participants. The previous section has provided a brief overview of key externalities from transport projects and also provided references for methods used for estimating these externalities.

The CBA is used by a decision maker in government or public authority in a way similar to the management of a private company. The management in the latter case is trying to maximise the profits whereas a decision maker in government or public authority is trying to maximise the welfare of the society. In CBA this is done by calculating all the costs and all the benefits and from them calculating a benefit to cost ratio. For a project to happen the benefit to cost ratio shall be more than 1.

## 8.4 OVERVIEW OF MULTI-CRITERIA DECISION ANALYSIS (MCDA)

MCDA is used for the decision-making process, including to rank options or short-list a limited number of options. MCDA involves several different techniques that assist decision-makers to approach complex problems and reach decisions consistent with their own value judgments. This is done by breaking down complicated decisions into smaller ones that are easier to handle and by aggregating them back through a logical process [7].

MCDA can thus provide a structured framework for comparing options across multiple criteria. It allows combining criteria which are valued in quantitative terms as well as qualitative terms. It is therefore used in some cases as an alternative to CBA where all the non-financial benefits have to be converted to monetary values. MCDA allows the use of a full range of social, environmental, technical, economic, and financial criteria for evaluation.

MCDA is a judgement-based system. It is thus important that the framework reflects a well-balanced judgement of all the important stakeholders and be developed through a consensus process in consultation with all the relevant stakeholders. The inputs from stakeholders can be obtained through personal communications, interviews and/or in a workshop setting.

MCDA follow a step-wise approach consisting of eight steps described in [8] and the interrelationships are shown in Figure 8.1.

**Figure 8.1** Steps in Mult-Criteria Decision Analysis
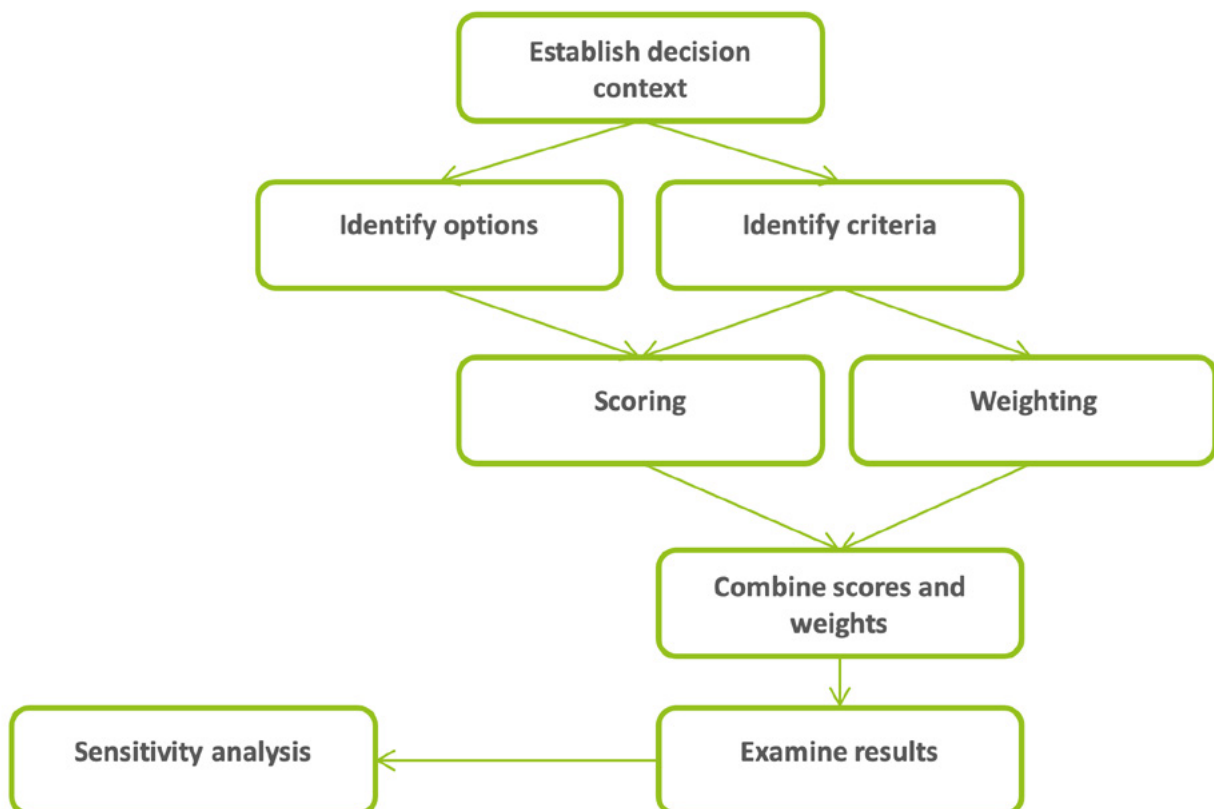
### Decision context

As a first step in the process, the context in which the decision takes place should be established. [8] The decision context is defined as the political, economic, social, technological, and environmental factors that surrounds the decision. The objectives of the project can be defined in terms of these factors. This is also the step where we identify the relevant stakeholders that will participate in the decision-making process.

### Options

MCDA is a technique that can be used to evaluate one single project but also to make a comparison across multiple projects (options) that have similar project objectives.

### Criteria

The criteria are measures of success, in addressing political, economic, social, technological, and environmental aspects. The criteria relate to the objectives of the project and can be defined in consultation with the stakeholders.

### Weighting

Weights are numeric values assigned to each criterion to reflect the relative importance of one criterion over the other criteria. These weights are provided by different stakeholders associated with the living labs.

### Scoring

Scoring is the process of assigning a value to the performance of an option against a specific criterion. Since the impact of an option against a criterion is always assessed in comparison to the baseline scenario it involves estimation of the criteria values for the option or project and in absence of the project (baseline). The difference between the values for project and baseline is also referred to as a key performance indicator (KPI). In MCDA the criteria can be assessed both quantitatively and qualitatively and here it is more flexible than CBA where every benefit has to be monetised.

### Combining weights and scores, examine results and sensitivity analysis

MCDA is a consensus-building technique, and the last three steps are quite important in this regard. Once scores and weights are available overall score and score obtained for each KPI are presented back to stakeholders to reflect on the results to identify any errors in assessment. In case there are disagreements between stakeholders during the scoring and weighting stage these alternative opinions can be analysed and are referred to as sensitivity analysis.

# **References** - Module 8

[1]  M. Maibach et al., Handbook on estimation of external cost in the transport sector. Delft: Internalisation Measures and Policies for All external Cost of Transport (IMPACT) https://transportpublic.org/images/pdf/20080425-eurovineta/02-eng.pdf, 2007.

[2]  UBA, "Economic valuation of environmental damages – method convention for estimating environmental costs," Dessau, 2006.

[3]  WHO, "WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide," https://apps.who.int/iris/handle/10665/345329, 2021.

[4]  IPCC, "IPCC Guidelines for National Greenhouse Gas Inventories," S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe, Eds. IGES, Japan, 2006.

[5]  S. F. A. Baqueri, W. Ectors, M. S. Ali, L. Knapen, D. Janssens, and A.-U.-H. Yasar, "Estimation of Value of Time for a Congested Network: A Case Study of the National Highway, Karachi," Procedia Comput. Sci., vol. 83, pp. 262–269, 2016, doi: https://doi.org/10.1016/j.procs.2016.04.124.

[6]  S. Gissel, "Decision aid methods in rail infrastructure planning," Technical University of Denmark, 1999.

[7]  Michael Bruhn Barfod, Multi-criteria decision analysis exemplified in the transport sector. Copenhagen: DTU, 2020.

[8]  J. S. Dodgson, M. Spackman, A. D. Pearman, and L. D. Phillips, Multi-Criteria Analysis: A Manual. 2009.

# Module 9. Training and capacity building[4]

## 9.1 MAIN FEATURES OF A COMPREHENSIVE TRAINING PROGRAMME ON ENERGY-EFFICIENT TRANSPORT

Energy Efficiency (EE) has a direct objective of reducing energy consumption without compromising outputs or products. The concept of EE, when considering the transport sector, has a much broader meaning, as discussed in various sections of this guidebook. EE in transport interconnected elements referred to as system efficiency, travel efficiency, and vehicle efficiency, as described briefly in figure 6.2 in relation to A-S-I approach. This approach serves to structure transport sector policy measures to achieve significant GHG emission reductions, reduced energy consumption, and less congestion, with the final objective to create more liveable cities. The elements mentioned in figure 6-2 become the main features of the activities and programme for implementation under each intervention area. Further to the above sources, many other information sources are available on transport sector interventions for energy efficiency improvements, which also become a valuable resource base for the establishment of subject areas, required competencies, and thus the curricula in related educational programmes.

## 9.1.1 THE PROGRAMME AND SETTING OF THE CURRICULUM

As education for EE in the transport sector requires trans-disciplinary and inter-sectoral approaches, multiple tools and mechanisms would be required to cater for different sectors and levels of knowledge described previously. The different education programmes, courses, and training programmes would be required to cater to the transport sector's knowledge, and skill needs to develop and implement EE improvement interventions. As all these educations and training are targeted for the common goal of improving the overall EE in the transport sector, it is more logical to follow a common curriculum development framework. Such a framework would essentially include program outcomes and core competencies as the guiding elements for developing other components. The methodologies for the development of curricula and related competency frameworks are well-established in the education field for the country of Sri Lanka.

**Figure 9.1** The overall energy efficiency concept in a transport system
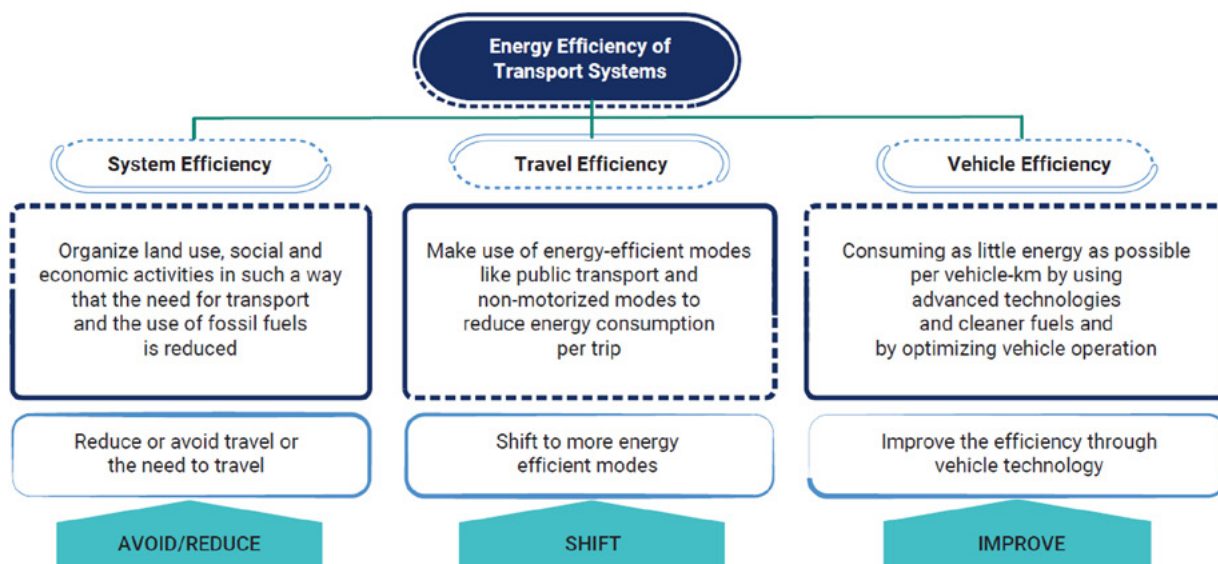


## 9.1.2 THE PROGRAMME OUTCOMES (POS)

POs are statements that describe learnings that are expected to attain and demonstrate by students from all programmes upon completion. The POs guide different education and training programmes in defining their learning objectives relevant to the specific programme. Table 8.1 presents eight (08) POs established for the education of EE in transport systems in the study conducted by C2E2 in Sri Lanka.

---

4  This chapter is adopted from Sugathapala, T., Dhar, S., Munshi, T., & Vithanage, C. (2021). *Assessment of Skills and Knowledge Gap in Energy Efficiency within the Transport Sector in Sri Lanka*. Copenhagen Centre for Energy Efficiency and Schein, L., Asensio, M., Soler, G., Munshi, T., & Audia, I. (2021). *Assessment of Skills and Knowledge Gap in Energy Efficiency within the Building Sector in Argentina*. Copenhagen Centre for Energy Efficiency.

**TABLE 9.1**  POs for the education of EE in transport systems

| After completion of the education program, the learner should be able to |
| --- |
| 1. Acquire,  analyse and interpret data and information to understand the governing contexts in contextualising a problem or action associated with EE in transport systems. |
| 2. Create critical thinking and analysis conditions to question assumptions and recognise and respect different trends and views in diverse and dynamic situations in Energy Efficiency (EE). |
| 3. Identify and connect economic, social and ecological dimensions of problems, conceiving conditions for systems thinking to work with complexity in supporting Energy Efficient and Environmentally Sustainable Transport (E3ST) systems. |
| 4. Envision scenarios for a desirable future and promote work with different visions and settings for the choices and future changes needed to ensure EE in transport systems. |
| 5. Create, select and apply proper techniques to complex transport problems in developing viable, inclusive and equitable solution options that promote EE in transport systems. |
| 6. Creatively adapt strategic approaches collectively to develop and implement innovative actions jointly for fostering EE transport systems that further sustainability. |
| 7. To engage in life-long learning approaches for nurturing EE in transport systems, with the realisation of interdisciplinarity, multidisciplinarity, and transdisciplinarity, while respecting needs, perspectives and actions of others and reflecting own norms and values, principles, goals and targets i n realising E3ST. |

## 9.1.3  THE CORE COMPETENCIES (CCS)

CCs define the desired knowledge, skills, and attitudes of students completing the educational programme to successfully perform in professional, educational, and other life contexts.

Accordingly, in line with the POs identified above, the CCs for EE in the transport systems are established as given in Table 8.2 for the case of Sri Lanka as developed in a consultancy assignment for C2E2.

**TABLE 9.2**  CCs for EE transport systems

| Cognitive Competencies (Knowledge) |
| --- |
| 1. Information competency: The ability to access, acquire and process the information on resource or EE in the transport sector (covering the three areas of system efficiency, trip efficiency and vehicle efficiency in line with the Avoid/Reduce-Shift-Improve concept). |
| 2. Systems thinking competency: The ability to recognise and understand EE relationships; to analyse EE in complex transport systems; to think of how systems are embedded within different domains and different scales, and to deal with uncertainty. |
| 3. Critical thinking competency: The ability to question norms, practices and opinions about transport sector efficiency; to reflect on self-values, perceptions and actions in EE interventions; and to take a position in the sustainability discourse. |

| Functional Competencies (Skills and know-how) |
| --- |
| 4. Anticipatory competency: The ability to understand and evaluate multiple futures – possible, probable and desirable of the transport sector EE; to create one's vision of the future; to apply the precautionary principle; to assess the consequences of actions; and to deal with risks and changes in the area of EE in the transport sector. |
| 5. Strategic competency: The ability to collectively develop and implement innovative actions for energy-efficient transport systems that further sustainability at the local level. |
| 6. Integrated problem-solving competency: The overarching ability to apply different problem-solving frameworks to complex transport problems and develop viable, inclusive and equitable solution options that promote energy efficiency, integrating the competencies mentioned above. |

| Attitudinal Competencies (Behavioural and Values) |
| --- |
| 7. Normative competency: The ability to understand and reflect on the norms, behaviours and values that underlie one's actions on EE in the transport sector; and to negotiate related sustainability values, principles,  goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions. |
| 8. Collaboration competency: The ability to learn from others; to understand and respect the needs, perspectives and actions of others; to understand, relate to and be sensitive to others; to deal with conflicts in a group; and to facilitate collaborative and participatory problem-solving in transport sector EE challenges. |
| 9. Self-awareness competency: The ability to reflect on one's role in the local community and (global) society; to continually evaluate and further motivate one's actions; and to deal with one's feelings and desires about EE in transport. |

*Source for both tables: Sugathapala, T., Dhar, S., Munshi, T., & Vithanage, C. (2021). Assessment of Skills and Knowledge Gap in Energy Efficiency within the Transport Sector in Sri Lanka. Copenhagen Cen-tre for Energy Efficiency*

### 9.1.4 THE THEMATIC AREAS

The list of thematic areas selected for the education of EE in transport systems is presented in the list below. These themes reflect topics that may be considered to have broad relevance to the purposes of specific programmes for the education of EE in transport systems and their wider context in the overall transport system. This list represents some indicative thematic areas identified for the case of Sri Lanka. So, these may not be comprehensive enough to capture the entire scope of the respective transport systems. When specific subjects or lessons are embedded within the curriculum, it is expected that they form an integral part of a programme of study, while learning and teaching activities are designed to take the POs and CCs into account. Further, the topics of the themes given are not prescriptive, recognizing that educators will be working within different educational programmes and local contexts, governed in some cases by broader institutional strategies, thus needing more flexibility. The topics cover the key areas within systems and sub-systems of the transport sector having a direct and indirect bearing on EE in the transport sector, thus the curricula and syllabi must be developed in the context of EE in each area and sub-area in the list in Table 8.3.

**TABLE 9.3**

| Main theme | Sub-themes/Subject topics |
|---|---|
| 1. Transport and Sustainable Development | Mobility, Transport and Scio-economic development linkage; The paradox of transport and its costs - planetary boundaries, ecosystem ecology, industrial ecology, circular economy; Environment dimensions of transportation (local, global) -; Environmentally sustainable transportation (EST) and Sustainable urban transport (SUT); Resource/energy efficiency in transport modes/systems; Role of transport in International conventions and related national/local commitments (SDGs, NDCs). |
| 2. Transport sector governance for energy efficiency and environmental sustainability | National development and sectoral policies and the role of EE of transport; Transport sector institutions and stakeholders and their role in EE; Economic instruments for EE in transport systems; Financing EST/SUT; Knowledge management for EE in transport; Systems approach to transport planning: Avoid/reduce-Shift-Improve (A-S-I) principle; EE model in transport (System efficiency, Travel efficiency and Vehicle efficiency). |
| 3. Land use planning and transport demand management | Sustainable transport infrastructures; Land use planning and urban transport systems for EE; Optimization of the road network and its use; Transport demand management (TDM); Mobility management programmes and measures: minimum occupancy limitations, congestion/corridor pricing, flexible working hours, online working, education, transactions, purchasing; Parking space management, access restriction, speed control, improve traffic flow, traffic smoothing. |
| 4. Energy Efficient and Environmentally Sustainable Transport (E3ST) Modes: Transit, walking and cycling | Mass transit options (BRT, LRT, Monorail) and public transport; Intermodal transport systems; Transit-oriented design features in cities and transport infrastructure; Regulations and planning for public transport; Non-motorised transport; Street design, streetscape and traffic calming; EE design features in transport infrastructure; Car-free developments. |
| 5. Cleaner fuels and efficient vehicles | Cleaner transport fuels: fuel quality improvements in diesel and gasoline, natural gas, alternative fuels – biofuels, renewable electricity, hydrogen; Efficient vehicle technologies: advanced ICEs, EVs, Hybrids, Fuel cell; EE improvement options for new vehicles: air and exhaust gas management, fuel preparation and injection systems improvements, thermodynamic combustion engine process improvements, light-weight designs, aerodynamic designs, size reduction, automotive transmission, waste heat recovery systems, advanced cooling technologies; EE improvement options for in-use vehicles: inspection & maintenance, vehicle retrofit, alternative fuel conversions, fuel treatment/combustion improvement devices, accelerated retirement programmes; Intelligent transport systems (ITS); Eco-driving. |
| 6. Impact assessment of the transport sector | Performance indicators and indices of transport modes and systems; Health and ecological impacts - direct, indirect and cumulative; Impact assessment frameworks and methodologies; Sustainability assessment tools; Transport sector performance and air quality management; Climate actions (mitigation and adaptation) in the transport sector; EE targets in the transport sector. |
| 7. Complementary themes | Diversity and inclusion in transport system: aspects related to human behaviour, culture, lifestyles, consumerism; Politics, advocacy and governance in the transport sector: SD and global agendas, environmental governance, active citizenship, social empowerment, local policy initiatives and regulations; Globalisation and sustainability: worldwide interdependence and transport, international trade and EST, Sustainable globalisation and transportation; Inequality, poverty, social security and gender issues in the transport sector, demographic diversity and transport sector performance; Science and technological progression in the transport sector: future perspectives of technological development and innovations, social innovation for sustainability, principles of urban symbiosis towards E3ST systems; circulatory material/resources; digital lifestyle innovation; Internet of Things (IoTs) for transport systems. |

*Source: Sugathapala, T., Dhar, S., Munshi, T., & Vithanage, C. (2021). Assessment of Skills and Knowledge Gap in Energy Efficiency within the Transport Sector in Sri Lanka. Copenhagen Cen-tre for Energy Efficiency*

## 9.2 TUNING THE EDUCATION SECTOR TO MEET THE SKILLS AND KNOWLEDGE REQUIRED FOR ENERGY EFFICIENT AND SUSTAINABLE TRANSPORT

The distinct features of courses and institutions demand specific attributes in the curriculum of each training programme. In particular, core competencies, program objectives, and thematic areas presented above must be refined and tailored to suit each of the specific education programme/course or module. Accordingly, the following requirements are established as guiding principles in developing course-specific EE education plan and curriculum:

- The specific course should demonstrate its contribution to EE education plan as well as the connectivity of their concepts and activities.
- The sector/subject-specific competencies (SCs) should be established, aligning with the CCs presented earlier.
- The sector/subject-specific learning outcomes (LOs) should be established, aligning with the POs presented earlier; and
- The sector-relevant subject topics should be identified under relevant thematic areas presented
- Figure 9.2 illustrates the above approach as a framework for the development of specific educational programme within overall education for EE in transport systems.

**Figure 9.2** Tune the education program to include energy efficiency skills in Transport
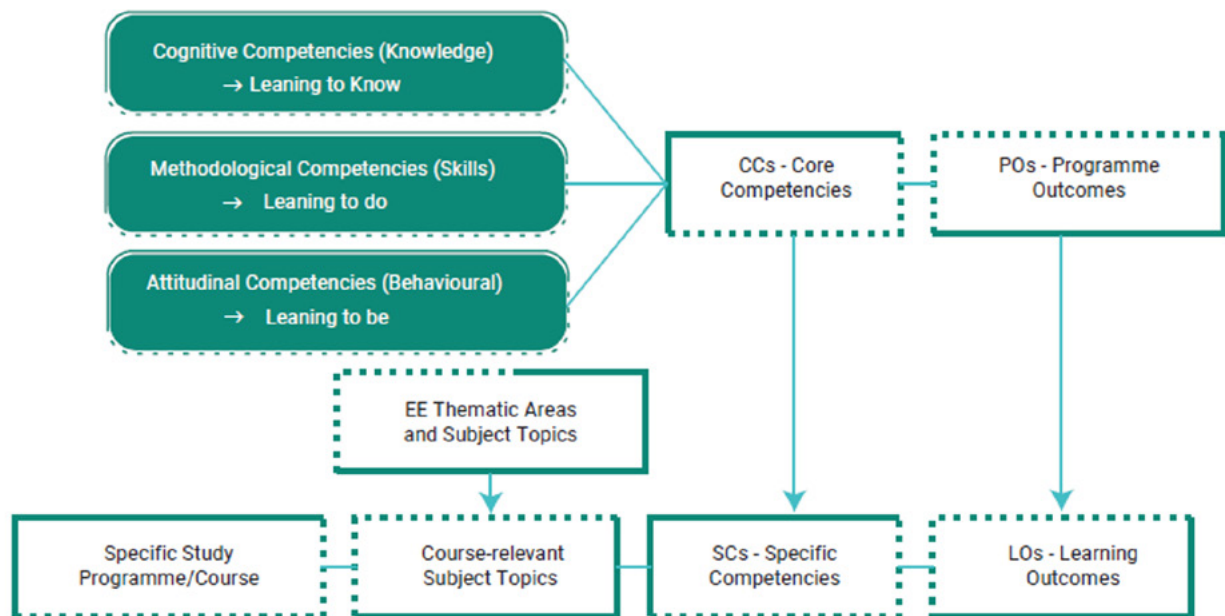


*Source: (Sugathapala, T., Dhar, S., Munshi, T., & Vithanage, C. (2021). Assessment of Skills and Knowledge Gap in Energy Efficiency within the Transport Sector in Sri Lanka. Copenhagen Centre for Energy Efficiency)*

The establishment of sound frameworks for the competencies for EE in transport systems and the curriculum for relevant educational programmes provides the basis for the identification and analysis of gaps in the stakeholder institutions, both in the transport sector and the education sector. For a sustainable delivery of these skills and knowledge the education programs in the countries need to be tuned to meet the requirements.

The first step towards any such development is to identify the gap within the system. The core competencies and the thematic topics that need to be identified first for this gap analysis, as in the case of Sri Lanka and shown in tables 8.2 and 8.3. Figure 8.3 (from C2E2 Argentina study) shows how keywords (representing thematic areas) can be used to query the courses taught in the country to identify the coverage of thematic topics in various course curriculum and the gaps therein.

**Figure 9.3** Identifying gaps in the education system
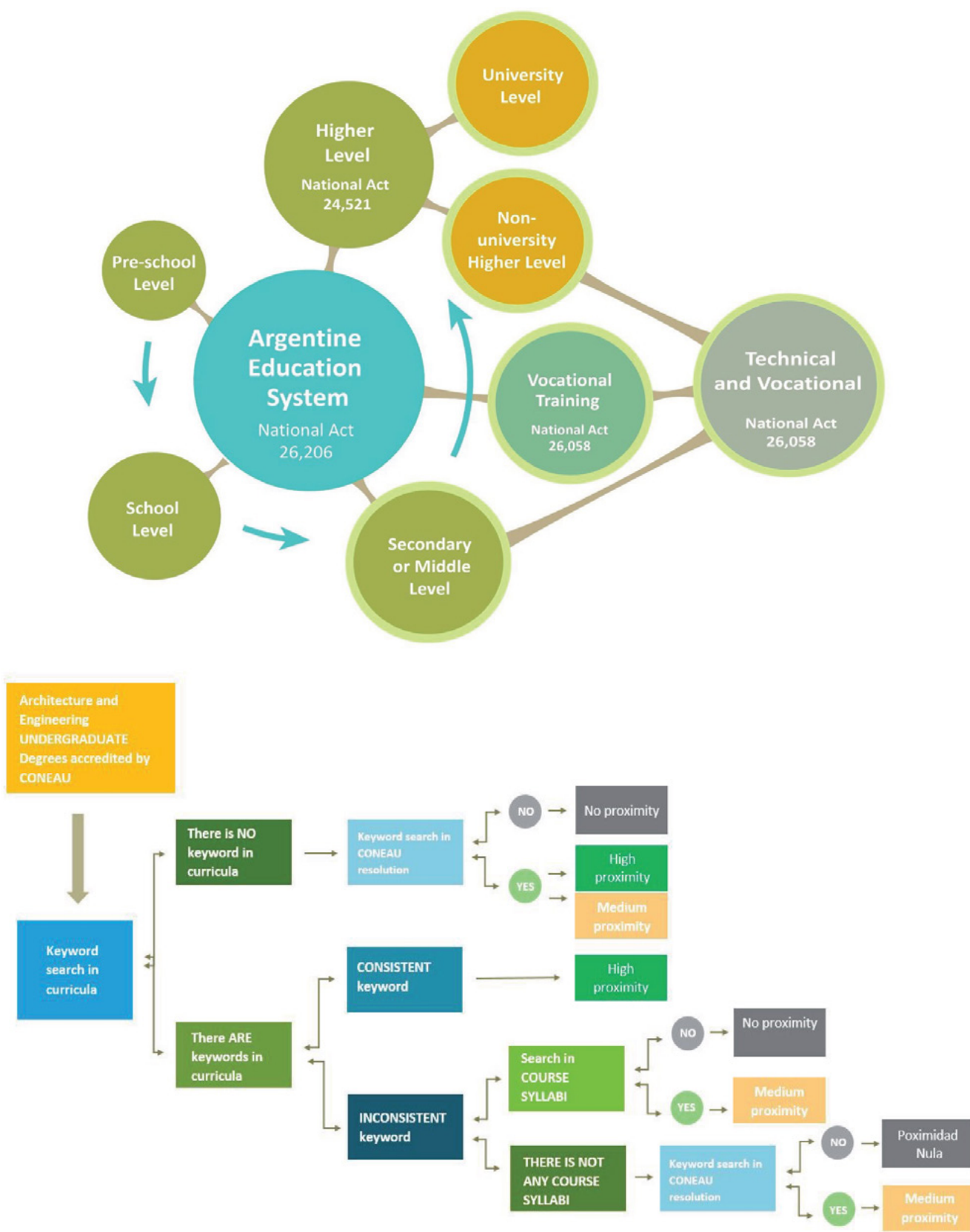


*Source: Schein, L., Asensio, M., Soler, G., Munshi, T., & Audia, I. (2021). Assessment of Skills and Knowledge Gap in Energy Efficiency within the Building Sector in Argentina. Copenhagen Centre for Energy Efficiency.*

**TABLE 9.4** Line of action for fine-tuning education programs to include energy efficiency skills in the transport sector

| Sr. no | Line of action |
| --- | --- |
| **Training and Awareness Raising Axis** | |
| 1 | Raise awareness (especially among officials and/or decision makers) by presenting usefulness of A-S-I framework as a means to achieve: energy savings. |
| 2 | Train officials to catalyse the application/implementation of new EE-Transport specific regulations. |
| 3 | Raise awareness of the student sector (advanced secondary school) about the training existing programs in EE-Transport to promote the development of career paths linked to the subject. |
| 4 | Train the teachers of training institutes, undergraduate and postgraduate courses. Integrate the topic corresponding to each educational level. |
| 5 | Offer more elective undergraduate subjects related to EE-Transport in the existing education programs. |
| 6 | Offer "packages" of elective subjects by subject (even in other degrees or institutions, in order to favour inter-institutional transversality). |
| 7 | Consolidate the EE-Transport orientation as part of the curriculum. |
| 10 | Incorporate contents related to EE-Transport in Technical and Vocational Education in line with the measures planned for the reduction of GHG emissions in the country associated with the reduction of energy demand |
| 11 | Design pedagogical strategies that favour the development of interdisciplinary work skills among professionals. |
| 12 | Ensure access to centralised/systematised and updated information on educational existing programs. |
| 13 | Develop a mechanism that includes periodic curricular updating in each institution. |
| 15 | Encourage research in master's and PhD Programs with targeted fellowships |

*Source: adapted from Schein, L., Asensio, M., Soler, G., Munshi, T., & Audia, I. (2021). Assessment of Skills and Knowledge Gap in Energy Efficiency within the Building Sector in Argentina. Copenhagen Centre for Energy Efficiency.*

The identification of gaps can then be translated into strategies for incorporating these skills into the taught programs. Table 8.4 presents the lines of action organised according to how the execution of each one contributes to or articulates specific skills. These lines of action need to be developed with stakeholders' consultation especially developed aspects related to the governmental and market spheres; it is considered pertinent that the measures proposed for the education sector, as the ultimate goal of this study, be complemented with others in those areas. This way, more comprehensive approaches are pursued, articulating with other extra-educational spheres, to strengthen the potential for implementation.

In the case of the educational lines of action, the measures to be developed focus on the adequate training of teachers, students, and practising professionals, through the consolidation of a technically sound, updated education that includes interdisciplinary skills. Regarding governmental actions, the proposals are oriented to establish and maintain the necessary conditions for developing the EEB sector.