Low-Carbon Transport – Health and Climate Benefits

FINAL version, March 1st 2016

Background paper for the Intergovernmental Ninth Regional Environmentally Sustainable Transport (EST) Forum in Asia

17-20 November, 2015

Kathmandu, Nepal

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Executive Summary

Emissions from road transport cause large problems in the Asian EST countries with an enormous impact on the health of people as well as climate change due to the contribution from road transport to greenhouse gases (health and climate resiliency). The objective of this Background paper is to provide an overview of the problems due to emissions caused by road transport and the possibilities for implementation of low-carbon transport solutions in Asia.

Outdoor air pollution levels in many Asian cities are far above WHO guidelines and the road transport sector is one of the contributors. Air pollution due to road transport is causing a range of acute and chronic health effects including heart disease and strokes, lung cancer and respiratory diseases, in particular in dense urban areas. This results, as is shown in this paper, in almost 100,000 premature death yearly in the Asian EST countries. The associated economic costs are estimated to be more than 81 billion US$. These estimates for premature death and economic impact are rather conservative and are based on some recent studies concerning the share of the road transport sector to outdoor air pollution.

The problem is expected to increase in the Asian EST countries due to the rapid motorisation taking place while it is decreasing in highly motorised countries due to among others stringent standards for emissions. The increasing health impact due to road transport pollution reduces the social, health and resilience of people in the cities. The estimated economic impact only concerns the health impact, so it does not include other types of pollution impacts like damage to agriculture, tourism, buildings etc..

In 2012 transport was responsible for 23% of global CO_2 emissions and road transport accounts for about 75% of these transport emissions. If the current emission trends continue the resultant increase in average global temperature could exceed 4°C by the end of century, which is well above the maximum increase of the recommended two degrees Celsius agreed in the Copenhagen Accord 2009. The resulting risks in extreme high sea levels and increasing numbers of heavy precipitation events in a number of regions in Asia in particular, will have a negative impact on public health, economy and environment in many areas.

The above negative impact of road transport emissions definitely justifies that mitigation strategies should be given rightful attention, including taking powerful, effective actions. Low carbon transport solutions have a significant potential to contribute to a reduction in global emissions. In this paper nine strategies have been defined leading to low carbon transport solutions:

1. Eco mobile city planning
2. Reduction in transport needs
3. Modal shift to more low-carbon or less energy intense transport modes
4. Energy-efficient and low-emitting vehicles
5. Higher occupancy and load per vehicle
6. Efficient driving
7. Low carbon fuels
8. Measuring and target setting
9. Management of sustainable transport.

Most of the measures within the various strategies aim to reduce both energy usage (so reducing CO_2 emissions - climate change impact) and road transport pollution (health impact). The strategies *"low carbon fuels"* and *"energy efficient and low-emission vehicles"* however also include measures with a special focus on reducing the health impact by introduction of cleaner fuels and technologies that limit the pollution from a vehicle. These strategies have been presented in detail in this paper.

Executive Summary

Almost all alternative fuel options presented in this paper, except for fuels and electricity based on coal, will gain public health and reduce greenhouse gas emissions. Which fuel and technology mix that will dominate in the future, is still an open question and it is not likely that there will be one single solution that will replace conventional oil-based fuels. Fuel quality is important to assure the consistency of the fuels, which is relevant for maintained efficiency, power and mechanical integrity over time in vehicles' engines as well as improve how fuels effect public health and environmental aspects. It is shown that in many Asian countries fuel requirements are much less demanding than in Europe.

Emission standards that deal with fuel consumption (CO_2 emissions) and pollutant emissions, are crucial to achieve more efficient and cleaner vehicles. This applies to all forms of motorized transport, so from heavy duty vehicles up to the lightest motorized two-wheelers. The importance of the implementation of more realistic driving cycles (like WLTP) in laboratory tests as well as introduction of real world driving emission (RDE) tests was shown. In addition it was noted that potential buyers of vehicles should be able to get independent reliable third party information about fuel economy and emission of pollutants of a vehicle.

Electrification/hybridisation of the vehicle fleet - assuming that electricity can be produced sufficiently clean - represents a powerful strategy to reduce emissions and is applicable to a wide range of transport options including public transport, distribution of goods in urban areas, light duty vehicles and in particular also 2- and 3-wheelers. The most affordable option are electrified 2-wheelers and in particular e-bikes. Large scale introduction and promotion of e-bikes on the longer term could replace motorcycles with a combustion engine.

The paper concludes with ten recommendations concerning, among others, the importance of implementing the Bangkok declaration goals, the importance of adequate fuel standards, the introduction of alternative fuels, introduction of electric and hybrid vehicles, introduction of stringent emission standards, availability of information on fuel efficiency and pollutants of a vehicle to consumers, modal shift to e-bikes, measures to promote the use of energy-efficient and low-emitting vehicles, and the importance or reliable air quality and health data in order to being able to take proper evidence based decisions on mitigation actions.

A number of the measures proposed in this paper will result in health benefits due to better outdoor air quality. However such measures may lead to negative effects concerning the protection of people in road accidents. This increased safety risk is for instance obvious in case of a large modal shift to NMT and e-bikes and therefore policies to minimize such negative impacts are needed.

Although on the long term an integrated system approach is needed, and will be much more effective than taking isolated measures, it is not recommended to wait until such an integrated strategy is available. Many of the provided examples of measures can already be introduced on the shorter term. It is recommended in any case that a "base-line" status is established and means to track progress and effectiveness are considered.

The recommendations given in this paper contribute to a number of the sustainable development goals (SDG's) since they contribute to achieving healthy cities (health resiliency) and since they contribute to the SDG concerning climate change, in other words meeting the 2 degrees C global warming target and in this way reducing the risk on extreme climate events (disaster resiliency).

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Acknowledgements

This study was funded by Chalmers University of Technology in Gothenburg, Sweden and Unites Nations Centre for Regional Development (UNCRD).

Abbreviations and acronyms

AAP	Ambient (Outdoor) Air Pollution
BC	Black Carbon
BEV	Battery electric vehicle
BRT	Bus Rapid Transit (an advanced bus system)
CBA	Cost Benefit Analysis
CBG	Compressed biogas
CH4	Methane (the dominating molecule in natural gas, biogas etc)
CI	Compression Ignition engines
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
COPD	Chronic Obstructive Pulmonary Disease
DALY	Disability Adjusted Life Year
DPF	Diesel Particulate Filter
DSP	Disease Surveillance Points (The People's Republic of China)
DME	Dimethyl ether (fuel option)
EC	European Commission
ERTRAC	European Road Transport Research Advisory Council
EST	Environmentally Sustainable Transport
ETBE	Ethyl tert-butyl ether (a gasoline additive based on ethanol)
EtOH	Ethanol
EU	European Union
EuroNCAP	European New Car Assessment Programme
FAME	Fatty acid methyl ester (biodiesel)
FCV	Fuel cell vehicle
FIA	Federation International d'Automobile
GBD	Global Burden of Disease
GCEC	Global Commission on the Economy and Climate
GDP	Gross Domestic Product
GHG	Greenhouse gases
GMS	Greater Mekong Sub region
GPF	Gasoline Particulate Filter
GTR	Global Technical Regulation
H2	Hydrogen
HC	Hydrocarbon (emissions of unburnt fuel)
HFO	Heavy fuel oil (conventional bunker oil for ships)
HVO	Hydrotreated vegetable oil (biodiesel)
ICEV	Internal combustion engine vehicle (conventional engine)
ICT	Intelligent Communication Technology
IHME	Institute for Health Metrics and Evaluation
ISO	International Organization for Standardization
ITF	International Transport Forum
ITS	Intelligent Transportation System
LBG	Liquified biogas
LCA	Life Cycle Assessment

LCT	Low Carbon Transport (low emissions of CO_2, CO, CH, PM)
LDV	Light Duty Vehicle (passenger car)
LMIC	Low and Middle Income Countries
LNG	Liquified natural gas
LPG	Liquefied petroleum gas (a common gas for cooking stoves)
LRT	Light Rail Train
MGO	Marine gas oil (a diesel alternative for ships with lower sulphur content than HFO)
MTBE	Methyl tert-butyl ether (a gasoline additive based on methanol)
N2O	Nitrous Oxide
NEDC	New European Driving Cycle
NCAP	New Car Assessment Program
NGO	Non-Governmental Organization
NH3	Ammonia
NMT	Non-Motorized Transport
NO_x	Nitrogen oxides, e.g. NO, NO_2 etc.
OECD	Organization of Economic Cooperation and Development
PHEV	Plug-in hybrid electric vehicle
PM	Particulate matters (solid particles, so called soot, and liquid particles)
PM_{10}	Particles up to the size of 10 micrometers.
PPM	Parts per million (concentration unit)
PPP	Purchasing power parity
RME	Rapeseed methyl ester (one type of FAME fuel)
SAFER	Vehicle and Traffic Safety Centre at Chalmers (Sweden)
SCR	Selective Catalytic Reduction
SI	Spark Ignition engines
SME	Soy methyl ester (one type of FAME fuel)
SO2	Sulphur dioxide
Syn-diesel	Synthetic diesel produced from e.g. natural gas, coal or biomass
TRIPP	Transportation Research and Injury Prevention Programme (India)
TTW	Tank-to-wheel (part of a WTW analysis)
TWC	Three Way Catalysts
UIC	International Union of Railways
UNCRD	United Nations Centre for Regional Development
UNECE	United Nations Economic Commission for Europe
UNRSC	United Nations Road Safety Collaboration
VSL	Value of Statistical Life
WHO	World Health Organization
WLTP	Worldwide harmonized Light vehicles Test Procedures
WTW	Well-to-wheel (a simplified LCA analysis)
YLD	Years lived with disability
YLL	Years of life lost

1 Introduction

1.1 Global transportation trends, health and climate impacts and objectives

Expected increases in income & population will push the world energy consumption to much higher levels compared with today and the increasing number of vehicles is one important contributor to global warming, since conventional vehicles emit fossil CO_2 to the atmosphere. Conventional vehicles do also contribute to air pollution, which has become a major issue, in particular in large cities.

The key drivers for the growing demand for transportation are population growth and increase in income per person. Figure 1 shows predictions for global population, GDP (Gross Domestic Product) and vehicle growth to 2035 according to the BP energy outlook 2035 [1]. In this period the population is expected to increase to 8.7 billion, an increase of more than 20% compared to 2015. The GDP is about to double in this period, like the number of vehicles (passenger cars and commercial), which is expected to increase from around 1.2 billion today to 2.4 billion by 2035. Most of the vehicle growth will happen in the developing world (88%) [1]. The yearly sales worldwide of motor vehicles in 2014 was around 45 million of which about 25% commercial vehicles [2]. Yearly global sales of motorcycles (including e-bicycles) is forecasted to 132 million units in 2018 [3] and electric two-wheel vehicles (e-scooters, e-motorcycles, and e-bicycles) take a large share in this, in particular in The People's Republic of China.

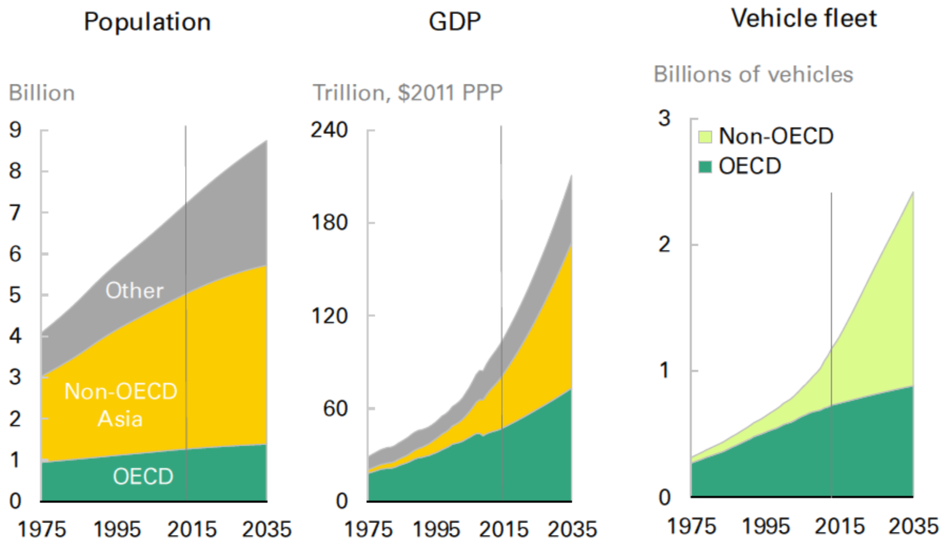


Figure 1 Predictions for global population, GDP expressed in purchasing power parity (PPP) and vehicles growth for OECD and non-OECD countries from 1975-2035 [1]

The increasing motorisation and corresponding energy demand will, if no further measures are taken, lead to a further increase in health problems due to outdoor air pollution in particular in cities and an increase in Greenhouse Gases (GHG) effecting the world climate. Main contributor to GHG is CO_2.

Ambient (outdoor) Air Pollution (AAP) is associated with a range of acute and chronic health effects including heart disease and strokes, lung cancer and respiratory diseases [5]. According to the World Health Organisation (WHO) AAP caused in 2012 about 3.7 million premature death [6]. This health impact due to AAP is much larger than was estimated some years before [UNEP Year book 2014]. Premature death are defined by WHO as the number of death that could have been reduced if Particular Matter (PM) concentrations would have been below the recommended maximum values for PM concentrations defined in the WHO Air quality guidelines [8]. According to the OECD the economic costs calculated for the value of lives lost and ill health due to AAP is estimated to 3.5 trillion USD dollars in the OECD countries, People's Republic of China and India combined [9]. This estimate only concerns health impact from AAP, so it does not include other types of pollution impacts like damage to agriculture and forests, tourism, buildings etc.. Note that the above estimates for premature death and economic costs are for AAP caused by all sectors including power generation, agriculture, residential energy, natural causes, industry, biomass burning and transport. See for instance a study of Lelieveld et al. (2015) in Nature [10] for an analysis on the contribution of various sectors to AAP. Estimates for the health impact in Asia specifically caused by road transport pollution have not been found in literature. Such estimates are needed in order to perform cost-benefit analyses for measures that would reduce transport pollution. Therefore an estimate on this will be made in Chapter 5.

In the period 1991-2010, CO_2 global emissions in the transport sector increased by almost 50% [17]. In 2012 transport was responsible for 23% of global CO_2 emissions. Road transport accounts for about 75% of these transport emissions [11] and this is expected to be the case also in 2035 [17]. According to Global Commission on the Economy and Climate (GCEC), if the current emission trends continue as usual, the resultant increase in average global temperature could exceed 4°C by the end of century [14] compared to pre-industrial time. This is well above the maximum increase of two degrees Celsius coming out of the reports of the Intergovernmental Panel on Climate Change (IPCC) [15] and agreed on in the Copenhagen Accord 2009 by the world's countries [16]. Changes in extreme weather and climate events have been observed since about 1950, including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea levels and an increase in the number of heavy precipitation events in a number of regions [15]. It will be clear that such events may have negative impact on public health, economy and environment. Both considering the direct health impact due to emissions as well as the negative impact on climate change, low carbon transport will be crucial in any future road transport strategy.

Another negative impact from road transport is the risk of injuries due to accidents. Recent WHO and IMHE-World Bank publications estimate that worldwide around 1.3 million people die every year due to injuries in road accidents, while almost 80 million are injured, often with long-term disabilities as a consequence [4]. The number of fatalities and injuries is predicted to increase in low and middle income Asian countries due to the increased motorisation [4].

The general objective of this Background paper is to provide an overview of the problems due to emissions caused by road transport and the possibilities for implementation of low-carbon transport solutions in Asia. The paper is based on an extensive review of recent research and policy studies in this field. The focus of the paper is on health effects. The Bali declaration, an output from the 7th Regional Environmentally Sustainable Transport (EST) Forum in Asia in Bali in 2013, introduced the "Vision Three Zero's - Zero Congestion, Zero Pollution, and Zero Accidents - towards Next Generation Transport Systems in Asia" [18]. This paper aims to better guide and support Asian countries for the effective implementation of "Zero Pollution" vision.

Specific objectives of this Background paper include to:

- Provide a brief insight in global population and transportation trends, their climate and health consequences (in this section) and provide an overview of Background papers dealing with this topic at recent meeting of the EST forum (Chapter 1.2).
- Describe the various types of transport emissions and the various climate and health consequences (Chapter 1.3).
- Discuss the status of low-carbon transport in Asia with the focus on low and middle income countries (Chapter 1.4) and discuss resiliency of cities in Asia in relation to a sustainable transport system (Chapter 1.5).

- Present a framework for strategies, including examples and case studies, to reduce CO_2 and pollution originating from transportation (the so-called Low Carbon Transport (LCT) strategies) (Chapter 2) and present a number of these strategies in more detail with the focus on fuels (Chapter 3) and vehicle technologies and emission testing (Chapter 4).
- Provide an insight in the health impact of transportation pollution in Asia and the cost-benefit of investments to improve low-carbon transport (Chapter 5).
- Discuss the Way Forward by means of a number of concrete recommendations concerning low-carbon transport solutions in Asia and how they link to the post-2015 development agenda / new global Sustainable Development Goals (SDG's) (Chapter 6).

1.2 Brief Review of recent EST Background papers in this field

Low-carbon transport in relation to health and climate has been discussed in a number of Background Papers at recent meetings of the Regional EST Forum, including:

- Bongardt et al. [19] at the 5th EST Forum in 2010 in Bangkok, discussing the problem of GHG emissions and introducing the **Avoid**, **Shift** and **Improve** strategies to reduce GHG emissions. These Avoid, Shift and Improve strategies were applied to present the 20 EST goals in a structured way in the Bangkok 2020 declaration. See also Chapter 6 "The Way Forward" later in this paper.
- Punte et al. in 2010 [20] and 2011 [21] discussing climate impact and health effects due to pollution caused by **Freight** transport in Asia. Data on vehicle caused $PM_{2.5}$ in selected Asian cities and data on Diesel usage in Asian countries were provided. Measures were proposed that, among others, improve the fuel economy of trucks, reduce air pollutant emissions and promote shifts from road freight to more low-carbon transport modes like rail and waterways.
- Veitch and Craven [23] in 2013 and Craven et al. [25] in 2014, representing the International Union of Railways (UIC), discussing **Rail transport** in relation to GHG and pollution. In the 2013 paper, among others, a number of case studies from The People's Republic of China, US, India, the Russian Federation, and Japan were presented. In the 2014 paper it was noted that Rail transport is one of the most sustainable means of transport. Railways worldwide emit only 3.3% of the total transport sector CO_2 emissions, while having a modal share of 9.3%. The UIC members worldwide have voluntary agreed to reduce CO_2 emissions from train operations by 50% in 2030 (relative to a 1990 baseline) and by 75% reduction in 2050 (relative to a 1990 baseline).
- Wittink et al. [26] in 2013, discussing **cycling** as transport mode with the focus on India. It was stressed that NMT (non-motorized transport), which includes walking, cycling, cycle-rickshaws etc., has no direct GHG emissions at all, while these transport modes constitute about 39 percent of trips in urban India. It was however also realized, while in many European cities the number of cycling trips is increasing due to prioritizing bicycling as a mode, in a number of Asian cities the contribution of cycling as a transport mode is decreasing.
- Wolter [27] in 2014, providing an introduction of the potential of **electric mobility** for sustainable transport in Asian cities as well as a number of case studies in Asia. The paper includes general data on population, vehicle and vehicle growth worldwide as well as in Asia and emission trends to 2030 including health risks. A brief introduction in e-mobility options is given, including e-bikes as well the environmental benefits. The paper concludes with a number of general recommendations for policy makers.
- Replogle, and Fulton [28] in 2014, providing an extensive overview of the benefit on emissions of an urban passenger **transport mode shift to public transport and NMT**. The study compares two future scenarios: a baseline urban scenario (the IEA ETP 2012 MoMo 4°C global warming scenario - 4DS) and a newly developed scenario called "High Shift" (HS), with has a much larger contribution of clean public transport and NMT. The main finding is that the HS scenario (at least

in the developing world) provides similar total mobility as the baseline scenario and on the other hand will sharply reduce CO_2 emissions and environmental ills.

1.3 Introduction in transport emissions

Internal combustion engines are major sources of air pollution. Combustion of fossil energy (natural gas, crude oil and coal) leads to climate change and air pollution. There are two principal classes of exhaust emissions; those that have a global impact, i.e. carbon dioxide CO_2 which is a greenhouse gas, leading to climate change and those operating locally / regionally i.e. oxides of nitrogen (nitric oxide, NO, and nitrogen dioxide, NO_2, these are collectively termed NO_x), carbon monoxide (CO), unburnt fuel, i.e. hydrocarbon (HC) emissions and particulate emissions (PM), leading to health effects. The transport sector on road are responsible for 17-18% of the global emissions of CO_2, and the share is growing.

Carbon dioxide (CO_2) and Water (H_2O) are the main exhaust products after combustion (together with nitrogen – N_2). Carbon dioxide together with methane (CH_4) and Nitrous Oxide (N_2O) are counted as greenhouse gases where Carbon dioxide is the dominating specie. Carbon dioxide emissions are proportional to the fuel consumption of the vehicle for a hydrocarbon fuel (e.g. gasoline and diesel).

Carbon monoxide (CO) is a poisonous gas that is a major air pollutant in most urban areas. It results from incomplete oxidation of the carbon atoms in the fuel (hydrocarbons). For Compression Ignition (CI) engines the carbon monoxide emission is in general relatively low due to lean combustion and air excess while Spark Ignition (SI) engines emits significant amounts due to stoichiometric or close to stoichiometric operation.

Hydrocarbon emissions (HC) are unburned or partially burned hydrocarbon fuel that escapes combustion. HC is participating in smog and ground-level ozone formation through reactions with nitrogen oxides in the presence of sun light, some of the hydrocarbons are also toxic. Example of toxic hydrocarbons are benzene, Formaldehyde and 1,3-butadiene. Generally SI engines emit much more HC than CI engines. Especially two-stroke SI engines emits very high amounts of HC through so called short-circuiting, meaning that the mixture of fuel and air sometimes passes the engine without being burned. HC emissions for a two stroke engine can be almost 10 times higher than for a four stroke engine, which also leads to poor fuel efficiency.

Nitrogen oxides (NO and NO_2) is caused by oxidation of atmospheric nitrogen at high combustion temperatures. Nitrogen oxides forms together with hydrocarbons smog (photochemical) and ground-level ozone. Nitrogen oxides in the air can significantly contribute to environmental effects such as acid rain. Nitrogen dioxide can irritate the lungs and lower resistance to respiratory infections.

Sulphur dioxide (SO_2) is a reactive gas known as "oxides of sulphur". The largest sources of SO_2 emissions are from fossil fuel combustion at power plants, but also from burning high sulphur containing fuels. SO_2 is linked with a number of adverse effects on the respiratory system.

Particulate Matter (PM) are solid or liquid particles found in the exhaust gases. Some particles are quite large, around 10,000 nm. Particles of this size can lead to irritation of the respiratory system but it is the particles of smaller size that gives serious health effects (these particle sizes are generally invisible). Particles less than 2500 nm in diameter ($PM_{2.5}$) are referred to as "fine" particles and are believed to pose the greatest health risks for humans. Combustion generated particles often vary between 10 and 1000 nm in size. Particulates is a serious problem in Diesel engines but not for gasoline engines except for direct injected gasoline engines. Particulates from Diesel engines are of two kinds; solid particles, so called soot, and liquid particles that consists of unburned fuel and lubrication oil that escapes combustion.

Soot is formed during diffusion controlled combustion at rich conditions and intermediate temperatures, conditions that exists in the spray centre. Two parameters characterize particulates: mass and number of particles. The major component in soot is Black Carbon (BC), BC consists of pure carbon and is generally of small size ($PM_{2.5}$). BC is the most effective form of PM, by mass, at absorbing solar energy (million times more than carbon dioxide). Soot is formed during diffusion controlled combustion of fossil fuels, biofuels, and biomass at rich conditions and intermediate temperatures, conditions that exists in the spray centre.

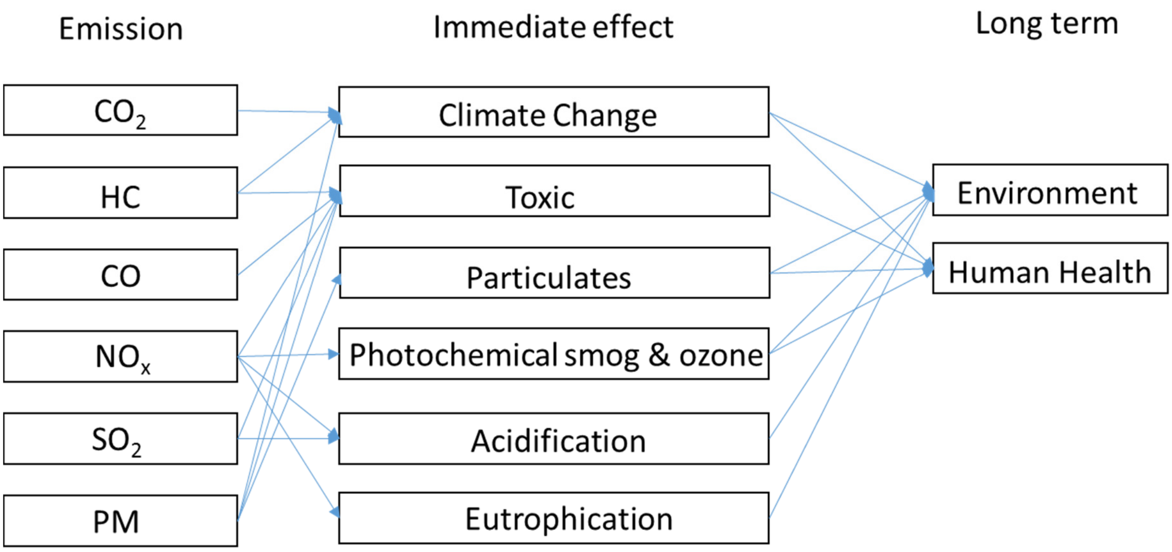


Figure *2* gives a summary of the major emissions from transportation and their effects.

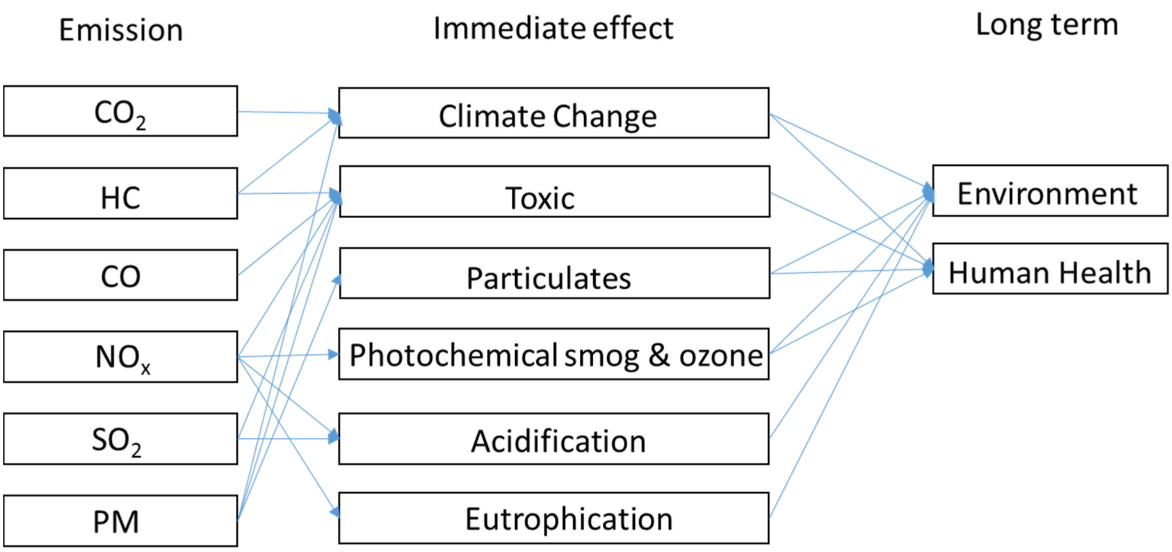


Figure 2 The most important emissions from combustion engines and immediate and long term effects

Today exhaust emissions from SI-engines is typically treated with so-called Three Way Catalysts (TWC). The catalyst converts the pollutants CO, NO_x and HC into non-toxic compounds like carbon dioxide (CO_2), water (H_2O) and nitrogen (N_2) by catalytic reactions. The ratio between air and fuel must be exactly such that all oxygen molecules are consumed, i.e. a so-called stoichiometric mixture. Oxygen-sensors control the air fuel ratio of the engine and catalyst performance in order to get highest possible conversion of the pollutants. A prerequisite to use catalytic converters is that the fuel is low sulphur because the sulphur poisons the catalyst.

CI (Diesel) engines are always operated with air excess (more air than what is needed to fully oxidize the fuel). The exhaust emissions of CI engines (especially heavy duty engines) is often first treated with an oxidation catalyst (CO and HC) and the NO_x emissions are treated by using Selective Catalytic Reduction (SCR) where ammonia is used to reduce NO_x. The ammonia is generated on board the vehicle using urea ($CO(NH_2)_2$). The ammonia (NH_3) is formed from urea by thermal hydrolysis.

CI-engines and direct injection SI-engines emits apart from gaseous pollutants Particulate Matter which can be removed by a Diesel Particulate Filter (DPF) or a Gasoline Particulate Filter (GPF) for SI-engines.

1.4 Emissions in Asia

In this paper the focus will be on urban areas where health problems caused by transportation are much larger than in rural areas. The world's urban population now is almost 4 billion and is expected to reach 6.3 billion in 2050 [29]. This growth in particular will take place in Asia and Africa where Asia is expected to be 64% urban in 2050 [29]. The People's Republic of China now has the largest urban population in the world (758 million), followed by India (410 million). The vehicle fleet in Asia is increasing much faster than many other areas of the world. For instance in The People's Republic of China passenger vehicle ownership per 1000 people is expected to increase almost 8 times - from 40 to 310 - in the period 2010-2035 [17]. Due to rapid motorisation Asian cities experience large problems including traffic congestion, pollution and traffic accidents.

In 2010 about 2/3 of global CO_2 emissions in the world was originating from just 10 countries and many of these countries are in the Asia region including The People's Republic of China, India, The Russian Federation and Japan [11]. The People's Republic of China has the largest share namely 26% of the world's total CO_2 emissions [11]. In many countries in Asia the yearly CO_2 emission is increasing. In The People's Republic of China for example in the period 2011-2012 the increase of CO_2 emissions was 3.1% and in the rest of Asia even 4.9% [11]. Freight transport contributes for about 24% to the CO_2 emissions from vehicle transport [21].

The health risk due to pollution can be directly linked to fine particulars $PM_{2.5}$ values. PM_{10} values are available for many cities in the WHO air pollution database and from these PM_{10} values, estimates for $PM_{2.5}$ values can be made in order to assess the health risk [12]. Figure 3 shows an overview of average annual PM_{10} levels in major cities in the world in 2012 based on WHO data in the UNEP 2014 yearbook [30]. The WHO air quality guideline level for PM_{10} is: 20 micrograms per cubic meter (µg/m3) and this level is exceeded in all major cities. For a number of the mega cities in Asia it is exceeded by more than a factor 5 and in Delhi and Lahore even by a factor 10. For $PM_{2.5}$ the average annual level in the guidelines is 10 µg/m3 and 25 µg/m3 for a 24 hour period. Air pollution levels in cities in LMIC's in Asia sometimes far exceed these levels. For example in Kathmandu $PM_{2.5}$ levels of over 500 µg/m3 have been recorded [30].

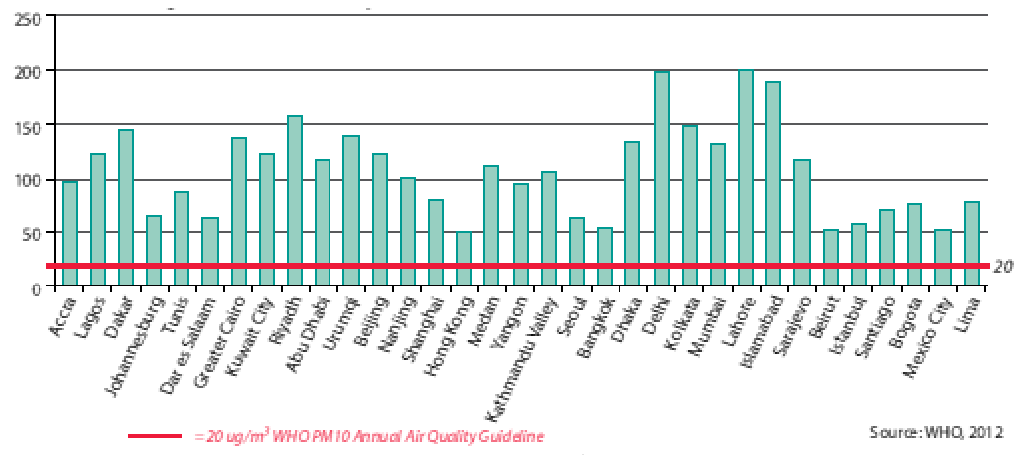


Figure 3 Annual average PM_{10} levels for major cities in 2012 [30]

Worldwide AAP levels were already high in 1990. They have declined considerable in the period 1990-2010 in Europe and North America, but have increased further in South and East Asia in this period [7].

Of the 3.7 million premature death attributable to AAP in 2012, estimated by WHO, the Western Pacific Region (which includes The People's Republic of China) takes the largest share with 1.67 million death followed by South East Asia (including India) with 936,000 death [6]. The relative risk - defined as premature death per 100,000 capita – is the largest in West Pacific Lower and Middle Income (LMI) Countries [6]. The costs due to AAP in 2010 is equivalent to 9.7–13.2% of The People's Republic of China's GDP and for India equivalent to 5.5–7.5% of its GDP [9]. Note that the estimates for number of premature death and costs is for the impact of AAP as a whole, so including traffic pollution (in particular diesel engines), power plants, industrial pollution, forest fires etc.

1.5 Sustainable and Resilient cities

Many of the Asian low and middle income countries and cities are highly vulnerable to natural disasters and climate impacts. According to UNESCAP Asia and the Pacific are the regions with the highest risk of disasters [31]. The risk of a person living in these areas to be affected by a disaster is almost 30 times as high as for a person living in North America or Europe. Resilient cities have the capacity to reduce vulnerability to disaster risk and extreme climate events, and respond fast, efficient and in creative ways to disasters, and have the ability to adopt well to changing circumstances in order to increase long-term sustainability [32]. Resiliency is one of the important characteristics of a sustainable city.

A sustainable transport system is a crucial prerequisite of a sustainable city. It offers people living in the city a healthy and safe environment by minimizing the health consequences of transport pollution and reducing the negative impact on the climate by minimized GHG emissions. But the reality is that in many of the Asian low and middle income countries, urban growth is unplanned, unstructured, and poorly managed. Such unmanaged expansion of urban growth leads toward inefficient and sprawled patterns of urban development. This is largely unsustainable, and imposes a range of significant economic, social and environmental costs, as was shown earlier in this chapter.

Various organisations, including UNCRD, support and promote the development of sustainable cities. One of these organisation is ICLEI - Local Governments for Sustainability, with more than 1000 members from urban regions, small as well as large cities, including 10 megacities, in 84 countries all dedicated to sustainable development. ICLEI has developed an action plan – the ICLEI Seoul Strategic Plan 2015-2021 – that consist of 10 priority area's (agenda's) that define actions to secure and enhance sustainability of cities at the local and global level [33]. Within this Plan a Resilient City agenda is included that requires evidence-based, long-term, and inclusive strategies for an integrated, systems approach to reduce vulnerability and disaster risk, while increasing adaptive capacity in line with sustainable development goals. In three of the other ICLEI agendas sustainable transport system in cities are addressed: the Low-carbon City Agenda, the Smart City agenda and the EcoMobile City (Sustainable Urban Mobility) Agenda.

The vision of the Low-carbon City Agenda is that all ICLEI members shall become low-carbon cities. A low-carbon city utilizes a step-by-step approach towards carbon neutrality, urban resilience and energy security, supporting an active green economy and stable green infrastructure. A Smart City has embedded "smartness" into its operations and is guided by the overarching goal of becoming more sustainable and resilient. A smart city monitors, analyses and optimises its urban systems including transportation and polluting emissions. The EcoMobile City (Sustainable Urban Mobility) Agenda aims to create more liveable and accessible cities by utilizing sustainable urban mobility principles to achieve significant reduction in GHG emissions and energy consumption, improvements to air quality, better use of public space and increased mobility opportunities for all citizens. Priority is given to integrated, socially inclusive, and environmentally friendly transport options including walking and cycling and wherever possible, integrates shared mobility as an integrated alternative personal automobile use [33].

2 Low Carbon Transport Solutions

2.1 Background and strategies for low carbon transport solutions

In this section a framework of strategies for low carbon transport solutions will be presented. There are multiple strategies and measures for achieving reduction of emissions from the transport system. The amount of emissions emitted depends on the following three parameters:

- The number of **km** (kilometres) **travelled**
- The amount of **energy used per km** travelled. For example a small light passenger car uses less energy than a heavy SUV (Sport Utility Vehicle)
- The amount of emissions emitted per energy unit: the **emission intensity**. For example the emission intensity of fuels produced from natural gas is less than that of coal in a well-to-wheel perspectives.

The **energy demand** depends on the number of km travelled multiplied with the amount of energy used per km. The amount of emissions depends on the amount of energy used – the **energy demand -** multiplied with the emission intensity. A reduction in any of the three categories “km travelled”, “energy use per km” and “emission intensity” will lead to a reduction of emissions from the transport system. This is illustrated in Figure 4 which can be seen as a framework of strategies for Low Carbon Transport (LCT) solutions. Seven important strategies that would contribute to LCT are:

1. Eco mobile city planning
2. Reduction in transport needs
3. Modal shift to more low-carbon or less energy intense transport modes
4. Energy-efficient and low-emitting vehicles
5. Higher occupancy and load per vehicle
6. Efficient driving
7. Low carbon fuels

In addition to the seven LCT strategies a number of cross-cutting strategies can be distinguished. Two important ones related to the scope of this Background paper are:

8. Measuring and target setting
9. Management of sustainable transport.

Such cross-cutting strategies themselves will not lead on their own to reductions in emissions but they are crucial for a number of the other strategies to be effective and to initiate and manage an integrated comprehensive approach where in an optimal way the various strategies are combined in order to achieve an optimal health and climate benefit.

An alternative way of presenting the strategies is the “Avoid-Shift-Improve” approach [19] [34]. “Avoid” deals with avoiding increased transport activity and reducing the need for travel (transport system level efficiency), “Shift” deals with actions that result in shifts to mode of transports that result in less emissions (travel/transport efficiency) and “Improve” deals with actions that improve vehicles and fuel performance (vehicle efficiency). We have categorized the LCT strategies according to the Avoid-Shift-Improve division and this is indicated by colours in Figure 4.

Table 1 defines the nine resulting LCT strategies in some more detail and/or illustrates the scope of a strategy by some examples of measures belonging to a strategy. In the remaining part of this section some examples related to various strategies will be given. A detailed presentation for two of the strategies: “Low carbon fuels” and “Energy-efficient and low-emitting vehicles” will be given in Chapters 3 and 4, respectively.

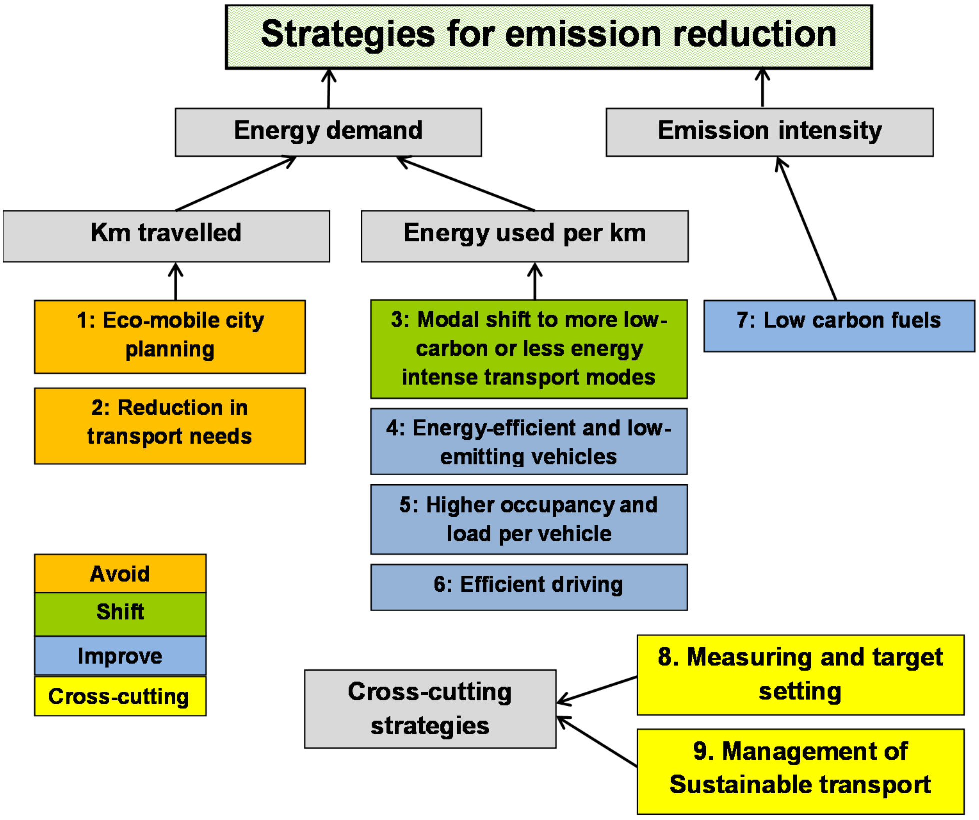


Figure 4 LCT strategies to reduce emissions from the transportation sector based on km travelled, energy used per km and emission intensity.

Table 1 Overview of Low Carbon Transport (LCT) strategies

LCT Strategy	Description/Examples
1: Eco mobile city planning	Efficient land use planning to reduce transport energy, safe environments, promote living close to work, high density living areas with adequate efficient public transport, separate lanes for pedestrian, cyclists and other slower traffic modes etc..
2: Reduction in transport needs	Use of ICT to replace physical meetings and avoid travelling, telecommuting (working from home), medical consulting/monitoring on the distance, shopping in web shops, longer trucks etc..
3: Modal shift to more low-carbon or less energy intense transport modes	Promote shifts to low energy and zero energy modes - public transport and Non-Motorized Transport (NMT). Make NMT and public transport more comfortable, safe, efficient and affordable, Eco zones in cities, road pricing, bike share programs, separate bike lanes, measures that discourage private car use, efficient intermodal connectivity, freight shift to modes that use less energy (rail, ships) etc..
4: Energy-efficient and low-emitting vehicles	More efficient vehicles (all categories), lighter vehicles, better tires, less friction and realistic emission standards for new and used vehicles, phase out older vehicles, etc..
5: Higher occupancy and load per vehicle	Increase occupancy rates of passenger cars, buses and other vehicles, better truck logistics to avoid empty trucks, special lanes for high occupancy vehicles etc..

6: Efficient driving	Eco-driving, speed limits including efficient enforcement, synchronized traffic lights, separation of transport modes having different speeds, optimal traffic flows, platooning vehicles etc..
7: Low carbon fuels	Increase the use of more sustainable fuels and the use of electricity for propulsion.
8: Measuring and target setting	Monitoring the health impact from traffic pollution, traffic intensities, air quality etc. and defining appropriate standards if applicable like air quality standards near high traffic concentrations etc..
9: Management of sustainable transport	An integrated system approach to develop and implement measures to reduce emissions from road transport incl. a lead agency for sustainable transport, promotion of strong cooperation between various actors on city and national level, capacity building, institutions for R&D and testing, promotional campaigns, financing and tax mechanisms, coordination with other agencies dealing with energy reduction and pollution etc..

2.2 Examples from some of the LCT strategies

An illustration of the strategy *Eco-mobile city planning* is given in Figure 5. The relation between urban density and transport-related energy consumption is shown for various cities in the world, indicating that a city with a higher urban density is usually associated with lower energy consumption per capita [35].

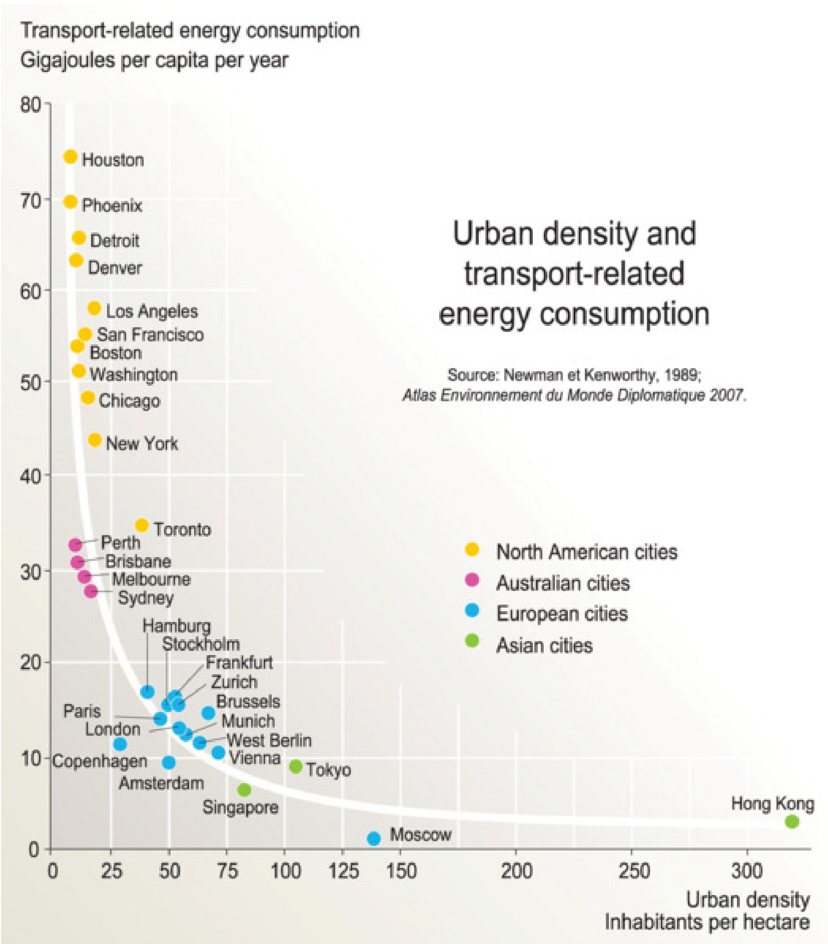


Figure 5 Relation between urban density and transport-related energy consumption per capita [35]

An illustration of the strategy *Reduction in transport needs* is telecommuting. According to a global poll conducted by Ipsos for Reuters News, using an online survey methodology where a total of 11,383 employees from 24 countries participated, finds that telecommuting appears to be quite popular in emerging markets. The term "telecommuting" is used to describe when an employee uses a computer to do their office work from a location outside of their office. The results show that in countries like The People's Republic of China and Indonesia more than 70% of the people interviewed are of the opinion that telecommuting is more productive than working at the office (see

Figure *6*) [36].

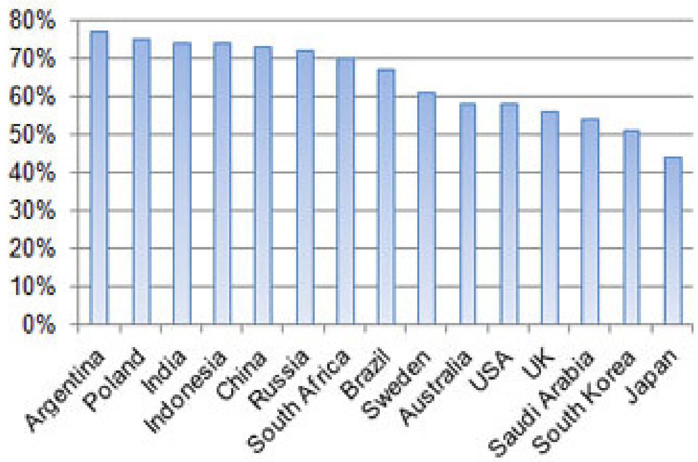


Figure 6 Results from a poll illustrating that in many countries people are of the opinion that telecommuting is more efficient than working at the office [36]

An example of the strategy *Modal shift to more low-carbon or less energy intense transport modes* is walking and pedal cycling which are by far the most sustainable transport modes since energy use and emissions are minimal. Moreover these forms of active transport are healthy according to a number of studies as long as pollution levels are acceptable at the locations where walking and biking takes place and the injury risk due to accidents is acceptable. See Mueller et al [37] for a literature review of health impact assessment of active transportation. Unfortunately in many Asian cities cycling has lost popularity in the last decades as was shown by [26] in contrast to many high income countries where the popularity of cycling is increasing.

How do various transport modes compare with each other concerning energy use and emissions? Figure 7 shows a comparison of energy efficiency for different modes of motorized transport per passenger-kilometre derived from [28]. Urban buses and minibuses are assumed to have an occupancy of 50% and cars 1.5 occupants (Average of OECD and non-OECD baseline in this study). The figure also includes electric bikes (e-bikes) which are becoming very popular in many countries in Europe and in The People's Republic of China. It can be seen that e-bikes are by far the most efficient way of motorized transport. Light duty vehicles (LDV) are more than 20 times less efficient than e-bikes and at least 4 times less efficient than public transport. So shifts to public transport, e-bikes and NMT will cut energy demand and thereby emissions significantly.

In order to get an impression of the effect of transport mode shift it is suggested to visit the UIC websites: http://www.ecotransit.org and http://www.ecopassenger.org. These websites allow to calculate and compare the environmental impact for different transport modes, both for freight and passenger transport, in case of a specific trip from one place to another [21].

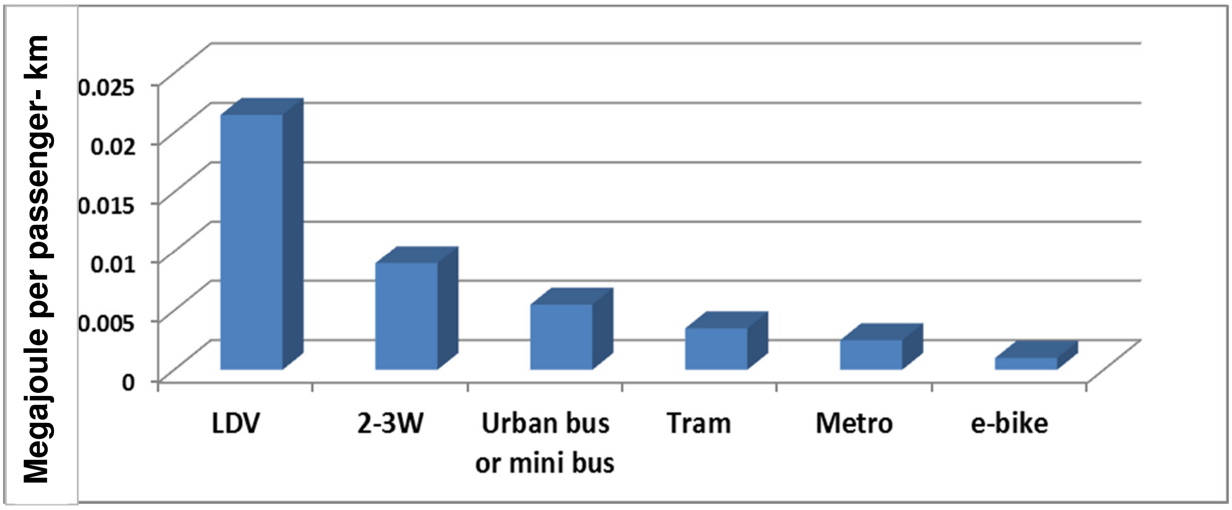


Figure 7 Comparison of energy efficiency for different mode of transport by passenger-kilometre based on Replogle et al. 2014 EST conference [28]. LDV: Light Duty Vehicle

Examples illustrating some extreme cases of the strategy *higher occupancy and load per vehicle* are shown in Figure 8.

Figure 8 Examples of a high occupancy and load per vehicles

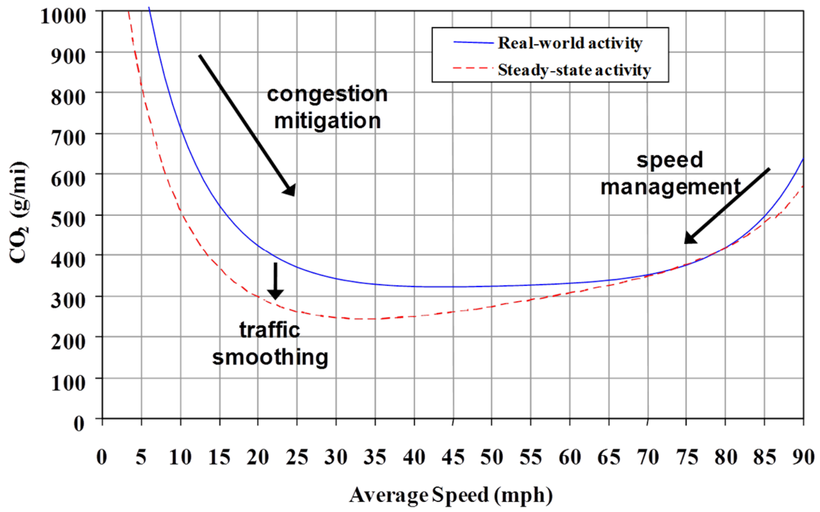


Figure 9 Relation between speed and CO_2 emissions for passenger cars, running on conventional oil-based fuels, with 3 different speed control measures. Note that the speed is in miles per hour (mph) [38].

An example of the strategy *efficient driving* is speed management. The speed that a vehicle is driving effects the emissions per distance travelled. The relation is shown in Figure 9 for CO_2 emissions [38]. If the speed increases above 70 miles per hour (113 km/h) the efficiency of the vehicle is rapidly decreasing and by introduction of speed limits, which should be strictly enforced, significant reductions in CO_2 emissions, as well as other types of emissions, can be achieved. As will be shown in Chapter 4, emissions of NO_x will strongly increase at speeds above 120 km/h. For speeds below 20 miles per hour (32 km/h) the efficiency of the vehicle also decreases rapidly and by congestions mitigation as is illustrated in the same figure improvements could be obtained. In practice in high density cities this can, however, only be achieved if private car usage can be significantly decreased (transport mode shift strategy). Traffic smoothing, meaning reducing the number of acceleration and deceleration events, will harmonize speeds and improve the engine efficiency, and this can be done by synchronized traffic lights and electronic speed recommendations.

2.3 Case studies and best practices

There are many good examples of low carbon transport case studies and best practices in Asia including examples of technology transfer and international research cooperation. Transportation policies aiming at low carbon transport solutions will require sophisticated inter-disciplinary research efforts and cross-disciplinary communication. In order to illustrate the possibilities and the involvement of the various Asian countries an overview of a number of initiatives is provided in Table 2. Also some of the boxes in this Background paper include examples.

Table 2 Overview of some case studies and best practices in Asia in the field of low carbon transport solutions

Region/Country/City	Description	More information
Worldwide	**Urban Electric Vehicles Initiatives:** the EV City Casebook presents case studies on city and regional EV deployment efforts around the world like in Shanghai	See Box 2
Nepal	**SAFA Tempo - Three Wheeler Electric Vehicles**: were introduced in Kathmandu valley in 1996. Currently there are more than 600 SAFA tempos and around 120,000 passengers daily use the services on different routes within the city.	Ref. [71]
The Philippines	**Energy Efficient Electric Vehicles Project:** development and introduction of electronic tricycles running on lithium-ion battery technology with solar and grid-connected charging stations. Costs: 504 mullion US$, funding provided by Asian Development Bank and Clean Technology Fund. Fully operational by 2017	Ref. [72]
PR China	**Banning of motorcycles in cities**: the use of motorcycles is banned or restricted in over ninety major cities in the People's Republic of China in order to reduce traffic congestion, improving safety and reducing air pollution. This banning of motorcycles appeared to be one of the major drivers for the electric bike boom in China.	Ref. [73]
PR China	**How carbon pricing can produce benefits:** by calculating among others the health impact of motorized transport (due to air pollution and accidents) it was found that for Beijing congestion charges and fuel taxes could bring a benefit of \$6.5–\$13.56 billion a year.	Ref. [74]
India	**Railway Contribution to Sustainable Development in India:** The Indian Railways Vision 2020 includes measures concerning low carbon transport solutions. For instance an additional 14,000 km of track will be electrified, allowing a reduction in emissions and a shift to low carbon energy sources. It also sets targets of a 15% improvement in energy efficiency and also taking 10% of energy from new and renewable sources.	Ref. [23]
Viet Nam, Thailand, Lao PDR, Cambodia	**Green Freight in the Greater Mekong Sub region (GMS):** from 2010-2014 a green freight feasibility analyses was conducted under the GMS Core Environment Program. One conclusion was that efficient road freight offers a major opportunity to reduce GHG emissions from the transport sector in this region. Three target areas to improve fuel efficiency of road freight are technology, logistics management and driver capacity.	[75]
Delhi/London	**Public health benefits of active travel and low emission vehicles:** Comparative Risk Assessment methods were applied to estimate the health e□ects of alternative land transport scenarios in Delhi and London (UK). It was found among others that policies to increase the acceptability, appeal, and safety of active urban travel, and discourage travel in private motor vehicles would provide larger health benefits than policies that focus solely on low carbon vehicles.	See Box 5
India	**Costs and Benefits of Cleaner Fuels and Vehicles in India:** this study showed that the benefits of cleaner fuels and vehicles in terms of reduced healthcare costs and higher productivity, far outweighs the costs of investments in refineries to produce cleaner fuels and the costs of introduction of clean vehicle technologies.	See Box 6

BOX 1. Organisations supporting Low Carbon Transport Solutions

There are a number of organisations active in Asia to promote and support initiatives in the field of Low Carbon Transport Solutions through, for example, policies and programs, capacity building, financial support etc.. Examples of organisations are given below; visit their websites for more information:

http://cleanairasia.org http://www.slocat.net http://www.fiafoundation.org

http://www.adb.org http://www.worldbank.org/en/topic/transport/brief/low-emission-transport

BOX 2. Urban Electric Vehicles Initiatives

There are many electric vehicle case studies already around the world. For examples see the EV City Casebook[1] that presents case studies on city and regional EV deployment efforts around the world like in Shanghai. Such case studies are illustrative examples of how cities are preparing for mass market EV deployment. The purpose of the EV City Casebook is to share experiences on EV demonstration and deployment, identify challenges and opportunities, and highlight best practices.

At the UN Climate Summit in September 2014 in New York the Urban Electric Mobility Initiative[2] (UEMI) was announced. The UEMI is a joint initiative of UN-Habitat and the European Commission project SOLUTIONS. The UEMI will pool expertise, facilitate exchange and initiate implementation oriented actions. UEMI will be implemented over the period 2014-2030 in a phased manner. One of the actions is to establish a fund to be contributed by Governments and Industry for undertaking innovative Electric Mobility demonstration projects and capacity building.

[1] https://www.iea.org/publications/freepublications/publication/EVCityCasebook.pdf
[2] http://www.uemi.net/

3 Low carbon fuels

3.1 Overview fuel options

There is a range of fuel options that are differently well suited for different vehicle technologies or engine concepts. Not all engine concepts are well suited for all transportation modes and not all fuel options (energy carriers) are equally well suited for all vehicle technologies (engine concepts). Plausible connections are illustrated in Figure 10, where dotted lines indicate possible but less likely large-scale options.

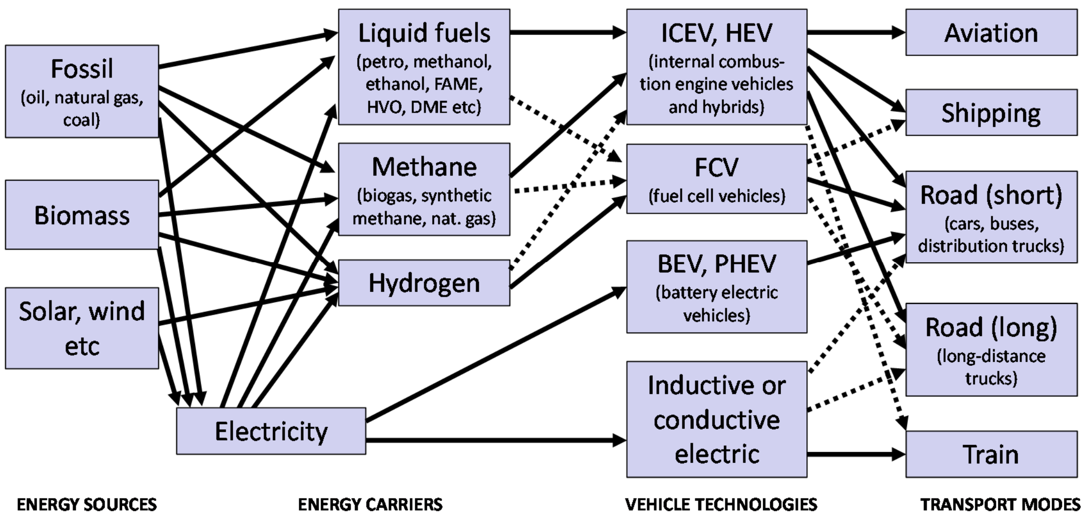


Figure 10 Different fuels and vehicle technology options in different transport modes. Acronyms used are: petro=gasoline and diesel, FAME=fatty acid methyl ester (biodiesel), HVO=hydro treated vegetable oil (biodiesel), DME=dimethyl ether, ICEV=internal combustion engine, HEV=hybrid electric vehicle, FCV=fuel cell vehicle, BEV=battery electric vehicle, PHEV=plug-in hybrid electric vehicle.

In Figure 10 it is shown that transportation fuels (energy carriers) can be produced from different primary energy sources such as oil, natural gas and coal, i.e., fossil sources, or biomass. Useful energy carriers that can be used in the transportation sector are also electricity generated from different power sources, e.g., solar and wind. From both fossil sources and biomass it is possible to produce *liquid fuels* such as gasoline, diesel, methanol and ethanol that can fuel internal combustion engines. These combustion engine concepts are used in all transport modes, i.e., aviation, shipping, road based transport as well as in some trains. Moving one step down, from "liquid fuels" in the options of energy carriers in Figure 10, we find *methane*. Methane is the main content in natural gas and biogas and is also (just as liquid fuels) well suited for the different combustion engine concepts, meaning that methane also can be used in all transportation modes. Next box, in Figure 10, among the options of energy carriers is *hydrogen*. Hydrogen can be produced from different primary energy sources, for example from a gasification process of solid primary energy sources (biomass or coal), from steam reforming of natural gas, or via electrolysis of water using electricity. Hydrogen is most efficiently used in fuel cells (that converts hydrogen into electricity which in turn runs an electric engine) but can also be used in different combustion engine concepts. Fuel cells are best suited for light-duty vehicles, and possible also in ships and trucks, but less likely in aircrafts. When it comes to *electricity*, it is obvious that it is well suited for charging the batteries in battery electric vehicles and plug-in hybrid electric vehicles. Electricity can also be utilized through road technologies that would allow electric cars and trucks to charge as they drive. The electric motors are then powered either via conductive cables or magnetic inductive fields. Currently, the most common way for a continuous transfer of electricity, is to power trams, trains and trolley buses by conductive cables. Electric vehicle concepts are best suited for light-duty vehicles, and also for city buses and delivery trucks, but less likely in aircrafts and ocean-going ships.

Electricity can also be used as the main energy source to produce methane (power-to-gas) and liquid fuels such as methanol from carbon dioxide and water. These “electrofuels” have the advantages that they can be tailor-made into almost any carbon based fuel molecule, and can therefore be used in all transport modes. Depending of choice of molecule, electrofuels can be blended with current fossil and biofuel options. Electrofuels may be an attractive option since it can fit into current fuel distribution infrastructure and used in existing vehicle fleets as well as that the fuels are feasible for aviation and shipping that have very few other low carbon options. The drawbacks are however the large amount of electricity needed and the limited amount of available renewable carbon dioxide (until it may be economically feasible to capture carbon dioxide from air or sea water). More about advantages and disadvantages of the most common fuel options in Chapter 3.2 Biofuel options.

3.2 Biofuel options

Biomass can be categorized by chemical composition. Different types of biomass are better suited for different processes that convert biomass into biofuels to be used in the transportation sector. The main biofuel production options, currently discussed, are illustrated in Figure 11. A description of each of the biofuel options can be found in Appendix 1: Biofuel options.

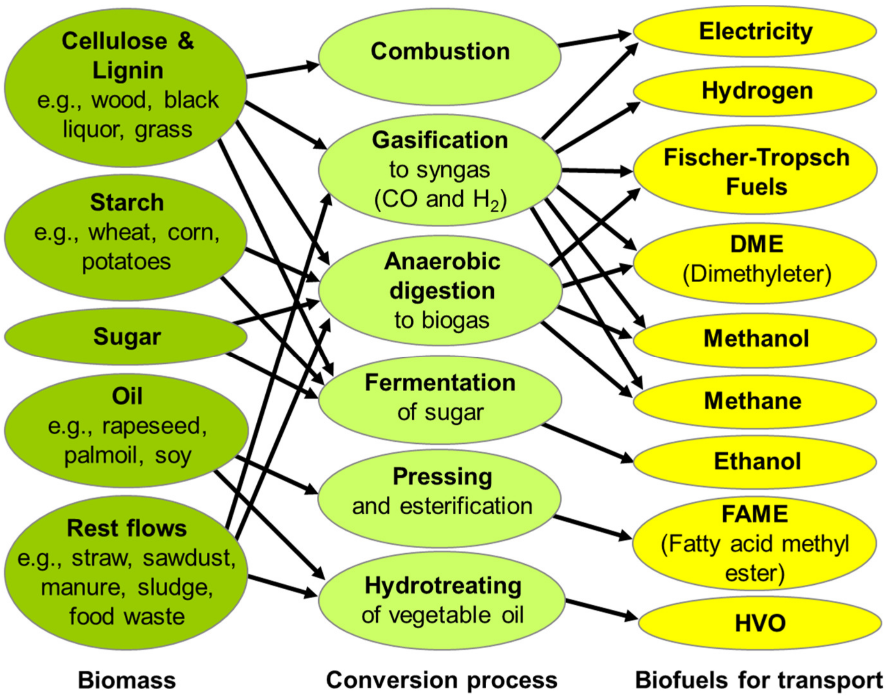


Figure 11 Biofuels production options illustrating the suitable conversion processes for various kinds of biomass. To avoid making the figure too difficult to read we have chosen to exclude arrows pointing out that all types of biomass can be combusted [39].

Biofuels have the potential to reduce greenhouse-gas emissions from the transport sector and work well in different engine concepts. Energy consumption is in most cases similar to that of diesel or gasoline with the exception of methanol and ethanol that due to their higher octane number improves the engine’s conversion efficiency leading to that less energy is needed per km. Biofuels are considered safe and in most cases associated with strong risk reduction with respect to cancer, other health aspects and environmental issues [40]. As presented, biofuels can be produced from a wide range of biomass feedstock. However, most of today's biofuels are produced from agricultural crops like corn, sugarcane and rapeseed. Currently, globally 16% of vegetable oils (rapeseed, soybean, palm and sunflower oil) are used for the production of FAME fuels (biodiesel), 15% of maize and some 2% of wheat are used for the production of ethanol [41]. While less than 1% of global cropland are used for producing biofuels, increased use of biofuels always means an increased competition for land indicating risk for biodiversity losses and increased food prices, read more in e.g. [42].

3.3 Comparison energy balance and CO_2 emissions

Biomass used for the production of biofuels absorbs the same amount of CO_2 from the atmosphere while growing, as later is emitted from the combustion of the biomass. Biomass is therefore defined carbon neutral. However, in the biofuel production process there is a need for additional energy, for example to produce fertilizers, fuel the tractors, trucks and machines used in forestry and agriculture. Additional energy is also needed in the fuel production facilities as well as when transporting the biomass and biofuels. The amount of this additional energy differs between the various fuel production pathways. In a highly cited regularly updated well-to-wheel (WTW) study, having a European Perspective, the total energy expended and total emissions of greenhouse gases (GHG) are assessed and results for different fuel production pathways are presented in Figure 12, where the lower the value is, the better [43]. The results show that wood-based fuels such as DME and syn-diesel (a synthetic diesel produced from gasification of biomass and synthesized in a Fischer-Tropsch reactor) as well as some FAME and HVO fuel pathways have the potential to fulfil both relatively low total WTW energy and low GHG emissions.

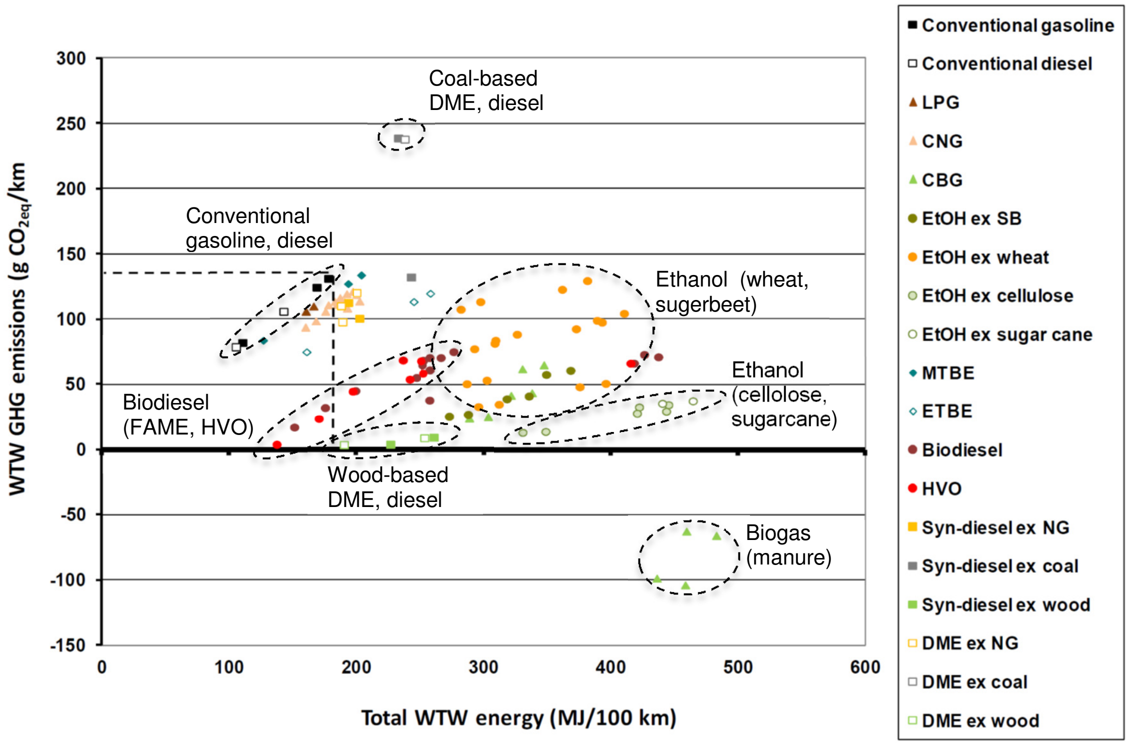


Figure 12 Well-to-wheel energy expended and greenhouse gas emissions for different fuel production pathways, assuming technology matureness by year 2020. All biofuel options are plotted as neat products. Pathways differ depending on different primary energy sources (e.g., farmed wood, waste wood, straw, corn, wheat, sugarbeet, sugarcane, municipal waste, manure), different types of added energy to the conversion process (e.g., renewable, natural gas, lignite coal), and different co-products (e.g., animal feed, biogas, electricity). Please see list on page 1-2, in this paper, for explanations to the acronyms used [43].

An analogous assessment is also made for different hydrogen production options showing that production pathways utilizing wind power for electrolysis, gasification of biomass or steam reforming of natural gas with carbon capture and storage are the ones having the lowest GHG emissions combined with the lowest WTW energy demand [43].

3.4 Comparison tail-pipe pollutions

Alcohol fuels (methanol and ethanol) offer reduced probability for soot emissions thanks to the oxygen present in the fuel. The reduced combustion temperature also leads to reduced emissions of both NOx and soot compared to regular diesel fuel. However, alcohol blends in regular diesel fuel often lead to slightly higher NOx emissions due to faster combustion. Engine out emissions of cancerogenic molecules such as formaldehyde can be high and require an effective catalyst to the tail-pipe. For biodiesel fuels (FAME and HVO), soot emissions are typically lower since FAME fuels include oxygen and HVO lack of aromatics, while NOx is often reported to be increased for FAME fuels since these fuels typically burns faster than diesel [40]. Compared to European diesel FAME fuels reduce soot with approximately 90% but increases NOx with approximately 50% [44]. For methane fuels (biogas and natural gas) NO_x can be reduced sufficiently and catalyst can reduce HC and CO emissions. As a substitute for diesel, methane should have somewhat lower NO_x and substantially lower soot emissions, unless diesel vehicles are equipped with a PM filter [45]. Unburned methane molecules can, however, be challenging to reduce sufficiently with catalytic aftertreatment. Regarding DME, emissions are very favourable and can meet ambitious emission regulations (heavy duty EURO V), without any aftertreatment systems [64][65]. Read more about EURO V in Chapter 4. In summary, emissions of soot, NOx, HC and CO vary between the biofuels, although the levels typically are lower than for conventional gasoline and diesel.

Bengtsson et al [46] present results from a life cycle analysis on health aspects connected to different fuel options. The study is made comparing fuel options for the shipping sector but insights are useful also for road transport. To assess the health effects of particles one need to understand that some emissions such as NO_x, SO_2 and ammonia (NH_3) react in the atmosphere and form particles, defined as secondary particles. These secondary particles will together with the primary PM_{10} emissions add up to the total health effect from particles, expressed as the change in disability adjusted life years (DALYs) per ton kilometre for inhabitants in Europe. Read more about DALYs in Chapter 5.2. Bengtsson el al [46] show that there is a clear trend that liquid fuels (heavy fuel oil [HFO], marine gas oil [MGO], FAME fuels and syn-diesel produced from gasification of biomass) have significantly higher contribution to human damage than the gaseous fuels (liquefied natural gas [LNG] and liquefied biogas [LBG] either produced from agricultural residues [LBGar] or from forest residues [LBGfr], see Figure 13. The result shows that NO_X emissions (converted into secondary particles) are the largest contributor to human health damage from particles.

3.5 Fuel quality

A specification or standard for each fuel options are typically made in order to assure the consistency of the fuel, which is important for maintained efficiency, power and mechanical integrity over time in vehicles' engines. The standards also typically differs between countries or larger regions. The substances that historically have been most discussed is the maximum content of lead, sulphur, benzene, oxygenates and aromatics in conventional gasoline and diesel. The standards may also regulate the fuels vapour pressure, volatility and other fuel properties. More recently some countries and regions have introduces also sustainability criteria in fuel standards and regulations, especially for the production of biofuels.

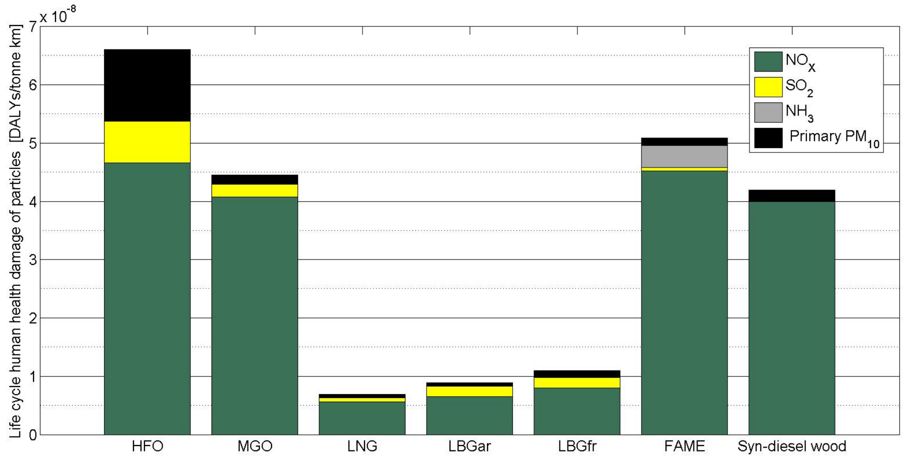


Figure 13 Human health damage by particles including contributions primary PM_{10}, and secondary particles formed from NO_X, SO_2 and NH_3 (ammonia) for some fuel options (DALYs/ton km) [46].

As an example, the European Commission has established minimum specifications for gasoline and diesel fuels for use in road and non-road mobile applications to achieve levels of air quality that do not give rise to significant negative impacts on, or risks to, human health and the environment [47]. This directive also describes mechanism to monitor and reduce greenhouse gas emissions, and methodological principles and values necessary for assessing whether sustainability criteria have been fulfilled in relation to biofuels. Member states can for example only qualify for the biofuel incentives when it can be guaranteed that the biofuels do not originate in biodiverse areas or from nature protection areas having threatened or endangered ecosystems or species. Other specific criteria do for example concern limits on vapour pressure, in order to control air pollutant emissions. This is especially important when new blends of renewable fuels in conventional fuels appear on the market. The directive highlights that ethanol blended into gasoline increases the vapour pressure of the resulting fuel and that diesel fuels with a higher biofuel content need regulation on e.g. oxidation stability, flash point, ash content, water content, lubricity, viscosity, cloud point, and cold filter plugging point. The details for each fuel are listed in [47].

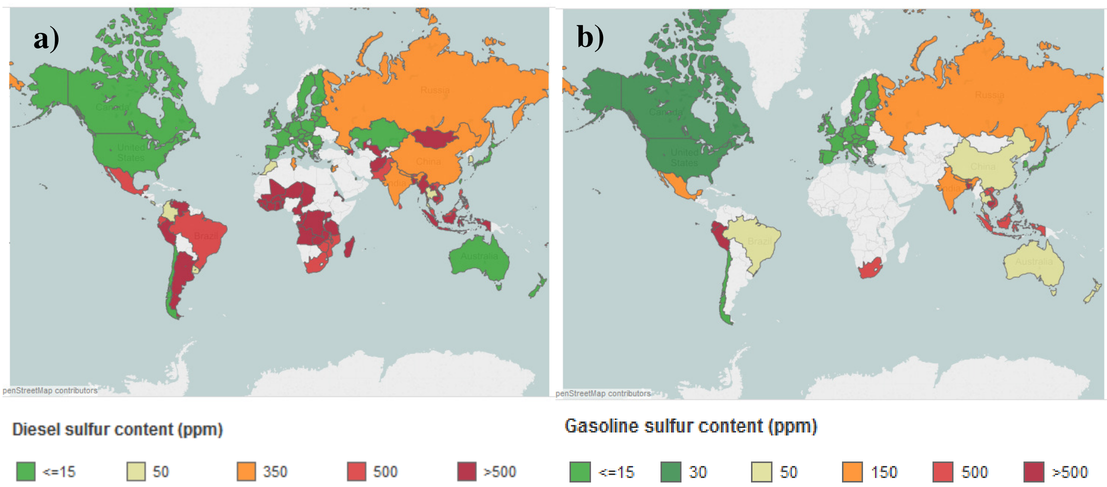


Figure 14 Maps showing (a) diesel and (b) gasoline sulphur limits. Note that only national regulations are shown, while several countries around the world, including Brazil, The People's Republic of China, and India, have sub-national regulations requiring higher quality fuels in key cities and regions [48].

According to [48] progress in reducing fuel sulphur levels around the world has been significant, but uneven. Figure 14 shows the nationwide fuel sulphur levels for diesel and gasoline around the world, for 2014, indicating that many Asian, African and South American countries have the potential to improve their regulations on sulphur content in conventional fuels.

According to Deutsche Gesellschaft für Technische Zusammenarbeit GmbH [45], who assist the German Government in achieving its objectives in the field of international cooperation, the following aspects are important for policy makers to take into account when developing fuel quality standards:

- Since improvements in fuel quality are driven by environmental and public health concerns a country's environment department should have a major role in setting the fuel standards.
- All countries should develop a short and medium term strategy that outlines proposed standards to be adopted over the coming years so as to allow fuel providers and vehicle industry sufficient time to adapt.
- In developing fuel standards, countries should attempt to work closely with neighbouring countries to harmonize standards where possible as long as it do not significantly delay or watering down the requirements.
- Subsidies that favour fuels that results in high emissions should be eliminated and tax policies may be adopted which encourage the use of the cleanest fuels.
- Primary steps for improving fuel quality should be removing lead and sulphur from conventional fuels, whereas secondary steps may be reducing vapour pressure and benzene content of gasoline.

3.6 Summary environmental and health effects from different fuel options

Regulations on fuel quality is important to assure the consistency of a fuel as well as improve how the fuels effect public health and environmental aspects. When basic issues are regulated (e.g., removing lead and sulphur) fuel standards can be used as a tool to monitor and assess whether sustainability criteria have been fulfilled when producing the fuels. There are many well developed fuel standards available in the world that can be used as inspiration when developing standards in countries that want to improve the health and environmental impact from transport fuels.

From a health perspective one would like to choose fuel options leading to as low local emissions as possible, whereas from a climate change perspective one would like to choose fuel options that give rise to as low greenhouse gas emissions as possible in a well-to-wheel perspective. Both battery electric vehicles (BEVs) and fuel cell vehicles (FCVs) run on hydrogen have zero local emissions, or only water vapour, from the vehicles' powertrains. Depending on how the energy carriers are produced the emissions instead come from power plants meaning that the total well-to-wheel emissions depend on the electricity mix. It can be concluded that substituting internal combustion engine vehicles (ICEVs) with BEVs and FCVs will improve air quality in urban areas leading to a positive effect on public health, except if the electricity comes from a polluting power plant near the urban area.

Using methane (biogas and natural gas) as a transport fuel leads to lower greenhouse gas emissions, compared to conventional oil-based fuels. Engines run on methane generally emit lower local emissions of NO_X, HC and CO and substantially lower soot emissions than diesel engines. Regarding alcohol fuels and biodiesel options, local emissions of NOx, HC, CO and soot vary between the different biofuels, although the levels typically are lower than for conventional gasoline and diesel, i.e., a transition from conventional oil-based fuels to natural gas or biofuels leads to improved air quality in urban areas. Almost all alternative fuel options (only exception is coal-based fuels and biofuel options that have used extensive amounts of fossil fuels in the production process) will lead to less greenhouse gas emissions, compared to fossil fuels, and thereby reduce the contribution to climate change.

From a greenhouse gas emission perspective it can be noted that there are three energy carriers that have the potential to substantially reduce the fossil CO_2 emissions from the transport sector: electricity, hydrogen and carbon based fuels (e.g. biofuels and natural gas). Advantages for both electricity and hydrogen are that fuel cells as well as batteries have lower noise and better energy efficiency factors compared to conventional ICEVs, and no or low local emissions. Disadvantages are that it is costly and relatively complicated to handle hydrogen (distribution and storage) and that both batteries and fuel cells still are rather expensive, and that improvements are required when it comes to production cost, life time, and dependency on scarce metals. Biofuels are already on the market, they offer a relatively low-cost solution, bioenergy resources can be grown in most countries, and most biofuels can be blended in fossil fuels indicating less need for new infrastructure and vehicles. However, increased production of biomass is limited by the availability of land and water, in a long-term perspective large-scale use of bioenergy imposes a risk of increased food prices and it may challenge biodiversity. There is also a demand for biofuels in sectors that have few other low-carbon alternatives, e.g., the aviation sector, indicating that prices on biofuels may increase when the demand is larger than the supply.

Which fuel and technology mix, that will dominate in future, is still an open question and it is not likely that there will be one single solution that will replace conventional oil-based fuels. These insights lead to the conclusion that the world should not wait for the "perfect solution", but start to implement fuel and vehicle solutions that each country find suitable. Almost all alternative options, except for fuels and electricity based on coal, will gain public health and reduce greenhouse gas emissions. Also remember that irrespective of fuel choice, CO_2 emissions can be reduced by more energy efficient vehicles and measurements towards reduced transport demand.

BOX 3. What can we learn from scenario modelling?

Scenarios have been developed in multiple research studies trying to understand under what circumstances conventional oil-based fuels, natural gas, biofuels, electricity or hydrogen would dominate the future fuel and vehicle technology mix. As an example results from the Global Energy Transition (GET) model are here presented and discussed. The GET-model is a linearly programmed energy systems cost-minimizing model that generates the fuel and technology mix that meets the demand (subject to the constraints) at lowest global energy system cost[1)]. In Figure 1a, a scenario is presented, showing cost-effective choices for a global car fleet assuming an ambitious CO_2 reduction leading to a stabilized CO_2 concentration of 400 ppm. Since future prices and costs, on advanced technology options, are rather uncertain, alternative scenarios are presented in Figure 1b-c. Results assuming a less ambitious CO_2-reduction scheme is also presented in Figure 1d.

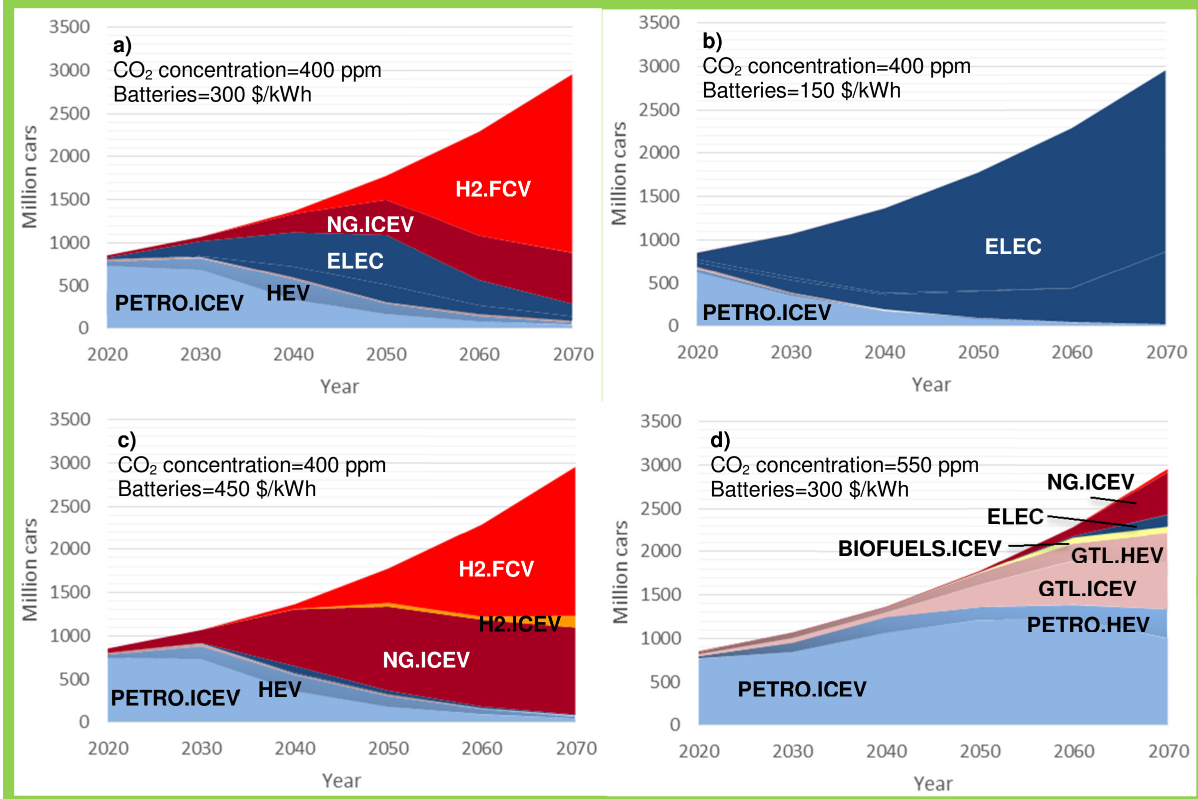


Figure 1. Global scenarios generated by the GET model presenting cost-effective fuel and vehicle technology choices for the global car fleet assuming CO_2 reduction targets towards (a, b, c) 400 ppm and (d) 550 ppm, using different assumptions on battery prices. Acronyms used: H2=hydrogen, NG=natural gas, PETRO=gasoline and diesel, ICEV=internal combustion engine vehicles, HEV=hybrid electric vehicles, FCV=fuel cell vehicles.

The results show that cost assumptions on key technologies, for a low carbon car fleet, have a significant impact on the scenarios. Especially future battery prices are shown to be extremely sensitive. When assuming low battery prices (150 $/kWh) the scenarios totally dominates by electric vehicles, see Fig 1b, whereas there are no electric vehicles shown when battery prices are assumed to be higher (450 $/kWh), see Fig 1c. Scenarios shown in Fig 1a-c all present a future with a large share of vehicle technologies having zero local emissions, indicating that if ambitious climate targets are met it will have positive synergy effects also on public health. From Fig 1d, it is clearly shown that less ambitious CO_2 reduction targets tend to favor a car fleet dominated by internal combustion engines. Such scenarios will not benefit public health nor climate mitigation. Lessons learned from scenario modelling is that scenarios are sensitive for different input data and since future costs are uncertain the world should keep the doors open for different fuel options. In the context of health issues it is of interest to understand what assumptions that lead to scenarios that tend to include a large share of fuel cells and/or electric vehicles which if substituting conventional combustion vehicles will improve urban air quality and thus public health.

[1)]: Grahn M, Azar C, Williander MI, Anderson JE, Mueller SA and Wallington TJ (2009). Fuel and vehicle technology choices for passenger vehicles in achieving stringent CO2 targets: connections between transportation and other energy sectors. Environmental Science and Technology 43(9): 3365–3371.

4 Energy-efficient and low-emitting vehicles

4.1 Emissions tests

The energy efficiency of a vehicle and the amount of pollution emitted by a vehicle is tested in emission tests. Governments have regulated such tests in order to reduce greenhouse gases and reduce the health and environmental impact of road transport pollutions (type approval and certification tests). CO_2 emissions per distance travelled are measured to assess the energy efficiency and concerning pollution the focus is primarily on four types of exhaust gas emissions: carbon monoxide, hydrocarbons, nitrogen oxides and PM. Emission standards set quantitative limits on the allowed amounts of specific pollutants that may be released from a vehicle often per driven distance.

Two types of tests can be distinguished: tests in a laboratory environment and real world driving tests and this last category is gaining rapidly in importance since in a laboratory environment it is difficult to reproduce real driving conditions and since real world driving tests repeatedly have shown that emissions in such tests often exceed the limits significantly, while in a laboratory environment the emission stayed below the limits. See Chapter 4.3 for further details and Box 4 dealing with the Volkswagen fraud [66].

In a laboratory test (Figure 15) the vehicle, in case of a passenger (light duty vehicle), is driving on a rolling road, the so called chassis dynamometer, operated by a driver or a driver robot and following a standardized driving cycle. The prescribed test cycle must be followed as closely as possible. A driving cycle describes vehicle speed versus time and is intended to represent real world driving. The driving cycle currently used in Europe, and a number of other countries, is the New European Driving Cycle (NEDC) as shown in Figure 16. The vehicle speed in this test is slow and has insufficient acceleration and therefore it is expected to be replaced in 2017 by the Worldwide harmonized Light vehicles Test Procedures (WLTP) developed as a global regulation within the UNECE World Forum for Harmonization of Vehicle Regulations [49]. The more realistic WLTP test cycle is also illustrated in Figure 16.

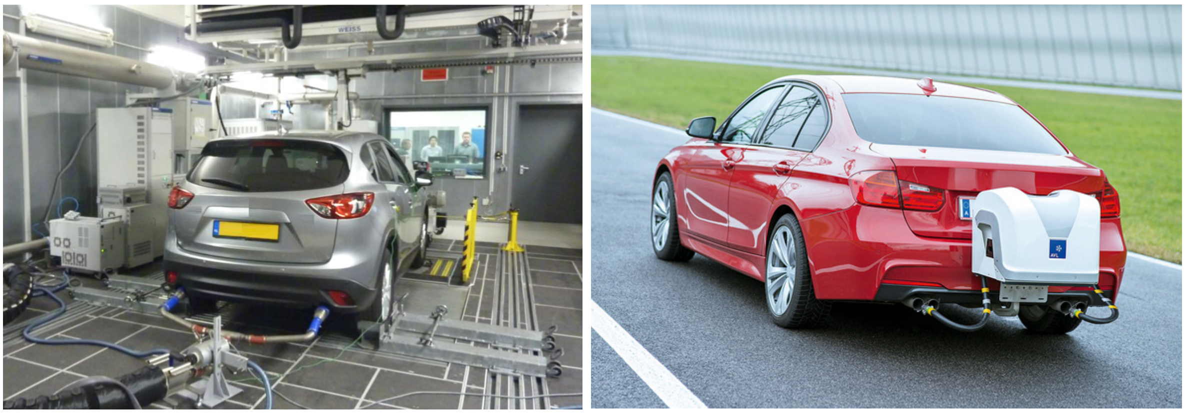


Figure 15 Vehicle on a chassis dynamometer, left [54] and real world driving test, right [69].

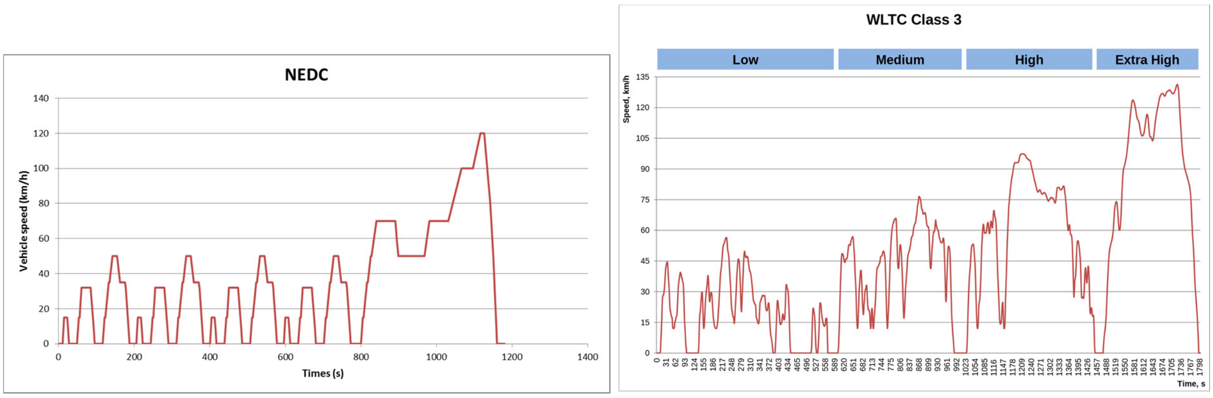


Figure 16 Driving cycle New European Driving Cycle (left) and the Worldwide harmonized Light vehicles Test Procedures WLTP (right).

Motorcycles are tested in a similar way on a chassis dynamometer using basically the same driving cycles as light duty vehicles, but sometimes with reduced maximum speed. For heavy duty vehicles emissions tests are usually performed by an engine dynamometer due to the difficulties to place a complete heavy duty vehicle on a chassis dynamometer. By this method, the dynamometer has to simulate the behaviour of the complete vehicle and transmission.

The knowledge that especially Diesel powered vehicles emit significantly more nitrogen oxides in real driving conditions compared to during the certification procedure has led in Europe to the introduction of real driving emission measurements [50]. The Real Driving Emissions (RDE) test procedure is based on Portable Emission Measurement Systems (PEMS) and will be performed on public roads and will target mainly NOx and PM emissions, see Figure 15. The driving should cover European normal driving at typical ambient conditions in terms of temperature, humidity and altitude. NOx limits for new models using RDE is foreseen to be implemented in 2017. Particulate Number (PN) measurements will be implemented at a later stage when a suitable portable PN instrument has been developed.

4.2 Worldwide Emissions Standards

Requirements to prevent emissions of greenhouse gases has led to CO_2 emission limits for vehicles sold in 80% of the markets around the world. Figure 17 shows fuel economy standards as implemented, or planned to be implemented in the different countries as well as the European Union region [51]. The resulting targets for CO_2 reduction represent a challenge for vehicle manufacturers especially for the period from 2025 and onwards, where for example the European standard for CO_2 is expected to fall in the range 68-78 gCO_2/km. Since the test procedures, to certify a vehicle used, in this figure are not the same in the various countries, the data have been normalized to the New European Driving Cycle (NEDC).

Europe, the US and Japan have been leading the standards concerning pollutions from emissions, where limits for NOx and PM were the main focus. The stages are typically referred to as Euro 1, Euro 2, etc., where for light duty vehicles Euro 1 was introduced in 1992 and the most demanding standard Euro 6 introduced in 2013. Figure 18 shows a comparison of the standards in Europe, USA and Japan with the different stages of introduction and the corresponding NO_x (horizontally) and PM limits (vertical) for heavy duty vehicles.

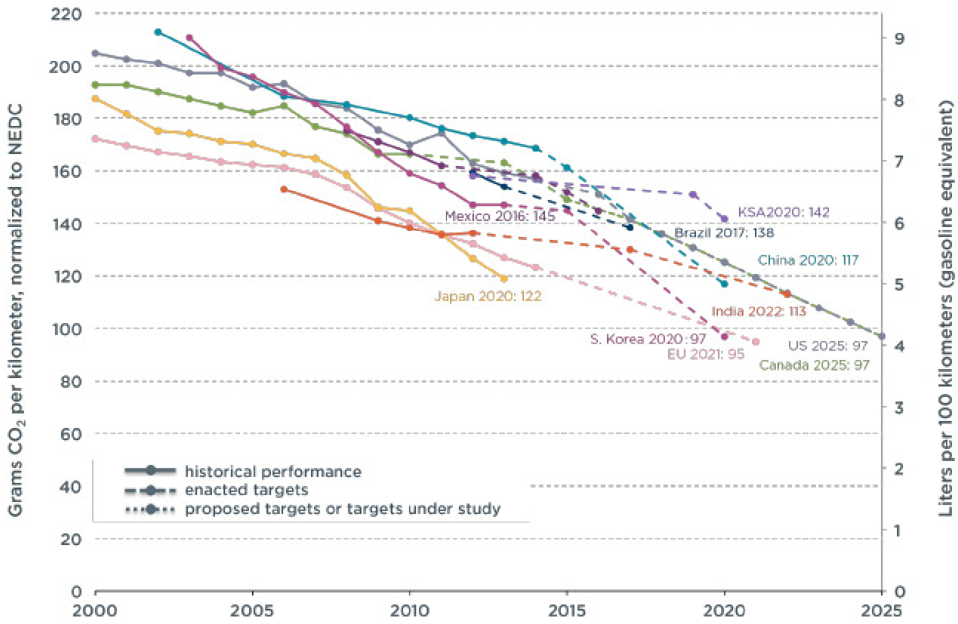


Figure 17 Historical and predicted CO_2 emissions normalized to NEDC for passenger cars [51]

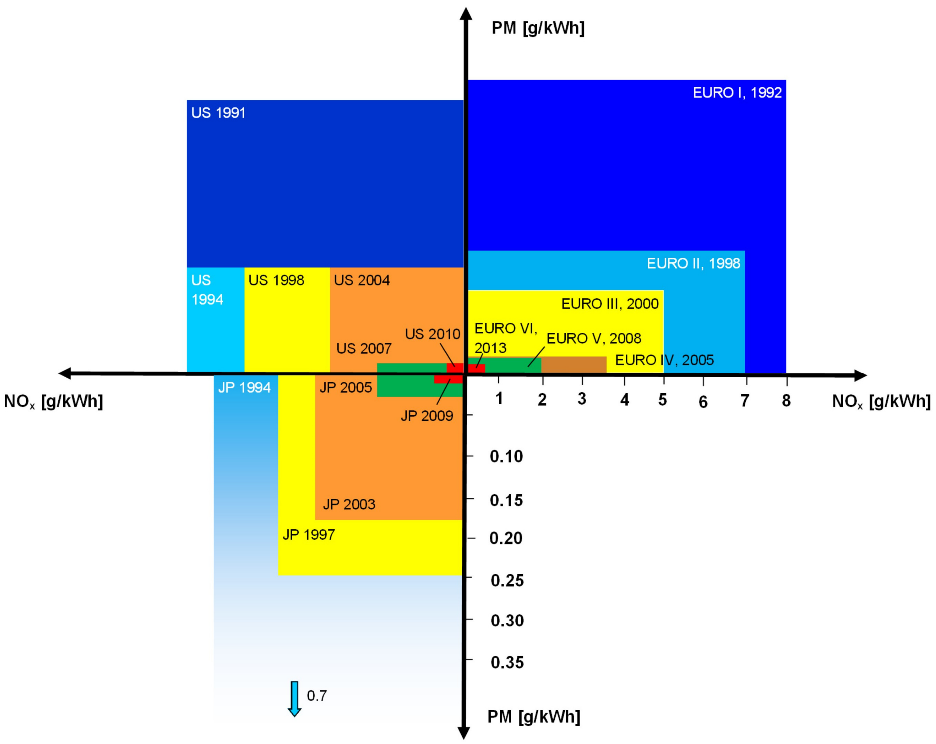


Figure 18 Various stages of emission standards for NO_x and PM for heavy duty vehicles

For Euro 6 the manufacturer has to verify that the emissions performance of their vehicles in real driving are in compliance with the Euro 6 standard. It probably will not be possible for a vehicle to meet the Euro 6 type approval emissions limits under all driving conditions since the driving cycle that the vehicle is operated over may be more demanding than the test cycles. Therefore a “conformity factor” will be agreed and applied to the on-road measurements. This would take the form of a multiplication factor. If, for example, the conformity factor was set at 1.5, then the measured on-highway emissions would be allowed to be up to 1.5 times the type approval limit value.

In Europe it is also discussed whether to use WTW (Well-to-Wheel) CO_2 instead of TTW (Tank-to-Wheel) CO_2, this will have an impact on alternative fuels and also electric vehicles (see Chapter 4.3).

An overview of different emission standards in the world is given in Table 3 for light duty vehicles, Table 4 for motorcycles and Table 5 for heavy duty trucks. It can be seen, in Table 3, that Asian countries in general tend to harmonize their legislation with the European regulations both for emissions and fuel efficiency (CO_2), however they are in some cases a few years behind Europe in terms of implementation.

Table 3 Emissions regulation for passenger cars in various countries

Country	Standard	CI/SI	NOx	CO	PM	PN	CO2	Cycle
			mg/km	mg/km	mg/km	#/km	g CO2/km	
Europe	Euro 6b	SI	60	1000	4.5 [1]	$6\ 10^{12}$ [1]	130	NEDC
	Euro 6b	CI	80	500	4.5	$6\ 10^{11}$	130	NEDC
Japan	Phase III	SI	50	1150	5 [1]		139	JC08
	Phase II	CI	150 [4]	630	14		139	JC08/ 10-15
PR China	CN5 [5]	SI	60	1000	4.5 [1]	$6\ 10^{11}$ [1]	161	NEDC
	CN5 [5]	CI	180	500	4.5	$6\ 10^{11}$	161	NEDC
India	Bharat IV [6]	SI	80	1000			130 [10]	IDC [8]
		CI	250	500	25		130 [10]	IDC [8]
the republic of Korea	Euro 6	SI	60	1000	4.5 [1]	$6\ 10^{12}$ [1]	140 [11]	NEDC
	Euro 6	CI	80	500	4.5	$6\ 10^{11}$	140 [11]	NEDC
the Russian Federation	Euro 4 [9]	SI	80	1000			-	NEDC
		CI	250	500	25		-	NEDC

1) Applicable to gasoline direct injection engines, 2) Bin 5@120000 m (there are 8 bins available the manufacturers average NOx must be 0.7 g/m), 3) NMOG (Non methane organic gases), 4) Depends on vehicle weight >1265 kg, 5) Beijing, otherwise CN4, 6) Entire North India, 7)HC, 8) Modified NEDC cycle, 9) Euro V from Jan. 1, 2016, 10)Target 2016-2017, 11)Test cycle: U.S Combined

Table 4 Exhaust gas legislation for two- and three-wheel vehicles equipped with four stroke SI engines in different countries

Country	Standard	SW	HC	CO	NOx	HC+NOx	Cycle [1]
		cm^3	g/km	g/km	g/km	g/km	
Europe	Euro 3	<150	0.8	2.0	0.15		ECE R 47
	Euro 3	>150	0.3	2.0	0.15		ECE R 47
	Euro 2	3-w [2]	1.5	7.0	0.4		ECE R 47
Japan	2nd	<125	0.5	2.0	0.15		ECE R40 Cold
	2nd	>125	0.3	2.0	0.15		ECE R40+EUCD
PR China	Stage III	<50		1.0		1.2	ECE R47
	Stage III	50-150	0.8	2.0	0.15		ECE R40
	Stage III	>150	0.3	2.0	0.15		ECE R40
	Stage III	3-w	1.0	4.0	0.25		
India	Bharat III			1.0		1.0	IDC
	Bharat III	3-w		1.25		1.25	IDC
The Republic of Korea	Euro 3	<150	0.8	2.0	0.15		UDC Cold [3]
		>150	0.3	2.0	0.15		ECE R40+EUCD
		3-w	1.5	7.0	0.4		CVS-40
Vietnam	Type 2 [4]	<150	1.2	5.5	0.3		ECE-R40
	Type 2 [4]	>150	1.0	5.5	0.3		ECE-R40
	Type 2 [4]	3-w	1.5	7.0	0.4		ECE-R40

1) A new test cycle WMTC (Worldwide-Harmonized Motorcycle Test Cycle will be gradually introduced from 2016 with the new EURO 4 2) Three wheeler 3) ECE R40 (with emissions measured for all six modes - sampling starts at t=0). 4) equal to Euro 2

Table 5 Examples of present exhaust gas legislation for heavy duty vehicles

Country	Standard	NMHC	NOx	HC	CO	PM	PN	Cycle
		mg/km	g/kWh	g/kWh	g/kWh	g/kWh	#/kWh	
Europe	Euro VI		0.4	0.13	1.5	0.01	$8\ 10^{11}$	WHSC
PR China	China IV	0.55	3.5		1.5	0.02		ESC + ELR
India	Bharat IV		3.5	0.46	1.5	0.02		ESC
The Russian Federation	Euro V		2.0	0.48	1.5	0.02		ESC + ELR

*) g/bhp/h

Two- and three wheelers are important for transportation in many Asian countries, Asia accounts for more than 80% of the world's total population of two-wheelers. Motorcycles emit substantial quantities of emissions (hydrocarbons, carbon monoxide, nitrogen oxides and particulate matter). The contribution to urban air pollution from these vehicles are increasing especially in densely populated areas. Due to the rapid increase of especially the number of two-wheelers in Asia they cause serious pollution problems and it is therefore important that strategies and regulations are developed that leads to a substantial reduction of harmful emissions and fuel consumption from two- and three-wheel vehicles. Most motorcycles have an engine capacity of between 50 and 350 cm^3. While small displacement, 2-stroke engines over time have become quite uncommon in Europe, they are still used in significant numbers in major cities in Asia and Africa. In Europe 10-20% of the households own a motorcycle while in Asian countries like Thailand, Vietnam or Indonesia this is more than 80%. To lower the emissions from 2-wheelers equipped with 2-stroke engines the best solution is to replace them with modern 4-stroke engines or retrofitting them with direct injection or at least use a good quality 2-stroke lubrication oil in correct quantities.

The growth in freight transport by heavy duty vehicles (often vehicles with a load capacity above 3500 kg) presents a challenge in preventing an increasing hazardous air pollution and greenhouse gas emissions. Most heavy-duty vehicles are powered by Diesel engines that, without emissions control, can emit high levels of pollutants that contribute to both global warming and local air pollution. Unregulated Diesel vehicles produce high levels of especially particulate matter (PM) and nitrogen oxides. Europe, Japan, the United States and other nations have adopted heavy-duty vehicle emission control standards requiring the use of technologies that reduce harmful pollutants almost to zero. Truck sales are however higher in Asian countries especially The People's Republic of China and India and although the countries in principal follows the European standards, but 5 to 10 years later, it is critical that as soon as possible adopt similar standards. Though most countries have fuel economy standards for passenger vehicles, relatively few have set efficiency and GHG emission standards for heavy-duty vehicles.

4.3 Energy efficient and clean vehicles

The present and future emission standards as discussed in 4.2 are the main driver for vehicle technological development. Figure 19 shows CO_2 emissions (official certification values) for 1500 vehicles of model year 2010-2012 which all fulfil the Euro 5 emissions standards. This figure also shows the limit line for 2015 and the proposed limit line for 2020/2021. It can be seen that many vehicles are above the limit, in particular gasoline vehicles. The heavier the vehicle the larger the distance to the limit lines.

Car manufacturers need to find cost-effective solutions for the challenge to meet these limits. There are many solutions leading to lower CO_2 emissions and not just one optimal solution, but rather several technological areas need to be included and combined.

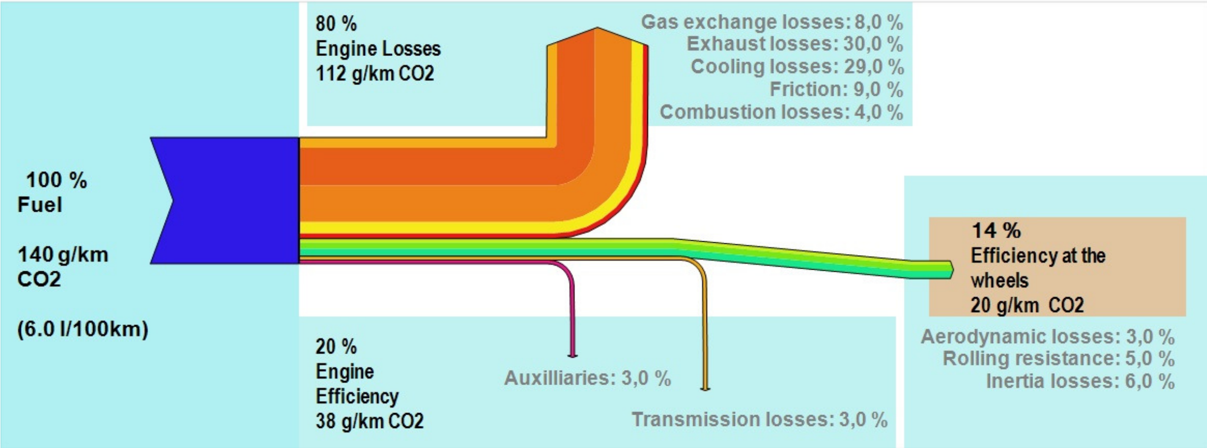


Figure *20* shows the energy distribution for a typical medium sized passenger car equipped with an SI engine, tested with the NEDC. The emissions of carbon dioxide for this particular vehicle is 140 gCO_2/km, which is equivalent to a fuel consumption of 6 litre/100 km. Of the supplied fuel energy just 14% is used to propel the vehicle, the remainder is lost during the energy conversion. Of the 14% useful energy 3% is used to overcome the aerodynamic drag, 5% the rolling resistance and 6% overcoming accelerations (the inertia loss can partly be recovered with a hybrid drivetrain).

A similar diagram, see

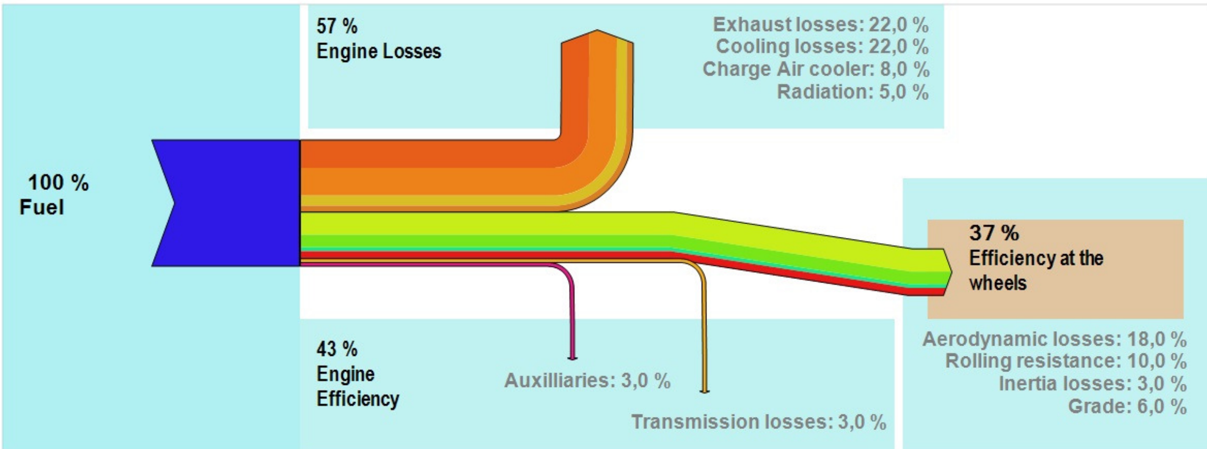


Figure *21*, can be drawn for a heavy duty truck. Mainly due to the much higher efficiency of the Diesel engine a higher portion of the supplied energy is used to propel the vehicle (the data is for real driving, therefore the term "Grade").

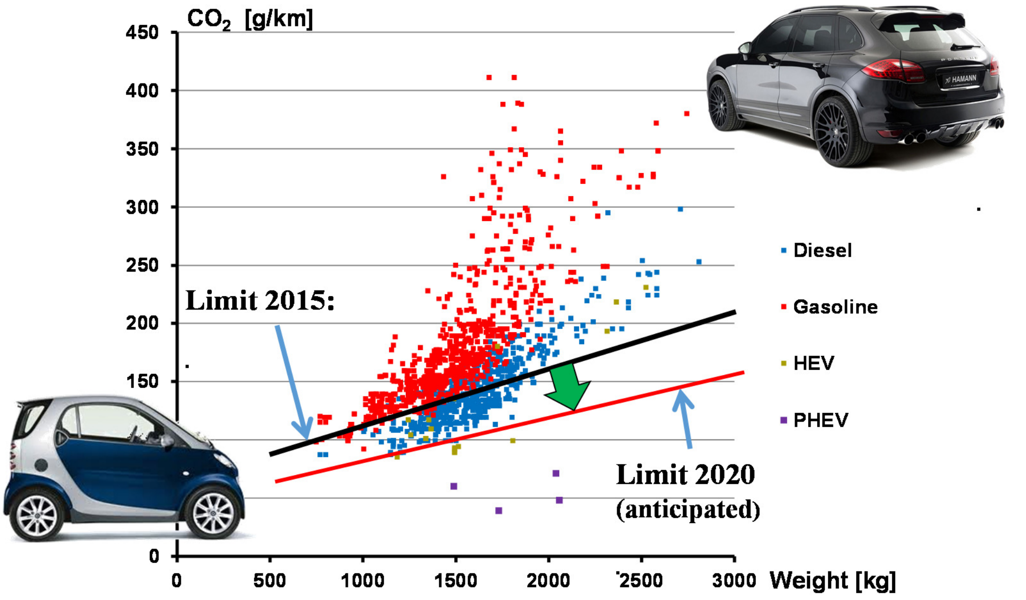


Figure 19 CO_2 emissions for 1500 vehicles on the European market of model year 2010-2012

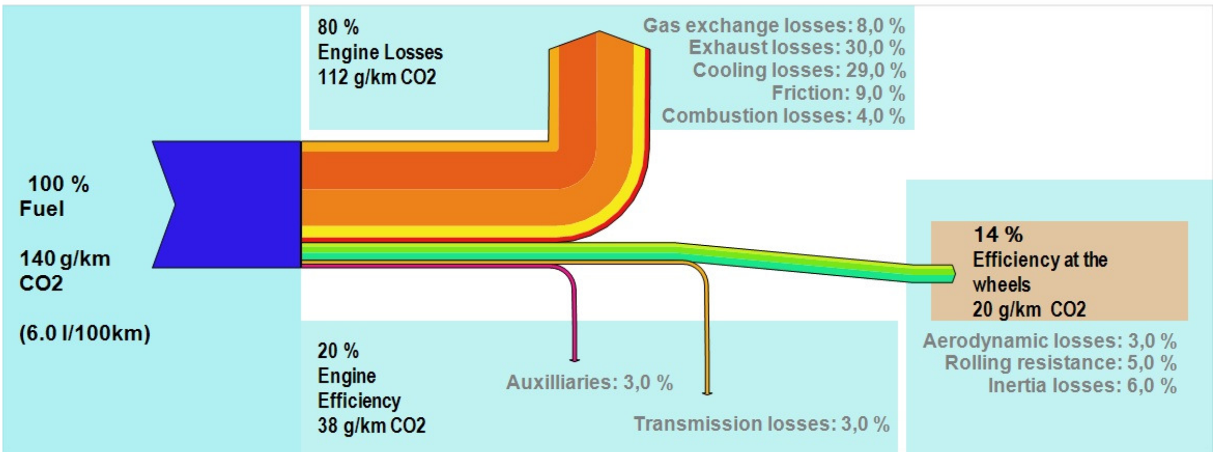


Figure 20 Energy distribution for a passenger car when tested with the New European Driving Test (NEDC).

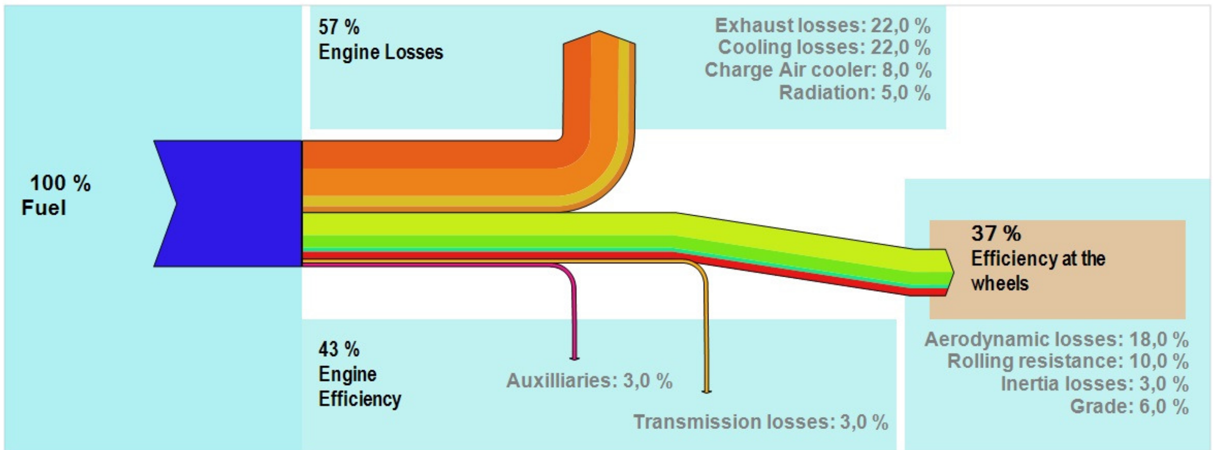


Figure 21 Energy distribution for a heavy duty truck during "real" driving.

Improving the efficiency of the internal combustion engine is one of the most promising and cost effective ways to increase fuel efficiency and decrease carbon dioxide emissions. The internal combustion engine has the potential to become substantially more efficient and can easily be adopted to renewable fuels. Especially SI engine efficiency can in some parts of their operational area (low load) be improved by more than 50%. Advanced internal combustion engines can also be combined with hybrid electric drivetrains for a further increase in efficiency.

To meet the future demands for energy efficiency, as an example, the objectives for decarbonisation and CO_2 reduction in 2030, set in the ERTRAC "Strategic Research Agenda" (SRA) [53], are energy efficiency gains of 80% for urban traffic and 40% for long distance freight transport. Part of this efficiency improvement has to come from the vehicle itself by improvements to the following components/systems:

- Combustion engine improvements
- Electrification and hybridization
- Alternative and renewable fuels (decarbonisation), see Chapter 3
- Aerodynamics
- Weight
- Friction and rolling resistance (like adequate tire pressures)

The other challenge car manufacturers have to deal with is meeting the standards for pollution - PM and NO_x in particular for Diesels. Tests conducted by independent institutes have shown that NO_x emissions may exceed the limits in real world driving conditions for some vehicles by more than 5-10 times (Figure 22). It should be noted that the NO_x standard for Euro V is higher for CI-engines compared to SI-engines (0.18 g/km versus 0.06 g/km); this difference is much smaller for Euro VI. For some vehicles driving at speeds above 120 km/h NO_x limits where exceeded by up to a factor 100 - so 100 times the limit [54].

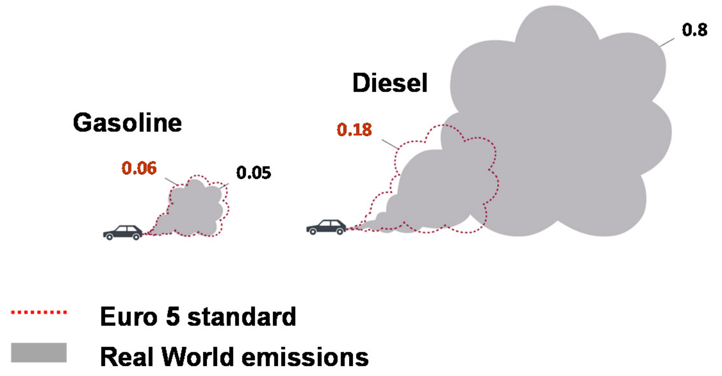


Figure 22 Real world driving emissions for NO_x compared to Euro 5 limits [52]

Such differences became even clearer from the Volkswagen fraud, made public by the US Environmental Protection Agency (EPA), Sept 18 2015 [66]. Volkswagen installed defeat devices in some of their vehicle fleet that detect whether a car is tested in a laboratory environment and the engine management software was manipulated to achieve improved emissions in laboratory conditions. See also Box 4.

As it was mentioned in Chapter 3 electrification/hybridization represents a very important strategy to decrease both CO_2 emissions and pollution from the road transport sector. When the benefits of electrification/hybridization are compared with conventional drivetrains, it is important to take into account how the electricity is produced. The results can be quite different if one takes into account the vehicle's complete lifecycle, from vehicle production through vehicle use and electricity generation to disposal and/or recycling as is shown in Figure 23. This figure shows that the largest contribution to life-cycle emissions comes from the use phase of the vehicle. The figure also shows that the greenhouse gas emissions increase significantly if coal fired power plants are used for producing the electricity. Power plants, however, are often located far outside from the city centre so even if greenhouse gas emissions may increase, the air quality in urban centres can be improved.

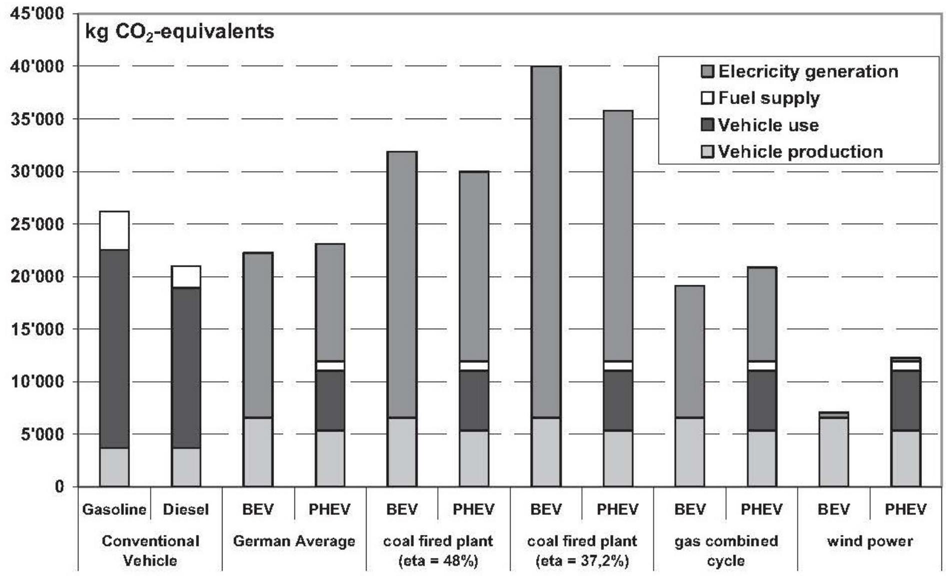


Figure 23 Life cycle greenhouse gas emissions of a compact car with different drive trains (120'000km), 70% urban driving [55]

This chapter clearly shows that emission standards that deal with fuel consumption (CO_2 emissions) and pollutant emissions, are crucial to achieve a major step forward in low carbon vehicle solutions (thus more efficient and cleaner vehicles). This applies to all forms of motorized transport, so from heavy duty vehicles up to the lightest motorized two-wheelers. A number of independent studies, supported by the facts that were released after the Volkswagen fraud was made public, show the importance of the implementation of more realistic driving cycles (like WLTP) in laboratory tests as well as introduction of real world driving emission (RDE) tests.

Also important is that vehicle buyers can get independent and reliable information by a third party about how efficient and clean the vehicle is, they are considering to purchase. This type of independent information is very common nowadays in the field of vehicle safety. Tests carried out and performance limits used often exceed the regulatory requirements and performance of a car is expressed by a star rating system [4]. The Global NCAP organisation coordinating worldwide vehicle safety consumer information programs is considering to introduce in 2016/2017 such a program for vehicle emissions - so-called eco testing or GreenNCAP.

Electrification/hybridisation of the vehicle fleet - assuming that electricity can be produced sufficiently clean - represents a powerful strategy to reduce emissions and is applicable to a wide range of transport options including public transport, distribution of goods in urban areas, light duty vehicles and in particular also 2- and 3-wheelers. The most affordable option are electrified 2-wheelers and in particular e-bikes. Large scale introduction and promotion of e-bikes, which nowadays already can reach speeds up to 50 km/h, could replace to a large extent motorcycles with a combustion engine in urban areas in the future. In highly motorized countries in Europe the introduction of e-bikes motivated people to stop using a private car (modal shift). Moreover e-bikes are a form of active transport, so directly contributing to the health of people (assuming that the air in the areas where they are cycling is sufficiently clear).

Other solutions that help achieving cleaner vehicles are:

- Retrofitting of existing 2-stroke engines with direct injection for reduction of HC and CO emissions by potentially 70% and also introduction of an oxidation catalyst to further reduce HC and CO emissions.
- Conversion of engines to CNG operation, leading to especially less PM emissions
- Use of cleaner fuels as was discussed in Chapter 3.

Introduction of cleaner and more efficient vehicles is often only possible and efficient on a large scale if it is done in conjunction with measures from other LCT strategies (see Table 1), so an integrated system approach is required. Examples are introduction of eco-zones, tax measures, incentive programs, avoiding empty trucks, longer trucks (that may lead to 10-20% improved fuel economy), regular vehicle inspections on emissions etc..

BOX 4. The Volkswagen fraud and how to influence the results of emission tests

In September 2015 the Environmental Protection Agency (EPA) announced that Volkswagen had manipulated millions of Diesel vehicles in the USA in order to be able to pass emission tests. In the Volkswagen vehicles defeat devices were installed which can detect when a vehicle is tested in a laboratory and the engine management software has been manipulated to achieve improved emissions during the laboratory tests. The cars passed in this way the tests but when on the road NOx emissions by far exceeded the limits. This happened already for a number of years. Initially VW denied the allegations but when the EPA announced to withhold certification for future vehicles VW admitted that they had manipulated their vehicles. Volkswagen is facing billions of fines and has to recall many of their vehicles. In Europe more than 50% of all cars sold are Diesels but in the USA the share of Diesels is relatively small. Later it became clear that also in Europe cars have been manipulated to pass emission tests and this was not only done by Volkswagen but also by other manufacturers.

There are many ways that test results in emissions tests can be influenced also in real world driving test conditions. The next figure illustrates this in case of fuel economy tests. This illustrates the need that independent third parties perform such tests on cars as they are sold to consumers (so not provided/prepared by the manufacturer).

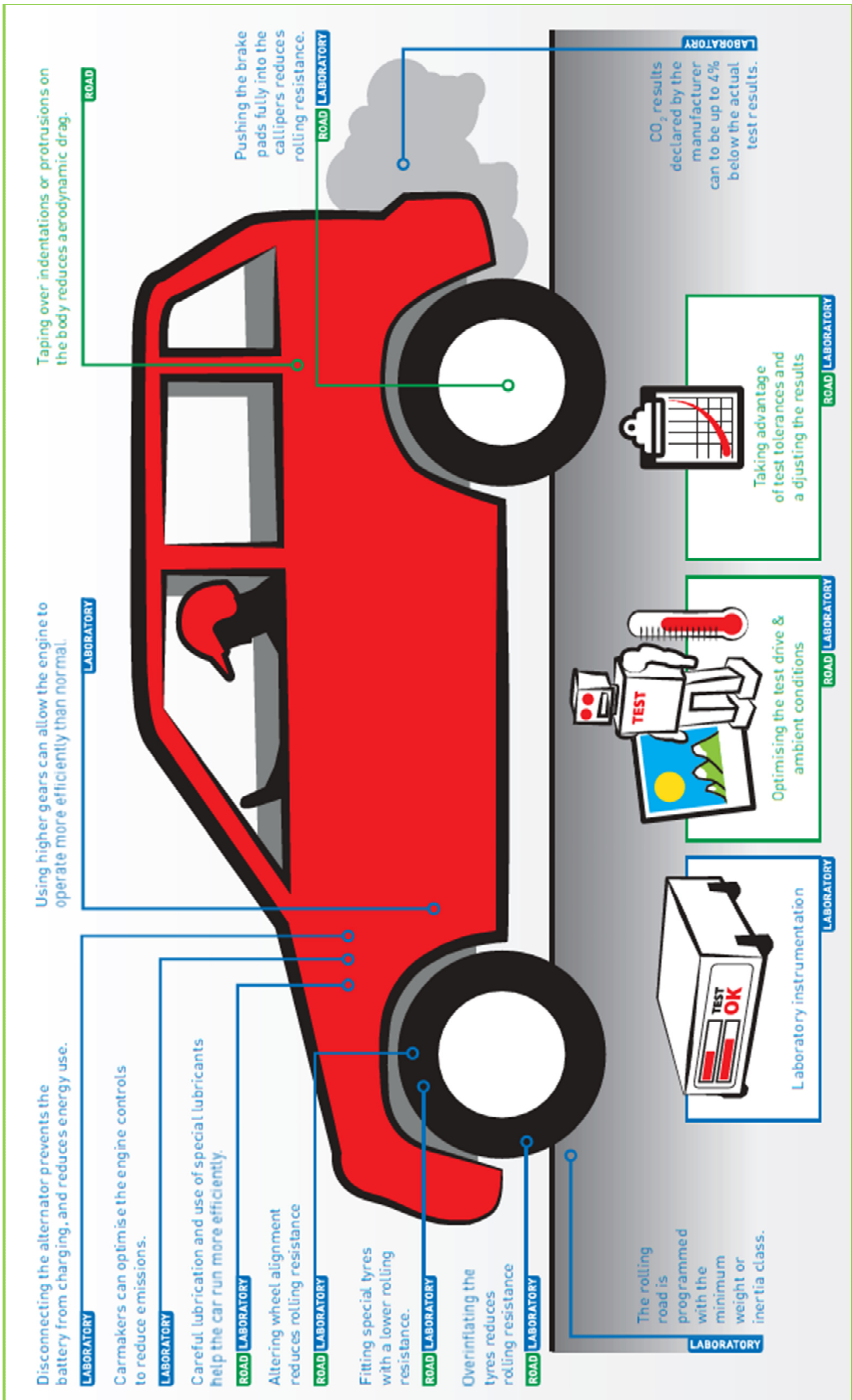


Figure: Ways to influence test results for CO_2 emissions testing: source
http://www.transportenvironment.org/sites/te/files/publications/CarTest_general.3.pdf

5 Health Benefits of Low Carbon Transport Development

5.1 Introduction

The aim of this chapter is to provide insight in the health impact of road transport emissions in Asia in order to make estimates for the benefit of investments in his field. The focus is on the health benefit, so the benefit on climate change and the benefit to other areas like agriculture, building etc.. will not be considered here.

In Chapter 1 information has been provided on the number of premature death and the resulting economic cost on a global level due to Ambient (outdoor) Air Pollution (AAP). WHO has estimated for 2012 about 3.7 million premature death [6] caused by AAP and according to the OECD based on the Global Burden of Disease study GBD 2010, the economic costs for the value of lives lost and ill health due to AAP is estimated USD 3.5 trillion dollars in the OECD countries, People's Republic of China and India combined [9]. The economic costs due to AAP in 2010 is equivalent to 9.7–13.2% of The People's Republic of China's GDP and for India equivalent to 5.5–7.5% of its GDP [13].

AAP is caused by a number of sectors including agriculture, industry, power generation, nature and transport etc. In this chapter it will be tried to make an estimate for the contribution from the transport sector to the above number of premature death and economic costs, with the focus on Asia. In the OECD 2014 study [9] it was estimated that in the OECD countries about 50% of the premature death and economic costs can be assigned to road transport as the cause. This 50% estimate was primarily based on a few European studies conducted around the turn of the century. It was noted that for a number of reasons this 50% ratio may be too high for Asian countries, so in the OECD report no estimates for The People's Republic of China and India have been included for health impact due to pollution of the road transport sector [13]. For a further discussion on the 50% estimate for Europe see also the WHO/OECD 2015 study on "economic cost of the health impact of air pollution in Europe" [56].

The four most common air pollutants are PM, ozone, nitrogen dioxide and sulphur dioxide and these pollutants are associated with a range of acute and chronic health effects, including heart disease and strokes, lung cancer and respiratory diseases as was discussed in Chapter 1. Many studies have shown that the health risk due to pollution directly can be linked to fine particulars $PM_{2.5}$ values. See for instance: [10] [57][58]. Parallel to and after the above mentioned OECD study a few new studies have been published, based like the OECD study on the GBD 2010 (read more about the GBD study in Chapter 5.2), that have made estimates for the number of premature death and other health effects due to pollution caused by the transport sector based on $PM_{2.5}$ observations. In Chapter 5.2 the findings will be discussed. The consequences of these findings for the economic costs of transport caused AAP in Asia will be presented in Chapter 5.3. This chapter concludes with a discussion on cost and benefits of investments in low carbon transport solutions.

5.2 Premature death and DALYs due to transport related air pollution

Three recent studies have tried to make estimates for the health impact due to pollution from road transport: a 2014 study by the World Bank in cooperation with the Institute for Health Metrics and Evaluation [7], a 2014 by Chambliss [59] and a 2015 study in Nature by Lelieveld et al [10]. The methodology used in the three studies is quite similar, but a detailed discussion on differences in methodologies used would be out of the scope of our paper. All three studies take as a basis the Global Burden of Diseases, Injuries, and Risk Factors Study 2010 ("GBD 2010") published in seven papers in The Lancet in 2012 [60]. The GBD 2010 quantified the comparative magnitude of health loss due to 291 listed diseases and injuries, including the burden that can be attributed to outdoor air pollution due to motorized road transport. For a description of the methodology used in GBD 2010, see [7] and the papers in the Lancet [60]. All three studies take measurements for $PM_{2.5}$ distribution as the main source of information for their estimates, among others based on data derived from satellite-based remote sensing. The study of Lelieveld et al [10] also includes the effect of Ozone. Population exposure to air pollution includes populations in rural areas. The contribution from road transport to the $PM_{2.5}$ concentrations is estimated in the studies by using models like the source-receptor model TM5-FASST [7] and the chemical transport model MoZART-4 [59]. The part of AAP that can be contributed to transport varied in 2005 from more than 20% in high income North America, Western Europe and high income Western Pacific to 7.2% in South-East Asia, 5.9% in South Asia and 4.9% in East Asia (which includes The People's Republic of China) [59]. The 20% contribution of road transport to AAP in Europe is lower than the contribution of 50% that was assumed in the OECD study mentioned earlier [56].

The IHME/World Bank study showed for the year 2010, **184,000** premature death worldwide [7]. In this study also the health impact due to road accidents was included as discussed in [4]. Table 6 shows the distribution of premature death over five health problems caused by transport pollution. Almost 50% of the premature death are due to ischemic heart disease and 32% due to stroke. The table also includes the resulting DALY's for the various health problems. DALY's is the years of healthy life lost, defined as the sum of YLL's and YLD's. YLL is the number of years of life lost due to premature death and is calculated by multiplying the number of deaths at each age by a standard life expectancy at that age [7]. YLD's is the years lived with disability adjusted for severity of the health problems. These estimates for premature death and DALYs represent underestimations, among other since the effect of ozone and other pollutants is not included and due to limitation of the models used. See for a discussion on the limitations: [7].

Table 6 Global burden of disease due to motorized road transport caused air pollution in 2010 [7]

Cause	Premature Deaths	DALYs
Ischemic heart disease	90,639	1,909,563
Stroke	58,827	1,148,699
Chronic Obstructive Pulmonary Disease (COPD)	17,266	346,376
Lower respiratory infections	5,670	489,540
Lung cancer	11,395	232,646
Total	**183,797**	**4,126,824**

The results from the two other studies for the number of premature death globally due to transport pollution were from the same order of magnitude then the IHME/World Bank study: Chambliss et al, 2014 [59] reported **242,000** annual premature deaths for 2005 and Lelieveld et al 2015 [10] **164,000** premature death for 2010 [10]. From the study of Lelieveld also a distribution is available how mortality is linked to the various sectors causing AAP for the top 15 countries and worldwide. Figure 24 illustrates this distribution for the world showing that on a global level 5% of the mortalities can be contributed to land transport [10].

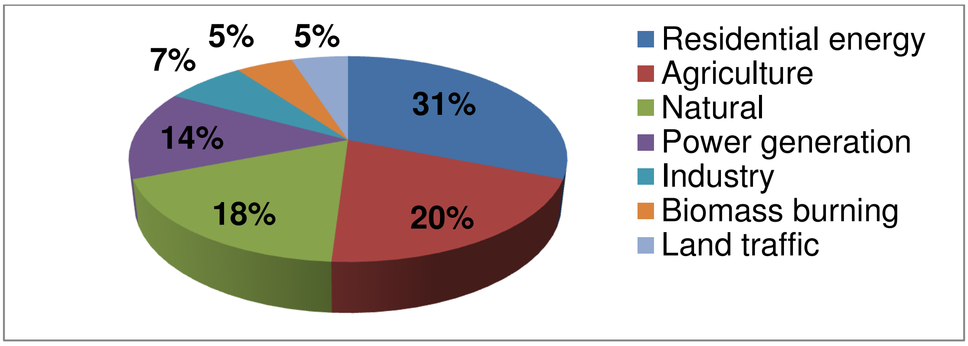


Figure 24 Distribution of mortality over various sectors contributing to AAP and worldwide. Based on [10]

Table 7 Comparison of premature death due to road transport caused air pollution in Asian EST countries in 2010. Also population per country and number of premature death per 1 million inhabitants is included.

	Population	Premature Death due to road transport caused air pollution	Death per 1 million inhabitants
Source/Country	***WHO 2013***	***IMHE/World Bank 2014***	
Afghanistan	31,411,742	1,388	44.2
Bangladesh	148,692,128	2,667	17.9
Bhutan	725,940	12	16.5
Brunei	398,920	1	2.5
Cambodia	14,138,255	129	9.1
PR China	1,348,932,032	27,379	20.3
India	1,224,614,272	38,804	31.7
Indonesia	239,870,944	1,374	5.7
Japan	126,535,916	8,280	65.4
Laos	6,200,894	68	11.0
Malaysia	28,401,017	405	14.3
Maldives	315,885	2	6.3
Mongolia	2,756,001	26	9.4
Myanmar	47,963,010	548	11.4
Nepal	29,959,364	675	22.5
Pakistan	173,593,384	4,496	25.9
The Philippines	92,260,800	554	6.0
The Russian Federation	142,958,156	6,572	46.0
Singapore	5,086,418	44	8.7
The Republic of Korea	48,183,586	2,126	44.1
Sri Lanka	20,859,949	217	10.4
Thailand	69,122,232	1,521	22.0
Timor-Leste	1,124,355	1	0.9
Vietnam	87,848,460	607	6.9
Total	**3,891,953,660**	**97,896**	**25.2**

The IHME/World Bank study contains estimates for the number of premature death due to transport caused AAP on a country level. The resulting values for the 24 EST countries are shown in Table 7 together with the number of premature death per 1,000,000 inhabitants. The total number of premature death in the 24 Asian EST countries is 97,896, where India and The People's Republic of China have the largest share, 38,804 and 27,379 premature death respectively. The number of premature death per capita is the highest in Japan (65) followed by the Russian Federation (46), Afghanistan (44), and the Republic of Korea (44).

5.3 Economic costs of transport caused air pollution in Asia

In this section an estimate for the economic costs in the Asian EST countries to due to health impact from road transport pollution will be made. Such estimates are currently not found in literature. The estimates from OECD for total economic costs of the health impact due to AAP in The People's Republic of China and India will be taken as the basis [9]. The costs for The People's Republic of China are 1,372 billion US$ and for India 459 billion US$ in 2010. The OECD estimates are largely based on estimates for the Value of Statistical Live (VSL), a standard method that has been widely accepted in economics to estimate the burden of death [9]. For the effect of loss of health (morbidity) a standard method is not available yet and to account for this in the OECD estimates a 10% margin has been added to the mortality estimates.

The total number of premature death due to AAP (so caused by all sectors) in The People's Republic of China and India were 1,278,890 and 692,425 in 2010 respectively [9]. The ratio "premature death due to road transport from the IHME/Wold Bank study"/ "total number of premature death from AAP" was multiplied with the total economic cost for The People's Republic of China and India due to AAP. This resulted in the following estimates for the health impact due to road transport pollution: The People's Republic of China: 29,34 billion US$, India: 25,69 billion US$ and The People's Republic of China and India combined: about 55 billion US$.

The ratio of total number of premature death due to road transport pollution for the 24 Asian EST countries (97,896) divided by the total number of death for The People's Republic of China and India combined (38,804 + 27,379 = 66,183) was then multiplied with the estimate for the health impact for The People's Republic of China and India combined (55 billion US$) resulting in more than **81 billion US$** cost to the economy in the 24 Asian EST countries. This estimate is a conservative estimate since the number of premature deaths is primarily based on the health impact from PM, so the health impact from other pollutants including NOx were not or probably insufficiently addressed. Also the contribution of urban areas and the impact on residential areas close to traffic concentrations may have been insufficiently taken into account as well the effect due to secondary effects on ozone formation.

5.4 Costs and benefits of measures

In Chapter 5.2 the impact on health due to road transport air pollution was expressed by the number of premature death per year as well as in DALYs - the years of healthy life lost. For the number of premature death per year data were presented for 2010 for the world in total (183,797), the Asian EST countries combined (97,896) and each Asian country separately, see Table 7. DALYs only were available from the available studies for the world in total: 4,126,824, so not on a country level.

Reductions in the number of premature death and/or DALY's resulting from actions to reduce road transport pollution are often used to quantify the benefit of such actions. For example in the study [61] which is summarized in Box 5, DALYs were used to show the benefit of actions in Delhi and London dealing with various scenarios for lower carbon-emission motor vehicles and increased active travel (non-motorized travel). Policies to promote active urban travel and discourage travel in private vehicles would provide much larger health benefits than policies that focus solely on lower emissions from vehicles.

Premature death and DALYs that can be avoided leads to a stronger economy due to less health costs, increased productivity, among others. This economic benefit can be monetized by the value of statistical life (VSL) method as was shown in Chapter 5.3. A minimum estimate in US$ of the health impact due to road transport pollution has been given for all Asian EST countries combined (81 billion US $) and for The People's Republic of China and India separately. These estimates were based on OECD estimates for the health impact due to all sources of outdoor air pollution combined with recent estimates from other studies concerning the contribution of road transport pollutions to the outdoor air pollution.

For the other Asian countries (besides India and The People's Republic of China) no estimates for the health impact due to road transport pollution expressed as economic costs have been made. A possibility to obtain such an estimate is to assume that the share in economic costs is the same as the share in premature death as shown in Table 7. For Nepal, for example this would result in about 560 million US$ economic costs due to the heath impact from road transport emissions in 2010.

An example of such a cost-benefit analysis is included in Box 6. It concerns the costs and benefits of cleaner fuels and vehicles in India [62]. The conclusion was that India would benefit tremendously by implementing ultra-low-sulphur fuels and tighter vehicle emission standards. Although the Indian oil and automobile industry would have to make initially significant investments, these costs on the longer term would be far below the benefit for the Indian economy.

BOX 5. Public health benefits of active travel and low emission vehicles in Delhi and London

In this study[1)] Comparative Risk Assessment methods were applied to estimate the health effects of alternative land transport scenarios in Delhi and London (UK). A comparison was made between a business-as-usual 2030 scenario, without policies for reduction of greenhouse gases, with alternative scenarios involving vehicles with lower emissions, increased active travel, and a combination of the two. Models were developed that link transport scenarios with physical activity, air pollution, and risk of road traffic injury. In both cities, it was noted that reduction in emissions through an increase in active travel and less use of motor vehicles had larger health benefits per million population (7332 DALYs in London and 12,516 in Delhi in 1 year) than from the increased use of lower-emission motor vehicles (160 DALYs in London, and 1696 in Delhi). However, combination of active travel and lower-emission motor vehicles would give the largest benefits. It was concluded that, although uncertainties remain, climate change mitigation in transport should benefit public health substantially. Policies to increase the acceptability, appeal, and safety of active urban travel, and discourage travel in private motor vehicles would provide larger health benefits than policies that focus solely on low carbon vehicles.

[1)]: James Woodcock et al, Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport, Lancet 2009; 374: 1930–43

6 Way Forward - Conclusions and Recommendations

This paper clearly shows that emissions from road transport cause large problems in the Asian EST countries with an enormous impact on the health of people as well as climate change due to the contribution from road transport to greenhouse gases. Outdoor air pollution levels in many Asian cities are far above WHO guidelines (Chapter 1.4) and the road transport sector is one of the contributors. Air pollution due to road transport is causing a range of acute and chronic health effects including heart disease and strokes, lung cancer and respiratory diseases, in particular in dense urban areas, and is resulting in almost 100,000 premature death yearly in the Asian EST countries (Chapter 5.2). The associated economic costs are estimated to be more than 81 billion US$ (Chapter 5.3). These estimates for premature death and economic impact are rather conservative and are based on some recent studies concerning the share of the road transport sector to outdoor air pollution.

The problem is expected to increase in the Asian EST countries due to the rapid motorisation taking place while it is decreasing in highly motorised countries due to among others stringent standards for emissions. The increasing health impact due to road transport pollution reduces the social, health and resilience of people in the cities. Note that the estimated economic impact only concerns the health impact, so it does not include other types of pollution impacts like damage to agriculture and forests, tourism, buildings etc..

In 2012 transport was responsible for 23% of global CO_2 emissions and road transport accounts for about 75% of these transport emissions (Chapter 1.1). If the current emission trends continue the resultant increase in average global temperature could exceed 4°C by the end of century, which is well above the maximum increase of the recommended two degrees Celsius. The resulting risks in extreme high sea levels and increasing numbers of heavy precipitation events in a number of regions in Asia in particular, will have a negative impact on public health, economy and environment in many areas.

The above negative impact of road transport emissions definitely justifies that mitigation strategies should be given rightful attention, including taking powerful, effective actions. Low carbon transport solutions have a significant potential to contribute to a reduction in global emissions. In this paper in Chapter 2 nine strategies have been defined leading to low carbon transport solutions. In Table 8, the LCT strategies are shown together with links to the Bangkok declaration goals, which will be discussed in Chapter 6.1 in conjunction also with the high level sustainable developments goals (SDG's) from the United Nations.

Most of the measures within the various strategies aim to reduce both energy usage (so reducing CO_2 emissions - climate change impact) and road transport pollution (health impact). The strategies "low carbon fuels" and "energy efficient and low-emission vehicles" however also include measures with a special focus on reducing the health impact by introduction of cleaner fuels and technologies that limit the pollution from a vehicle.

The strategies "measuring and target setting" and "management of sustainable transport" are cross-cutting strategies, that will not lead on their own to reductions in emissions, but they are crucial for a number of the other strategies to be effective and to initiate and manage in an integrated comprehensive way measures - low carbon transport solutions - to achieve optimal health and climate benefits.

Table 8 Low Carbon Transport (LCT) strategies

	LCT Strategies	Related Bangkok declaration goals
1.	**Eco mobile city planning**	1, 2, 4
2.	**Reduction in transport needs**	3
3.	**Modal shift to more low-carbon or less energy intense transport modes**	4, 5 ,6, 7, 12
4.	**Energy-efficient and low-emitting vehicles**	9, 10, 12
5.	**Higher occupancy and load per vehicle**	12
6.	**Efficient driving**	
7.	**Low carbon fuels**	8, 9, 16
8.	**Measuring and target setting**	14, 15
9.	**Management of sustainable transport.**	16, 18, 19, 20

In earlier meetings of the Regional EST Forum a number of background papers were presented dealing with topics related to the LCT strategies, including the greening of freight and train transport, the importance of active transport (NMT), electro mobility and scenario's to shift to public transport and NMT (see Chapter 1.2).

The focus in this paper is on the strategies "low carbon fuels" and "energy-efficient and low-emitting vehicles". The main findings concerning these strategies will be summarized in Chapters 6.2 and 6.3. A general discussion, including limitations of the study is given in Chapter 6.4. This Chapter 6 ends with the most important recommendations from this paper in Chapter 6.5.

6.1 Low carbon transport solutions, sustainable development goals and Bangkok declaration goals

One of the main outcomes of the United Nations conference on sustainable development (Rio+20) - *The Future We Want*, held in Rio de Janeiro in June 2012, was the agreement by Member States to launch a process to develop a set of sustainable development goals (SDGs). The United Nations summit for the adoption of the post-2015 development agenda was held from 25 to 27 September 2015, in New York. This meeting resulted in the acceptance of 17 sustainable development goals (SDG's) with corresponding targets [67]. A number of these SDG's and underlying targets are directly linked to the topic of this paper: low carbon transport solutions and in particular the impact on health. Figure 25 shows an overview of the most relevant SDG's and targets in this respect.

One of the SDG goals (Goal 13) deals with climate change: Take urgent action to combat climate change and its impacts specifically deals with climate change. The COP 21 conference, Dec 7-8 2015 in Paris aims to achieve a legally binding and universal agreement on climate, in order to keep global warming below 2°C. Strategies for low carbon transport can deliver an important contribution to achieve this 2°C aim and therefore need full attention and commitments from all countries.

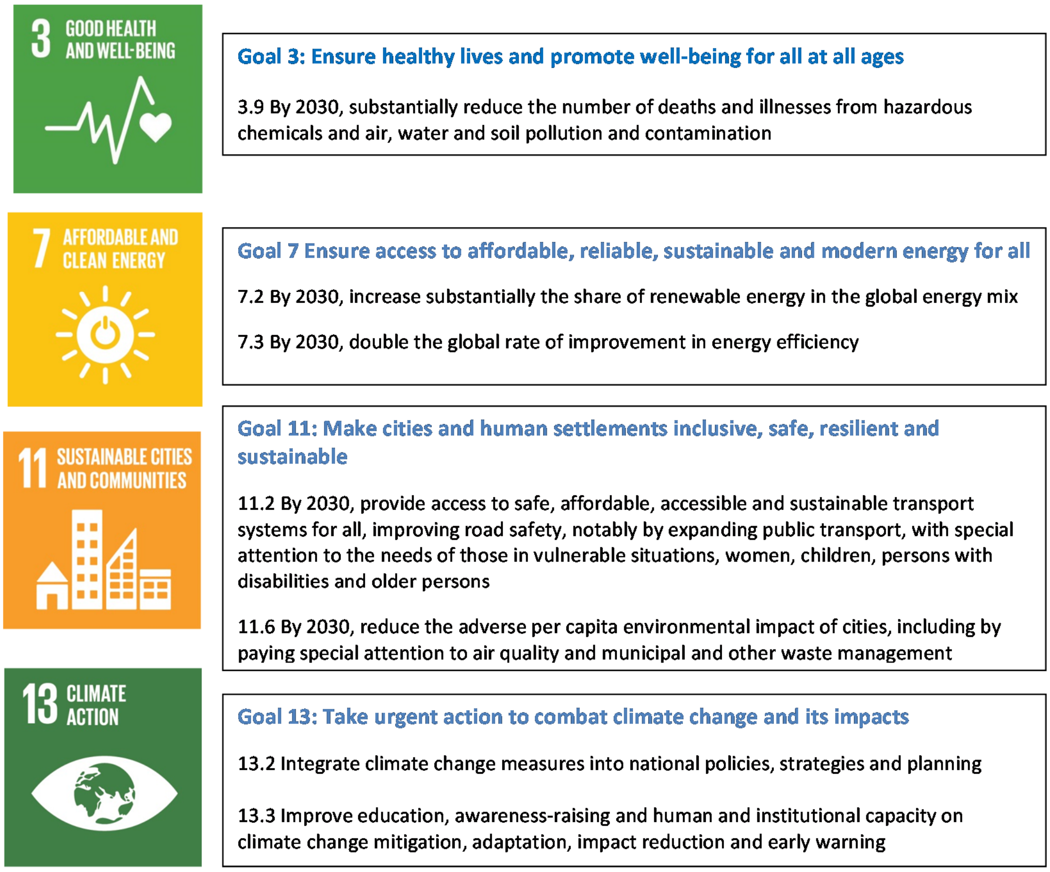


Figure 25 Sustainable Development Goals (SDG's) and underlying targets related to low carbon transport solutions [67]

The low carbon transport (LCT) strategies defined in this paper (see

Table **1** and Table 8) aim to reduce emissions from road transport and consequently the health and climate impact of road transport and can deliver a significant contribution to the implementation of the SDG's. A number of these strategies and the underlying measures have been addressed in various EST declarations. In the Bangkok declaration adopted in 2010 [62] this was done in the most comprehensive way. The Bangkok declaration, an important milestone in the development of the Asian EST initiative, resulted in the definition of the twenty sustainable Transport Goals for 2010-2020. These goals were divided in goals according to the Avoid-Shift-Improve approach (twelve goals) and in eight cross-cutting goals. Table 9 shows the focus of the various Bangkok declaration goals. The complete list of goals is included in Appendix 2.

Most of the twenty goals in the Bangkok declarations, except Goal 13 dealing with safety and Goal 17 dealing with social equity, concern low carbon transport solutions and are closely related to the LCT strategies, see Table 8. A comparison of the LCT strategies with the Bangkok declaration goals learns that most of the LCT strategies are reflected in one or more of the Bangkok declaration goals except the strategy "efficient driving". This strategy deals with items like eco-driving, speed limits including efficient enforcement, synchronized traffic lights, separation of transport modes having different speeds, optimal traffic flows, platooning vehicles etc.

The LCT strategy "Higher occupancy and load per vehicle" is included in Goal 12 of the Bangkok declaration, but only for freight, so not for passengers occupancy of the various transport modes.

The LCT strategy Energy-efficient and low-emitting vehicles is included as far as emission testing and corresponding standards is concerned (in Goal 9 for all vehicles and in Goal 10 with a main focus on commercial vehicles). So topics dealing with energy efficient vehicles like promotion of the use of lighter and hybrid vehicles are not directly visible in the goals of the Bangkok declaration.

Table 9 Scope of Bangkok declaration goals

Strategy	Goal	Scope
Avoid	1	Land use and transport planning
	2	Mixed-use development
	3	ICT to reduce travel needs
Shift	4	Non-motorized transport (NMT)
	5	Public Transport
	6	Transportation Demand Management (TDM)
	7	Inter-city passenger and goods transport
Improve	8	Transport fuels and technologies
	9	Standards for fuel quality, fuel efficiency and tailpipe emissions
	10	Inspection and maintenance with focus on commercial vehicles
	11	Intelligent Transportation Systems (ITS)
	12	Freight transport
Cross-cutting	13	Safety
	14	Monitoring of health impact
	15	Air quality and noise standards
	16	Global climate change and energy security
	17	Social equity
	18	Financing
	19	Information and awareness
	20	Institutions and Governance

6.2 Low carbon fuels

From a low carbon perspective there are three energy carriers that have the potential to substantially reduce CO_2 emissions from the transport sector: electricity, hydrogen and carbon based fuels (e.g. biofuels and natural gas). Advantages for both electricity and hydrogen are that fuel cells as well as batteries have lower noise and better energy efficiency factors compared to conventional combustion engines and no or low local emissions. Disadvantages are the costs of batteries and fuel cells and the costs of distribution and storage of hydrogen. Biofuels are already on the market, they offer a relatively low-cost solution and bioenergy resource can be grown in most countries. Also most biofuels can be blended in fossil fuels indicating less need for new infrastructure and vehicles. However, increased production of biomass is limited by the availability of land and water, in a long-term perspective large-scale use of bioenergy imposes a risk of increased food prices and it may challenge biodiversity.

From a health perspective one would like to choose fuel options leading to as low local emissions as possible, whereas from a climate change perspective one would like to choose fuel options that give rise to as low greenhouse gas emissions as possible in a well-to-wheel perspective. Battery electric vehicles (BEVs) and fuel cell vehicles (FCVs) have zero local emissions, or only water vapour, from the vehicles' powertrains. Depending on how the energy carriers are produced the emissions instead come from power plants meaning that the total well-to-wheel emissions depend on the electricity mix. It can be concluded that substituting internal combustion engine vehicles with electric (BEV and PHEV) and fuel cell (FCV's) vehicles will improve air quality in urban areas leading to a positive effect on public health.

Almost all alternative fuel options presented in Chapter 3, except for fuels and electricity based on coal, will gain public health and reduce greenhouse gas emissions. Which fuel and technology mix that will dominate in the future, is still an open question and it is not likely that there will be one single solution that will replace conventional oil-based fuels.

Fuel quality is important to assure the consistency of the fuels, which is relevant for maintained efficiency, power and mechanical integrity over time in vehicles' engines as well as improve how fuels effect public health and environmental aspects. Chapter 3 showed that in many Asian countries fuel requirements are much less demanding than in Europe. For example the allowable limits for sulphur in diesel fuels in some Asian countries, e.g. Indonesia (500 ppm) exceeds European level (15 ppm) by more than a factor 30. Therefore a critical review of the fuel standards within a country is needed and if they would deviate strongly from what currently is considered "state of the art" an agenda for updating them should be developed.

6.3 Energy-efficient and low-emitting vehicles

Chapter 4 showed that emission standards that deal with fuel consumption (CO_2 emissions) and pollutant emissions, are crucial to achieve more efficient and cleaner vehicles. This applies to all forms of motorized transport, so from heavy duty vehicles up to the lightest motorized two-wheelers. The importance of the implementation of more realistic driving cycles (like WLTP) in laboratory tests as well as introduction of real world driving emission (RDE) tests was shown in Chapter 4. In addition it was noted that potential buyers of vehicles should be able to get independent reliable third party information about fuel economy and emission of pollutants of a vehicle.

Electrification/hybridisation of the vehicle fleet - assuming that electricity can be produced sufficiently clean - represents a powerful strategy to reduce emissions and is applicable to a wide range of transport options including public transport, distribution of goods in urban areas, light duty vehicles and in particular also 2- and 3 wheelers. The most affordable option are electrified 2-wheelers and in particular e-bikes. Large scale introduction and promotion of e-bikes on the longer term could replace motorcycles with a combustion engine.

Different methods can be used to drive the development in a more environmentally friendly direction, first is of course to implement more stringent emission standards. Also some of the following methods may be considered; the introduction of fuels with better environmental specification, benzene reduction and low sulphur content, which enables efficient emission control for both SI and CI engines by three-way catalytic converters, particulate filters and catalytic NOx reduction (SCR). Other solutions that can help achieving cleaner vehicles are retrofitting of direct injection systems and catalysts to existing 2-stroke engines, conversion of vehicles to CNG operation etc. Inspection and maintenance programs can reduce pollutants significantly also preventing tampering or fitting of devices intended to bypass emissions control in order to reduce operational costs which can increase the emissions to very high levels. Buy-back programmes can also be used to accelerate a renewal of the vehicle fleet and the retirement of older out-dated vehicle technology, although by-back programs mainly so far have been used in the past of economic reasons. Other measures can be taxation schemes, incentives and technology mandates (like zero emissions vehicles in California). A key to reduce air pollution is to burn less fuel by either making vehicles more efficient i.e. improving fuel economy or reduce the driven distances by implementing fuel tax or tax per driven distance. Taxes can be used for road infrastructure maintenance and traffic management programs, such as traffic control and eco-zones.

6.4 Discussion and concluding remarks

Outdoor air pollution levels in many Asian cities are far above WHO guidelines and the road transport sector is an important contributor to it. Road transport pollution causes yearly almost 100,000 premature death in the Asian EST countries and the associated economic costs are estimated to be more than 81 billion US$. These estimates for premature death and economic cost from the health impact are based on some recent studies concerning the share of the road transport sector to outdoor air pollution combined with OECD estimates for the economic costs due to outdoor air pollution. These estimates are rather conservative, so they represent a lower boundary for the real number of premature death (and associated morbidity) and resulting economic costs. One reason that these estimates are conservative is that the studies primarily have focussed on the health impact from PM so other pollutants including NO_x were not or probably insufficiently addressed. In this respect is important to mention a recent study carried out for London which showed that the burden in London due to NO2 transport pollution is larger than the burden due to PM [70]. Also the contribution of urban areas and the impact on residential areas close to traffic concentrations may have been insufficiently taken into account as well as the effect due to secondary effects on ozone formation.

Such estimates of the impact on health from road transport pollution are crucial to estimate the economic benefit of actions to mitigate the impact of road transport pollution (cost benefit analyses). In such analysis of the benefit of mitigation actions it is also important to include other benefits, such as the contribution to reduction of greenhouse gases and positive impact of cleaner air on agriculture, forests, tourism, buildings etc..

PM due to motorized transport is not only caused by exhaust emissions but also by brake and tyre wear and also from asphalt. For modern vehicles fulfilling the latest emission standards the contribution to PM_{10} from tyres and brakes is becoming equally important in particularly in urban environments and major cities [68] and therefore need to be addressed in the mitigation strategies.

In this paper a framework of strategies for Low Carbon Transport (LCT) solutions has been presented consisting of seven strategies that can lead on their own to reductions in emissions and two cross-cutting strategies that are crucial for a number of the other strategies to be effective and to initiate and manage an integrated comprehensive approach, where in an optimal way the various strategies are combined.

The first cross-cutting strategy is “Measuring and target setting” and concerns among others monitoring the health impact from traffic pollution, traffic intensities, air quality locally as well as on a national level and defining appropriate standards like air quality standards near high traffic concentrations. Such data need to be reliable in order to be able to make cost-benefit analyses which are needed as a basis for priority setting and to measure in a reliable the progress of mitigation actions. The importance of this is stressed in view of the limitations of the current data on health impact due to road transport pollution as mentioned earlier. The methodologies to achieve such estimates certainly needs to be improved.

The second cross-cutting strategy “Management of sustainable transport” is needed to reach an integrated system approach to develop, implement and evaluate measures to reduce emission from road transport. Few, if any, of the recommendations mentioned in this paper can act in isolation and therefore should be the result of a persistent systems approach and collaboration towards a shared challenging goal. This requires a lead agency for sustainable transport, promotion of strong cooperation between various actors on city and national level, capacity building, institutions for R&D and testing, promotional campaigns, financing and tax mechanisms, coordination with other agencies dealing with climate change and air pollution etc.. On the long term an integrated system approach will be much more effective than taking isolated measures. But on the other hand it is not recommended to wait until such an integrated strategy is available. Many of the provided examples of measures can and should be introduced already on the short term in spite of that the effect may be sub-optimal. It is recommended in any case that when introducing measures a "base-line" status is established and means to track progress and effectiveness are considered.

Many items related to the scope of this paper could not, or only to a limited extend, get proper attention within this paper. For instance a major enabler which is crucial for all LCT strategies in road transport, is ICT. Intelligent transport systems, connectivity (internet of things), automated driving etc. will all dramatically change road transport in the future. Research and development will be needed to investigate and develop further all the upcoming new opportunities.

A number of the measures proposed in this paper will result in health benefits due to better outdoor air quality. However such measures should not lead to negative effects concerning the protection of people in accidents. This increased safety risk is obvious in case of a large modal shift to NMT and e-bikes and to avoid negative effects on public health from biking accidents it may be needed to introduce policies such as compulsory helmet wearing. Another example is the trend to (ultra) light vehicles. Such vehicles will be beneficial for reducing the fuel demand and thus improving the effect on both climate and public health, but the vehicle will at the same time become less safe unless special provisions in the vehicles are implemented to compensate for this increased risk.

6.5 Recommendations

In this section the most important recommendations resulting from this paper are summarized. The first recommendation relates to all strategies for lower carbon transport solutions and stresses the importance of the Bangkok declaration goals. The other recommendations focus on low carbon fuels and vehicles and directly related strategies.

Recommendation 1: Importance of the Bangkok declarations goals
Many measures within the LCT strategies are well reflected in the Bangkok declaration goals, representing a unique set of highly relevant sustainability goals which deserve attention by the Asian EST countries. Based on a comparison with the LCT strategies in this paper it is recommended to update the Bangkok declaration goals by considering also:

- The strategy "efficient driving", dealing with items like eco-driving, speed limits, optimizing traffic flows etc.. The cost-benefit ratio of some of the measures within this strategy is assumed to be very high, for example concerning eco-driving (education of drivers how to drive a vehicle with minimal energy consumption) and introduction of speed limits on high ways in urban areas aiming to reduce pollution from road transport.
- Measures related to "Occupancy of vehicles" aiming at an increase of the number of passengers per vehicle like facilities for people that share cars to work (carpooling), introduction of lanes and city areas only for high occupancy vehicles (HOV lanes) and measures to increase occupancy of public transport.

Recommendation 2: Fuel standards
It is recommended that all countries should review their fuel standards and compare them with global standards. When basic issues are regulated (e.g., removing lead and sulphur) take the opportunity to use standards to monitor and assess whether sustainability criteria have been fulfilled when producing the fuels. Adopt a short and medium term strategy that outlines standards to be improved over the coming years, so as to allow fuel providers and vehicle industry sufficient time to adapt.

Recommendation 3: Alternative fuels
Almost all alternative fuel options lead to less greenhouse gas emissions and less local pollution compared to fossil fuels. It is recommended not to wait for the "perfect solution" but instead start to

implement low carbon fuel (and related vehicle) solutions that are suitable for your country. For example the introduction of electric buses for public transport, biofuels to blend in conventional fuels, and CNG for two and three wheelers, see Figure 26.

Figure 26 Rickshaws in Delhi fuelled by compressed natural gas, CNG.

Recommendation 4: Electric vehicles

Electrification/hybridisation of the vehicle fleet benefits both greenhouse gases and local pollution and rapidly becomes more affordable, among others due to fast developments in the field of batteries. Large scale penetration is foreseen in the future and authorities should start preparing by getting involved in demonstration projects, planning for a proper infrastructure etc. and in particular also by promoting implementation in public transport and in trucks for distribution of goods in dense urban areas. On the longer term also fuel cell vehicles are considered to become a feasible alternative.

Recommendation 5: Emission regulations

Implement, if not done yet, more stringent emission regulations for fuel economy and reduction of pollution. Apply realistic tests including the Worldwide harmonized Light vehicles Test Procedures (WLTP) introduced by UNECE in 2015 and real driving tests to assess and certify vehicles by an independent authority. Consider also implementation of a GreenNCAP program (expected to be introduced in 2016/2017) aiming to inform car buyers to make informed choices of vehicles by providing a comparative rating on fuel economy and polluting emissions.

Recommendation 6: Pollution by motorcycles and shift to e-bikes

Promote measures that reduce the pollution by 2-wheelers with a combustion engine. This can be done on the short term by retrofitting existing 2-stroke engines. On the mid- and longer term a strategy where all motorized 2-wheelers are replaced by electric 2-wheelers – in particular e-bikes- will be much more effective. E-bikes, which are becoming more and more affordable and allowing higher speeds, are also a viable alternative for the private car (modal shift). Moreover e-bikes are a form of active transport, so directly contributing to the health of people, assuming that the air in the areas where they are cycling is sufficiently clear and assuming that the negative effects due to increased biking accidents can be minimized by introduction of policies such as compulsory helmet wearing.

Recommendation 7: Measures to promote the use of energy-efficient and low-emitting vehicles

Introduce measures to promote the use of energy-efficient and low-emitting vehicles. Many examples fit in this recommendation. For example the introduction of eco-zones in dense urban areas. In such area's only non-motorized transport and vehicles with a high fuel economy and low pollution are allowed. For example as long as Diesel vehicles do not meet stringent emission standards (independently assessed by a third party) they could be prohibited to enter that area. Other measures are taxes based on fuel economy and the amount of pollution emitted. This can apply to all vehicle categories and in particular also to heavy-duty trucks. Taxes can also be based on the weight of the vehicle and the type of propulsion (higher taxes for Diesels and other vehicles with a higher weight). Another example is to make people aware of the importance of proper tire pressure which will improve the fuel economy and therefore reduce the emissions from the tail-pipe (also important for safety).

Recommendation 8: Importance or reliable air quality and health data

The methodologies to measure air quality and to assess the health impact (premature death, morbidity, DALYs and economic costs) due to road transport pollution need to be improved in order to be able to take proper evidence based decisions on mitigation actions and to measure the progress of the impact of such actions. Take into account that the contribution of non-exhaust PM due to brake and tyre wear and from wear of asphalt is becoming increasingly important with stricter emission standards.

Recommendation 9: Take actions now

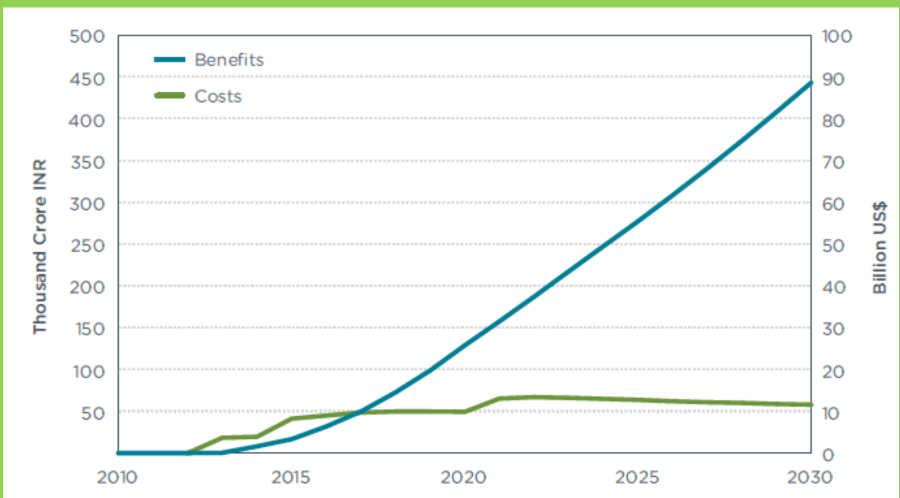
Although on the long term an integrated system approach will be much more effective than taking isolated measures it is not recommended to wait until such an integrated strategy is available. Many of the provided examples of measures can and should be introduced already on the short term in spite of that the effect may be sub-optimal. It is recommended in any case that a "base-line" status is established and means to track progress and effectiveness are considered.

Recommendation 10: Resilient cities

Measures reflected in the Bangkok declaration goals and the recommendations given in this paper all need full attention, not only due to the positive contribution to achieving healthy cities (health resiliency) and the SDG's related to this, but also due to the contribution to the SDG concerning climate change, in other words meeting the 2 degrees Celsius global warming target and in this way reducing the risk on extreme climate events (disaster resiliency).

BOX 6. Costs and Benefits of Cleaner Fuels and Vehicles in India

Sulphur (SO_2) in gasoline and diesel is linked to a number of adverse effects on the respiratory system [1)]. It was found for example in the Hong Kong Special Administrative Region of China that after lowering the fuel sulphur content the annual all-cause mortality fell 1–2%. By reduction of sulphur in fuels the performance of emission control devices improves and lower sulphur fuels enable the adoption of advanced emission control technologies that allows reduction of other pollutants as well. So low sulphur fuels are a pre-requisite for stricter emission standards. This study investigated the cost-benefit of investments in refineries to produce ultra-low-sulphur fuels (ULSF) with less than 10 ppm sulphur content and investments in related clean vehicle technologies in India. It was shown that the benefits of these investments, in terms of reduced healthcare costs and higher productivity, far outweigh the costs. This is illustrated in the next figure which compares annual costs and benefits between 2010 and 2030. The figure shows that while there are costs associated with clean fuels and vehicles, benefits far outweigh costs.



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Appendix 1: Biofuel options

Ethanol

Worldwide, ethanol is the biofuel option that is most used in road transport. Ethanol is commonly made from biomass such as corn, wheat, cassava or sugarcane. World ethanol production for transport fuel tripled between 2000 and 2007 from 17 billion to more than 52 billion litres. In 2011 worldwide ethanol fuel production reached 84.6 billion litres, with the United States as the top producer, followed by Brazil (Renewable Fuels Association, 2012). Most cars on the road today can run on blends of up to 10% ethanol (Americanprogress, 2015) in gasoline. Since 1976 the Brazilian government has made it mandatory to blend ethanol with gasoline, and the blend is since 2007 around 25% ethanol and 75% gasoline (Agricultura, 2015). Millions of vehicles also use neat ethanol fuel. According to the International Energy Agency, cellulosic ethanol could allow ethanol fuels to play a much bigger role in the future (Worldenergyoutlook, 2015). Challenges for ethanol are e.g. that high ethanol blends have difficulties to achieve enough vapour pressure for the fuel to evaporate and spark the ignition during cold weather. To avoid this problem at temperatures below 11 °C, and to reduce ethanol higher emissions during cold weather, both the US and the European markets have adopted E85 (85% ethanol and 15% gasoline) as the maximum blend to be used in their flexible fuel vehicles, and they are optimized to run at such a blend.

Methanol

Methanol is the simplest alcohol, and in commercial use today in The People's Republic of China with some local variations. M5 (5% methanol and 95% gasoline) to M30 are used directly in standard gasoline engines while M85 and M100 are used in dedicated methanol vehicles. The experiences in The People's Republic of China still need to be properly evaluated (Chen, Yang, Zhang, & Harrison, 2014). Methanol is a preferred fuel in motorsports where it is considered to be safer than for instance gasoline since it can easily be extinguished with water in the case of fire. The main advantage of a methanol economy is that it could be adapted to present internal combustion engines with minor modification in both engines and infrastructure to store and deliver liquid fuel. Methanol is easier to store than hydrogen and burns cleaner than fossil fuels. Challenges for methanol are e.g. the effects if ingested in large quantities where it first metabolized to formaldehyde and then into formic acid (Barceloux et al, 2002) or form salts, which is poisonous to the central nervous system, and may cause blindness, coma, and death. Since methanol is highly toxic special regulations are needed at fuel stations to avoid spillage and direct contact on skin. Since methanol is miscible with water and biodegradable, it is unlikely to accumulate in groundwater, surface water, air or soil (Methanol, 2015). One of the potential drawbacks of using high concentrations of methanol as fuel is the corrosivity to some metals, particularly to aluminium. Concerns with methanol's corrosivity have been addressed by using methanol-compatible materials, and fuel additives that serve as corrosion inhibitors.

FAME fuels

Fatty-acid methyl ester (FAME) is a group of fuels originating from vegetable oils and animal fats commonly known as biodiesel. In Europe this is typically rapeseed methyl ester (RME) while in US it is more common with soy methyl ester (SME). Since essentially any vegetable oil or animal fat can be transesterified to biodiesel or used as fuel directly there is a substantial number of different fuel feedstocks, for instance oils from algae, palm, coconut, jojoba, mustard, tallow, chicken fat, and many other (Tunér, 2015). Several properties of FAME are similar to that of fossil diesel and they can therefore be used in diesel engines with little or no modifications. FAME fuels have been used in engines for a long time and there is substantial knowledge when using them either neat or blended in fossil diesel in conventional diesel engines. Currently up to 7% biodiesel is allowed in European diesel. Challenges for FAME fuels are e.g. that the high cloud point make them less suited for neat operation in colder climates and that FAME can be aggressive towards rubber. Problems with bacterial growth in the fuel tank as well as dilution and thickening of engine lubricating oil have also been reported. FAME is considered safe and with little impact on environment from spillage.

HVO

Instead of using esterification to form FAME, vegetable oils and animal fats can be hydrotreated to form what is known as Hydrotreated Vegetable Oil (HVO). The hydrotreatment removes the double bonds and oxygen that leads to stability and improved storage properties as well as reduced risk for oil contamination (Tunér, 2015). Biological oils, such as raw tall oil and slaughter-waste, are currently used for HVO production, but given proper pre-treatment many other feedstocks, e.g., straw, manure, algae, by-products and waste from forest and pulp, and all kinds of biological oils can be used. HVO is an excellent diesel fuel and may be used either neat or blended with fossil diesel. Challenges for HVO is that it is a rather new fuel that only has been on the market since 2012 and so far only in the Scandinavian countries.

Methane

Gaseous fuels such as methane rich gases (natural gas or biogas) are well suited to spark ignited operation. There is vast experience and several million gas fuelled vehicles in operation. Gaseous fuels are typically compressed or liquefied to allow a reasonable driving range. Compressed natural gas (CNG) is currently the most common alternative fuel to diesel and gasoline. Even when from fossil origin, due to its high hydrogen-carbon ratio, it can theoretically provide a reduction of 25% CO_2 during vehicle operation compared to fossil diesel or gasoline. In reality, the reduction of GHG is less due to methane leakages (methane is a 25 times stronger greenhouse gas than CO_2). By liquefying methane at -162 ^oC and 0.25 bar over-pressure to liquefied natural gas (LNG), the energy density can be increased 2.4 times compared to CNG. This is practical for shipping of natural gas. Natural gas has the benefit of not being poisonous and is also generally considered a safe fuel. Challenges for methane is the high cost for cryogenic storage tanks when using LNG, the great risk of fuel losses during vehicle stand still from boiling LNG, and the difficulties to capture unburned methane molecules in the aftertreatment system (Tunér, 2015).

DME

DME is currently not a fuel option that is used in large scale, but is a well-understood engine fuel from several fleet studies. For instance, Volvo has actively investigated and introduced DME on buses and trucks since 1999 and is launching the third generation DME trucks during 2015 in Europe and North America (Salsing & Denbratt, 2007; Hansen et al., 2000). Development of DME fuelled vehicles are on-going in several countries such as Japan, The People's Republic of China, the Republic of Korea and USA. DME is a gaseous fuel that can be handled as a liquid when pressurized above 5 bar. Due to its high cetane number it is suitable as a fuel in slightly modified diesel engines. DME is generally considered a safe fuel with little negative impact on human health (Tunér, 2015).

Hydrogen

Hydrogen is considered an excellent engine fuel, especially in SI engines, and has the obvious advantage of not yielding CO, CO_2, and HC emissions. All fuels burnt in air will however form NOx. If used in a fuel cell the only emission is water vapour. One advantage for hydrogen is that it can in principle be produced from any primary energy source. Fossil based hydrogen are e.g. produced through steam reforming of natural gas or from gasification of coal. Renewable hydrogen can be produced from gasification of biomass or from electricity via electrolysis of water (Edwards et al, 2014). Hydrogen can be blended with methane and then called hythane. Advantages of using hythane are e.g. that current natural gas infrastructure can be used and that the combustion generates even lower emissions of NOx. Advantages for using fuel cells are e.g. that fuel cells offer a better energy conversion efficiency compared to conventional ICEVs, no or low local emissions, and lower noise. Challenges for fuel cells are e.g. that improvements are required when it comes to production cost, life time, and dependency on scarce metals. Challenges for hydrogen is that pure hydrogen is the smallest possible molecule that tend to leak through metals. Hydrogen is thus incompatible with many steels, nickel and its alloys. To use hydrogen on a vehicle it needs to be either compressed to 700 bar, liquefied or cryo-compressed. Driving range can still be an issue. (Tunér, 2015).

Electrofuels and algae

Biofuels based on algae and synthetic fuels produced from renewable CO_2 and water using electricity as the main energy source, so called electrofuels, are examples of fuels that have a great supply potential but currently need further research and development before being available at large scale. The most discussed types of electrofuels are methane (a concept denoted "power-to gas") or methanol (which can be converted into DME) and the most discussed algae-based biofuels are methane or FAME fuels. Read more on electrofuels in e.g. (Faberi et al, 2014; Mohseni et al, 2013; Stechel & Miller, 2013) and more on algae fuels in e.g. (Mascarelli, 2009).

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Appendix 2: Bangkok declaration goals

I. Strategies to Avoid unnecessary travel and reduce trip distances

Goal 1: Formally integrate land-use and transport planning processes and related institutional arrangements at the local, regional, and national levels

Goal 2: Achieve mixed-use development and medium-to-high densities along key corridors within cities through appropriate land-use policies and provide people-oriented local access, and actively promote transit-oriented development (TOD) when introducing new public transport infrastructure

Goal 3: Institute policies, programmes, and projects supporting Information and Communications Technologies (ICT), such as internet access, teleconferencing, and telecommuting, as a means to reduce unneeded travel

II. Strategies to Shift towards more sustainable modes

Goal 4: Require Non-Motorized Transport (NMT) components in transport master plans in all major cities and prioritize transport infrastructure investments to NMT, including wide-scale improvements to pedestrian and bicycle facilities, development of facilities for intermodal connectivity, and adoption of complete street design standards, wherever feasible

Goal 5: Improve public transport services including high quality and affordable services on dedicated infrastructure along major arterial corridors in the city and connect with feeder services into residential communities

Goal 6: Reduce the urban transport mode share of private motorized vehicles through Transportation Demand Management (TDM) measures, including pricing measures that integrate congestion, safety, and pollution costs, aimed at gradually reducing price distortions that directly or indirectly encourage driving, motorization, and sprawl

Goal 7: Achieve significant shifts to more sustainable modes of inter-city passenger and goods transport, including priority for high-quality long distance bus, inland water transport, high-speed rail over car and air passenger travel, and priority for train and barge freight over truck and air freight by building supporting infrastructure such as dry inland ports

III. Strategies to Improve transport practices and technologies

Goal 8: Diversify towards more sustainable transport fuels and technologies, including greater market penetration of options such as vehicles operating on electricity generated from renewable sources, hybrid technology, and natural gas

Goal 9: Set progressive, appropriate, and affordable standards for fuel quality, fuel efficiency, and tailpipe emissions for all vehicle types, including new and in-use vehicles

Goal 10: Establish effective vehicle testing and compliance regimes, including formal vehicle registration systems and appropriate periodic vehicle inspection and maintenance (I/M) requirements, with particular emphasis on commercial vehicles, to enforce progressive emission and safety standards, resulting in older polluting commercial vehicles being gradually phased-out from the vehicle fleet, as well as testing and compliance regimes for vessels

Goal 11: Adopt Intelligent Transportation Systems (ITS), such as electronic fare and road user charging systems, transport control centres, and real-time user information, when applicable

Goal 12: Achieve improved freight transport efficiency, including road, rail, air, and water, through policies, programmes, and projects that modernize the freight vehicle technology, implement fleet control and management systems, and support better logistics and supply chain management

IV. Cross-cutting strategies

Goal 13: Adopt a zero-fatality policy with respect to road, rail, and waterway safety and implement appropriate speed control, traffic calming strategies, strict driver licensing, motor vehicle registration, insurance requirements, and better post-accident care oriented to significant reductions in accidents and injuries

Goal 14: Promote monitoring of the health impacts from transport emissions and noise, especially with regard to incidences of asthma, other pulmonary diseases, and heart disease in major cities, assess the economic impacts of air pollution and noise, and devise mitigation strategies, especially aiding sensitive populations near high traffic concentrations

Goal 15: Establish country-specific, progressive, health-based, cost-effective, and enforceable air quality and noise standards, also taking into account the WHO guidelines, and mandate monitoring and reporting in order to reduce the occurrence of days in which pollutant levels of particulate matter, nitrogen oxides, sulphur oxides, carbon monoxide, and ground-level ozone exceed the national standards or zones where noise levels exceed the national standards, especially with regard to environments near high traffic concentrations

Goal 16: Implement sustainable low-carbon transport initiatives to mitigate the causes of global climate change and to fortify national energy security, and to report the inventory of all greenhouse gases emitted from the transport sector in the National Communication to the UNFCCC

Goal 17: Adopt social equity as a planning and design criteria in the development and implementation of transport initiatives, leading to improved quality, safety and security for all and especially for women, universal accessibility of streets and public transport systems for persons with disabilities and elderly, affordability of transport systems for low-income groups, and up-gradation, modernization and integration of intermediate public transport

Goal 18: Encourage innovative financing mechanisms for sustainable transport infrastructure and operations through measures, such as parking levies, fuel pricing, time-of-day automated road user charging, and public-private partnerships such as land value capture, including consideration of carbon markets, wherever feasible

Goal 19: Encourage widespread distribution of information and awareness on sustainable transport to all levels of government and to the public through outreach, promotional campaigns, timely reporting of monitored indicators, and participatory processes

Goal 20: Develop dedicated and funded institutions that address sustainable transport-land use policies and implementation, including research and development on environmentally sustainable transport, and promote good governance through implementation of environmental impact assessments for major transport projects