Air pollution and transport policies at city level

Module 2: policy perspectives

CE Delft

Committed to the Environment

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Content

Summary

Introduction

Air pollution, particularly in urban areas, is a public health concern, as clean air is vital for the quality of life and well-being of the population. Recent research for the EPHA has indicated that every European citizen faces a welfare loss of over € 1,250 per year due to poor air. However, managing air quality is a common challenge for many of Europe's cities, where public exposure to high levels of air pollution is leading to the highest health costs.

At present, the transport sector contributes roughly 40 to 50% to overall NO_x emissions and 10 to 15% to PM emissions. On average, the current share of transport in ambient NO_2 concentrations is estimated at 50%, but there are major differences among regions and cities. The same holds for ambient $PM_{2.5}$ concentrations from transport, which contribute roughly 25%.

Even though European vehicle emission standards (the 'Euro standards') will lead to a decrease in exhaust emissions, with a positive impact on air quality between now and 2030, NO_2 and PM concentrations are still projected to have considerable negative health impacts. Since exposure to these pollutants in cities is relatively high, it is here that public health is most affected. As a consequence, policy measures geared to reducing emissions and improving air quality in cities are likely to reduce the health burden and associated social costs more effectively than other measures.

Goal of this study

This study reviews the impacts of transport-related policy measures in cities and how they affect air quality. We focus on five specific measures, with particular attention to the following aspects:
- examples of implementation;
- conditions for implementation;
- effectiveness and impact on social costs;
- governance issues.

The five policy measures of interest are:
- congestion charging;
- environmental (low-emission) zones;
- car-sharing schemes;
- parking policies;
- cycling/walking policies.

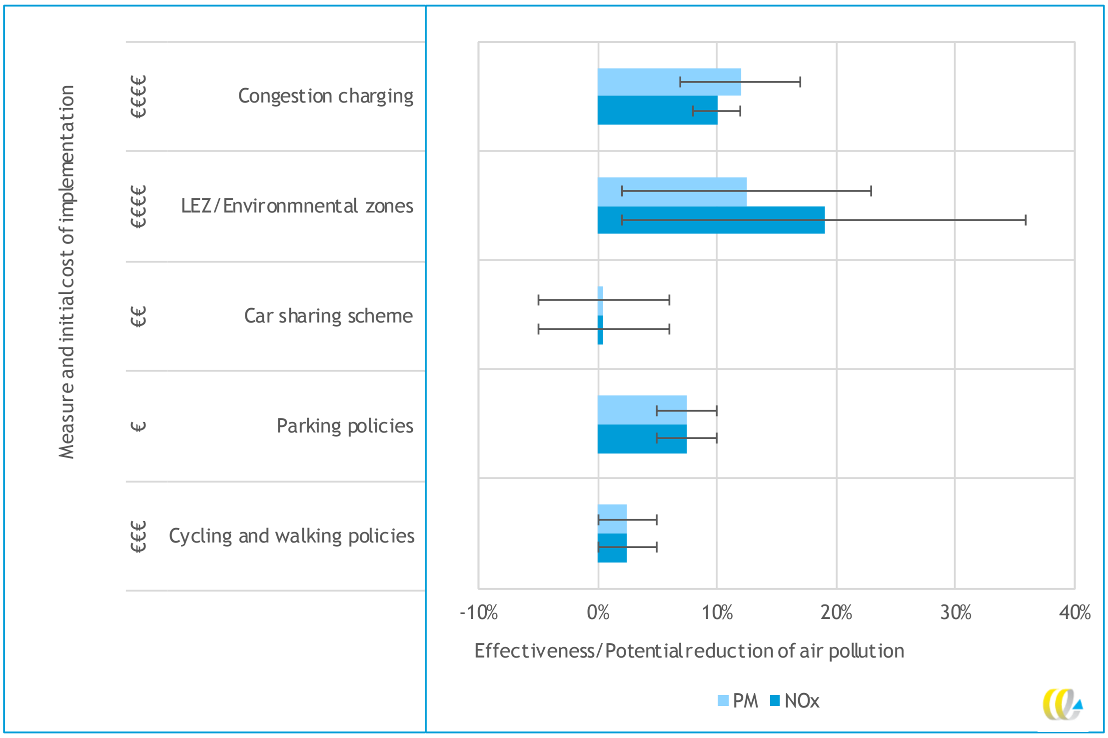
Findings

The impact of the five selected measures on PM and NO_x emission reductions are shown in Figure 1. It is clear that Congestion charging and Low-Emission Zones (LEZ)/Environmental zones have the greatest potential to reduce transport PM and NO_x emissions in cities. Based on evaluations of cities that have implemented these measures, a 10 to 20% reduction in emissions is attainable. There are major uncertainties, however, particularly for LEZ. This

illustrates, among other things, that their effectiveness depends largely on the stringency with which they are upheld and the size of the zone, which means tailor-made solutions are required to fully benefit from the potential. Parking policies can also be fairly effective, reducing PM and NO_x emissions by somewhere between 5 and 10%. Car sharing and cycling/ walking policies are much less effective in terms of PM and NO_x emission reduction, although particularly the latter has other benefits, such as increased health from active mobility and improved quality of city life if the space allocated to car traffic is simultaneously reduced.
It is possible to combine these measures to increase the total emission reduction, however, due to interactions between measures the total impact will be smaller than the sum of each part.

The Initial costs of Congestion charging and LEZ are highest, although the costs of the former can largely be recovered from the fees collected. Cycling policies are costly if infrastructural changes are required, particularly in dense city areas where the available space is limited.

Figure 1 - Potential impact of the five measures on PM and NO_x emission reduction in cities



Potential impact on social costs

Based on a previous evaluation of social costs in 432 European cities in 2018, an estimate was made of the potential reduction of social costs due to the five selected measures in 2020. Congestion charging and LEZ contribute most to reducing social costs.
For congestion charging in metropoles the expected range of social cost reduction in 2020 is between 30 and 95 mln euro per city, equivalent to 1 to 2.8% of the total social costs of these cities. For small cities the benefits can be calculated as 1 to 3 mln euro - a much smaller figure as those cities have lower social costs because they have much fewer inhabitants. For LEZ in metropoles the projected reduction in social costs is between 10 and

120 mln euro, and for small cities between 0.5 and 4 mln euro. For the other three measures (Car sharing schemes, Parking policies and Promoting of cycling and walking) the expected range of social cost reduction in 2020 is 0 to 60 mln euro in metropoles and 0 to 2 mln, euro in small cities.

These potential ‘savings’ in social costs, in addition to other benefits more commonly quantified in impact assessments, may encourage local/city governments to implement these measures: even if the initial investment costs are sometimes high, there may be a large ‘return on investment’ in terms of reduced health related social costs. The findings in this study point to the fact that the relative contribution of an individual measure is rather limited: city governments aiming to reduce the social costs should consider more than just one measure. It should also be emphasised that the reported potential social cost ‘savings’ are only a general indications of the expected benefits in terms of reduced social costs: individual authorities should carefully examine the local situation and determine the impact of any given measure on social costs for their specific circumstances. It is also important to note that transport NO_x and PM emissions will already decrease significantly between now and 2030 as a result of the Euro vehicle emission standards. This will also mean a decrease in potential social cost ‘savings’ in absolute terms.

1 Introduction

In a previous study for the EPHA, CE Delft found that the total costs of road traffic related to air pollution in the EU28[1] in 2016 were between € 67 and 80 billion (CE Delft, 2018). The share of diesel vehicles in these costs amounts to more than 80%. NO_x emissions have the largest share in the total costs (both health and non-health related) of air pollutants (65%), followed by $PM_{2.5}$ (32%). Although these costs are expected to drop considerably due to European emission legislation, the projected social costs in 2030 still amount to € 20 to 26 billion.

There is much evidence confirming that that the health impacts of transport emissions correlate with the proximity to the source. In densely populated areas where traffic volumes are high, the health impacts will therefore be more significant. There is also evidence that communities which contribute least to the problem are impacted more severely, for example because less inexpensive housing if more often situated at busy roads.

City air pollution stems from many sources: transport activities, household heating and a range of other activities including agriculture and industry (CE Delft, 2020a). Especially in cities, air pollution is an important cause of adverse health impacts. In 2018, for a sample of 432 European cities in 30 countries CE Delft (2020a) calculated that the total social costs associated with air pollution amounted to € 166 billion. City size is a key factor contributing to total social costs: all cities with a population over 1 million people feature in the top 25 cities with the highest social costs due to air pollution.

The study also looked specifically at the impacts of city transport and found evidence that transport policies significantly impact the social costs of air pollution. They find that reduced commuting and car ownership has a positive impact on air quality, thereby reducing the social costs of poor city air quality.

As a follow up on the above mentioned studies, EPHA and its national partners have asked CE Delft to review the available evidence to provide more insight into the share of transport in cities on air quality, the impact of different modes and the impact that policy measures may have to improve air quality. Some measures have been proven to be working in identified cities already.

1.1 Research question

In this research we focus on the contribution of transport to air quality in cities. The main research question is:

What is the effect of transport measures on air quality in cities?

To answer the main research question, first we answer the following questions:
- What is the share of transport in air polluting emissions in Europe?
- What is the expected share of transport in air polluting emissions in Europe in 2030?

1 EU28 in 2016 = current EU27 + United Kingdom.

- What policy measures are mentioned in literature?
- Which five policy measures are most effective in terms of costs and reduction of emissions from air pollution?

1.2 Methodology and scope

The findings in this study are based on a comprehensive literature review complemented by several interviews with experts from the field of city transport planning and or mobility related policies. Based on the findings in literature a rough estimate/calculation of the impact on social costs has been carried out. The basis for these calculations can be found in *Health costs of air pollution in European cities and the linkage with* (CE Delft, 2020a).

The report focuses on road transport measures since road transport is by far the largest contributor to air pollution in cities within the transport sector. Other sources such as household heating, industry and agriculture are out of the scope of this study as are aviation, international shipping and non-road mobile machinery.

1.3 Reader

In Chapter 2 the state of play of current NO_x and PM emission in Europe and the share of transport is highlighted. This chapter also gives information on the expected trends in transport emissions between now and 2030 and the share of transport in ambient concentrations of NO_2 and PM. Chapter 3 presents a framework for policy interventions and presents a long list of transport measures which could be adopted by cities to improve air quality. Chapter 4 focuses on five selected measures and highlights several aspects relevant for local/city policy makers considering implementation. Chapter 5 gives an overview (or resume) of the most important findings in the previous chapters.

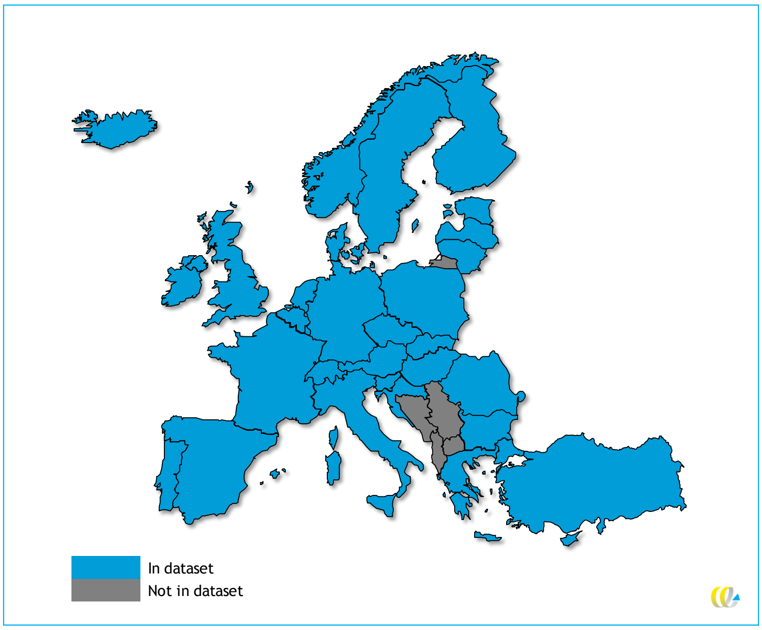
2 State of play

In this chapter we give an overview of the state of play of air pollution in the EU and in six other countries (EEA 33). We look at trends in NO_x and PM emissions between 1990 to 2018 for all sectors combined and the transport sector in particular. Following that we illustrate how NO_x and PM emissions from the transport sector are expected to develop from now to 2030. We will also zoom in on the shares of the different transport modes on emission levels. Finally we look at ambient concentrations of NO_2 and PM at the in on the urban/city level and illustrate to what extent the transport sector contributes to local air pollution.

2.1 Total emissions of air pollutants in EU

Air pollution has a significant impact on the health of the European population, especially in urban areas. A recent report from the European Environment Agency confirmed part of the EU urban population is still being exposed to air pollution above EU standards and WHO threshold level (EEA, 2020b). Most Europeans living in cities are still breathing air dangerous to their health (EEA, 2020b). There is also evidence that ethnic minorities and deprived communities hardest hit by air pollution (Imperial College London, 2015). As for harm to human health, the most serious pollutants in Europe are PM, NO_2 and ground-level O^3 (EEA, 2019a). In this paragraph we present an overview of the trends in PM and NO_x from 1990–2018 in Europe for all sectors. The overview is based on the LRTAP Dataviewer from the EEA (EEA, 2020a). The LRTAP Dataviewer contains information on emissions of air pollution in the European Union plus the United Kingdom, Iceland, Norway, Switzerland, Turkey and Liechtenstein, see Figure 2[2]. In this report these 33 countries will be called EEA33.

Figure 2 – Overview of countries in EEA dataset

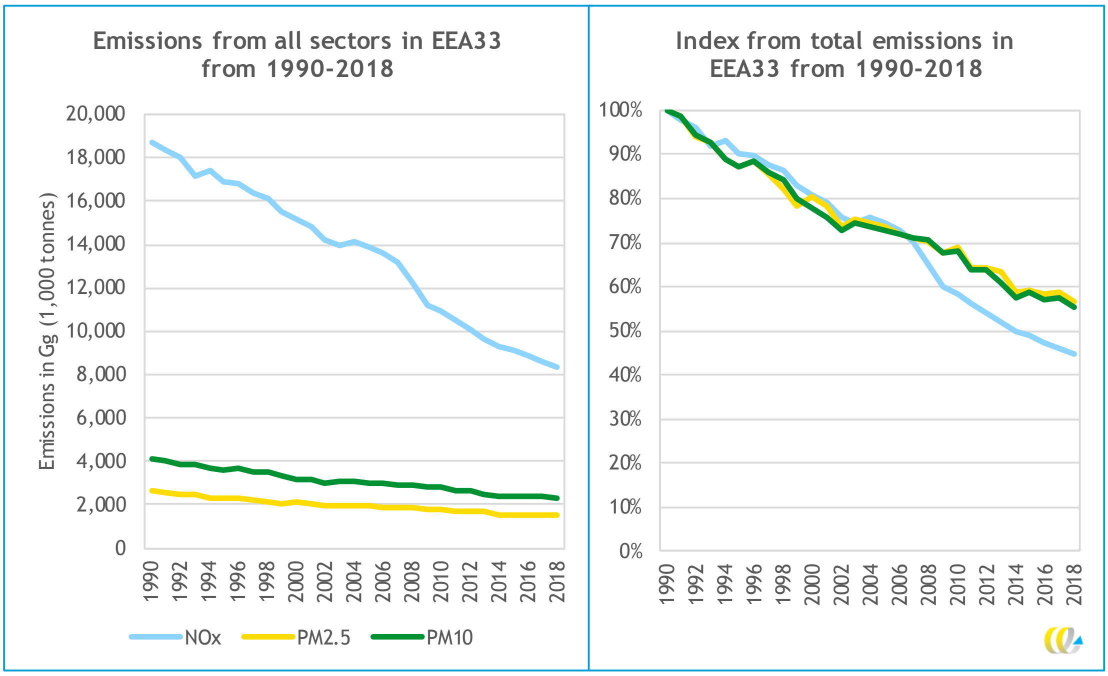


2 In the rest of the report we will use the abbreviation 'EEA33' for this group of countries.

Total emissions in EU

Figure 3 displays the PM_{10}, $PM_{2.5}$ and NO_x emissions in EEA33 from 1990–2018. All emissions are reduced by 43-55% between 1990 and 2018 for all sectors together (EEA, 2020a):
- agriculture;
- energy supply;
- manufacturing and extractive industry;
- residential, commercial and institutional;
- waste;
- transport;
- other.

Figure 3 – Total emissions in EEA33 between 1990-2018. Data obtained from: (EEA, 2020a)



2.2 Share of transport in total emissions

In Figure 4 we show the transport emissions as a share of emissions from all sectors together. **The share of transport emissions has remained about the same between 1990 and 2018.** In accordance with Figure 3, this implies a decline in transport emissions between 1990 and 2018. This finding is supported by Figure 5, where a decrease of 49-60% in emissions is shown in 2018 compared to 1990.

However, in comparison to 1990, both Figure 4 and Figure 5 show a moderate increase of emissions in the transport sector between 1994 and 2000. This is different from emissions from all sectors together because Figure 3 shows an immediate decline of emissions after 1990. The increase is the result of increased mobility (volume) which outweighed the decrease in emissions per kilometre due to emission standards mainly for road vehicles. After 2000 the ‘decoupling’ of volume growth and emissions is continued.

Figure 4 - Share of transport emissions from total emissions in EEA33 1990-2018

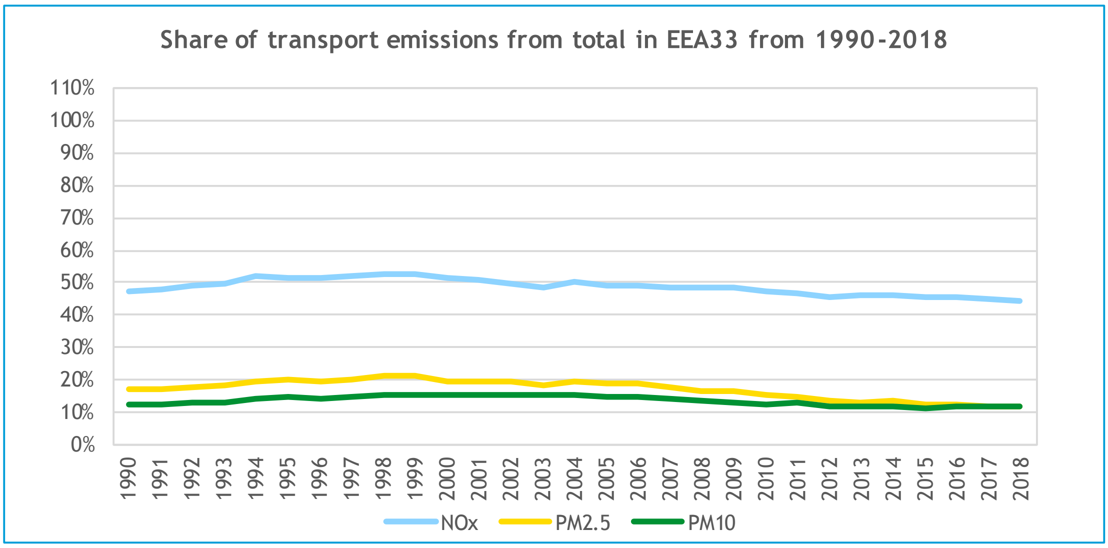


Figure 5 - Emissions from transport in EEA33 between 1990 and 2018. Data obtained from: (EEA, 2020a)

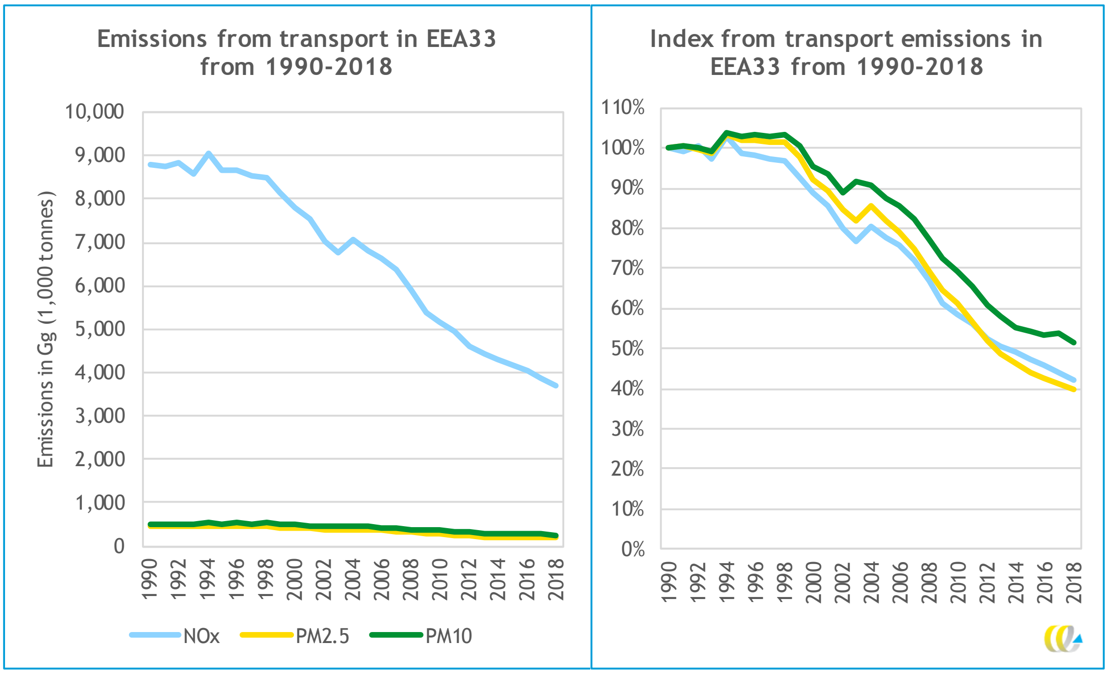


Figure 6 shows a reduction of PM_{10} emissions from 1990 onwards for the transport and non-transport sectors together. PM_{10} emissions for all sectors were reduced by about half. The share of transport in total emissions has only slightly changed between 1990 and 2018.

The share of $PM_{2.5}$ emissions from the transport sector has changed more drastically over time, as is displayed in Figure 7. In 2018, $PM_{2.5}$ emissions from all sectors are reduced by 43% compared to 1990. At the same time, $PM_{2.5}$ emissions are reduced by 60% in the transport sector.

The reduction of NO_x from the transport sector is about the same as the reduction of emissions from the non-transport sectors (53 and 55% respectively), see Figure 8.

Figure 6 - PM_{10} emissions in EEA33 between 1990 and 2018. Data obtained from: (EEA, 2020a)

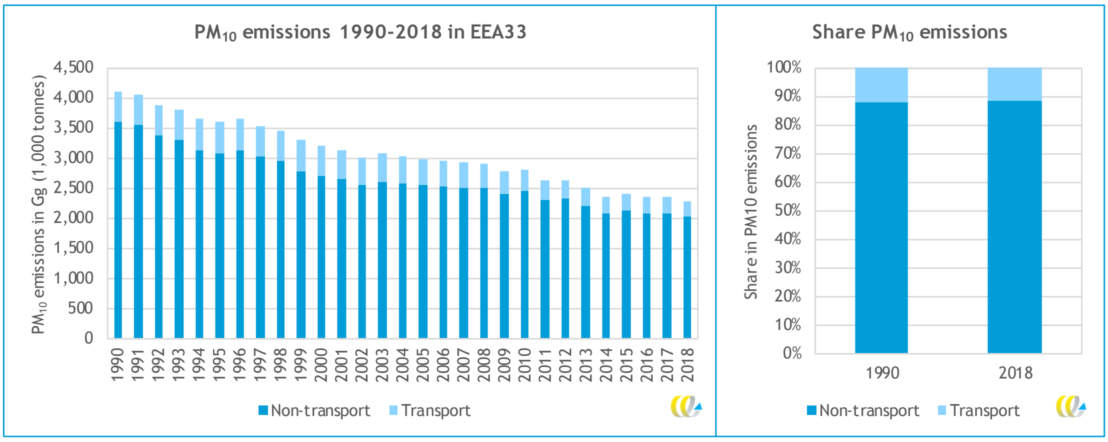


Figure 7 - $PM_{2,5}$ emissions in EEA33 between 1990 and 2018. Data obtained from: (EEA, 2020a)

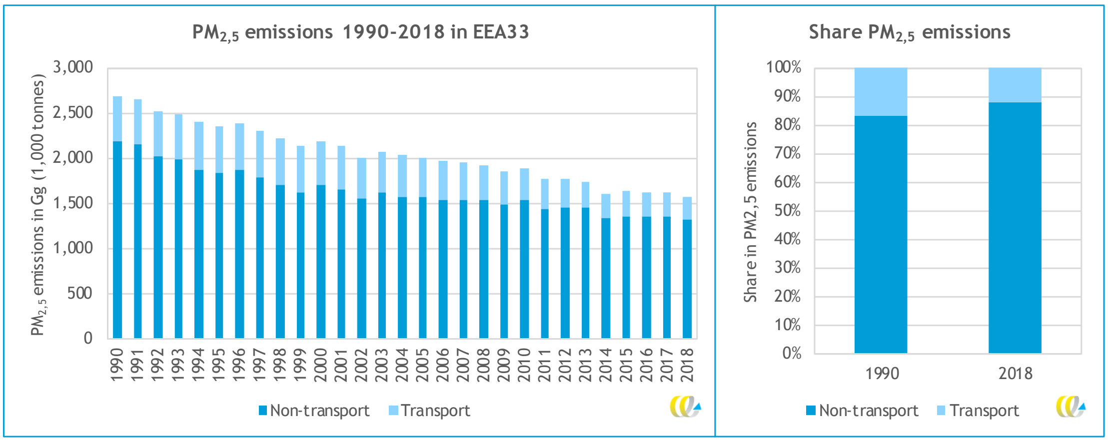
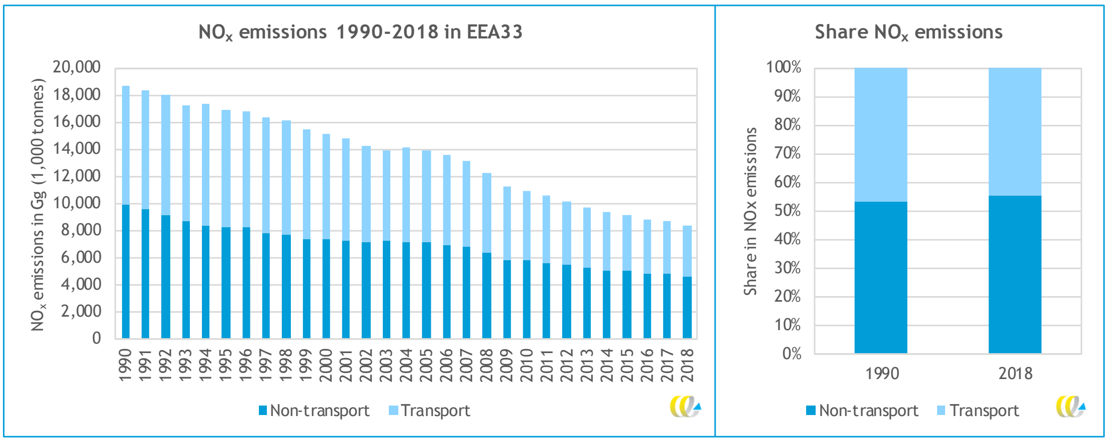


Figure 8 - NO_x emissions in EEA33 between 1990 and 2018. Data obtained from: (EEA, 2020a)



Figures 9 and 10 display the PM_{10} and NO_x emissions per country in the EEA33. Most countries show a reduction of PM_{10} and NO_x emissions between 1990 and 2018. However, emissions have increased between 1990 and 2018 in eight countries: NO_x emissions have increased in Poland, Romania and Turkey and PM_{10} emissions have increased in Turkey, Sweden, Slovenia, Romania, Poland, Hungary, Croatia and Bulgaria. From these countries, Poland was in 2018 the fifth most polluting country in EEA33 for PM_{10} and NO_x emissions. This is also visible in Table 1, where the top 5 most polluting countries in EEA33 is presented for the years 1990 and 2018. The top 5 in 1990 contains the same countries for both PM_{10} and NO_x emissions. The same applies to 2018 and the top 4 countries are the same as in 1990, although the order has changed. The fifth country in 1990 (Spain) is replaced by Poland as fifth most polluting country in the EEA33 in 2018.

Table 1 - The 5 most emitting countries for NO_x and PM_{10} emissions in 1990 and 2018 in EEA33 in Gg (1,000 tonnes). Based on (EEA, 2020a)

NO_x				PM_{10}			
Top 5 1990		Top 5 2018		Top 5 1990		Top 5 2018	
UK	1,645	Germany	531	Germany	105	Germany	39
Germany	1,508	France	452	France	78	France	32
France	1,278	UK	410	Italy	69	Italy	27
Italy	1,119	Italy	377	UK	60	UK	23
Spain	660	Poland	295	Spain	34	Poland	18

Taking Brexit into account, the top 5 for the European Union is slightly different than the top 5 for EEA33. The top 3 most polluting countries remains the same but the Netherlands has entered the top 5 in 1990 and Spain (NO_x) and Sweden (PM_{10}) have entered the top 5 in 2018 if only EU27 countries would be considered.

Table 2 - Top 5 countries PM_{10} emissions in 1990 and 2018 in in EU27 Gg (1,000 tonnes). Based on (EEA, 2020a)

NO_x				PM_{10}			
Top 5 1990		Top 5 2018		Top 5 1990		Top 5 2018	
Germany	1,508	Germany	531	Germany	105	Germany	39
France	1,278	France	452	France	78	France	32
Italy	1,119	Italy	377	Italy	69	Italy	27
Spain	660	Poland	295	Spain	34	Poland	18
Netherlands	319	Spain	281	Netherlands	20	Sweden	18

Figure 9 – PM_{10} emissions from transport sector per country in Europe 1990 and 2018. Data obtained from: (EEA, 2020a)

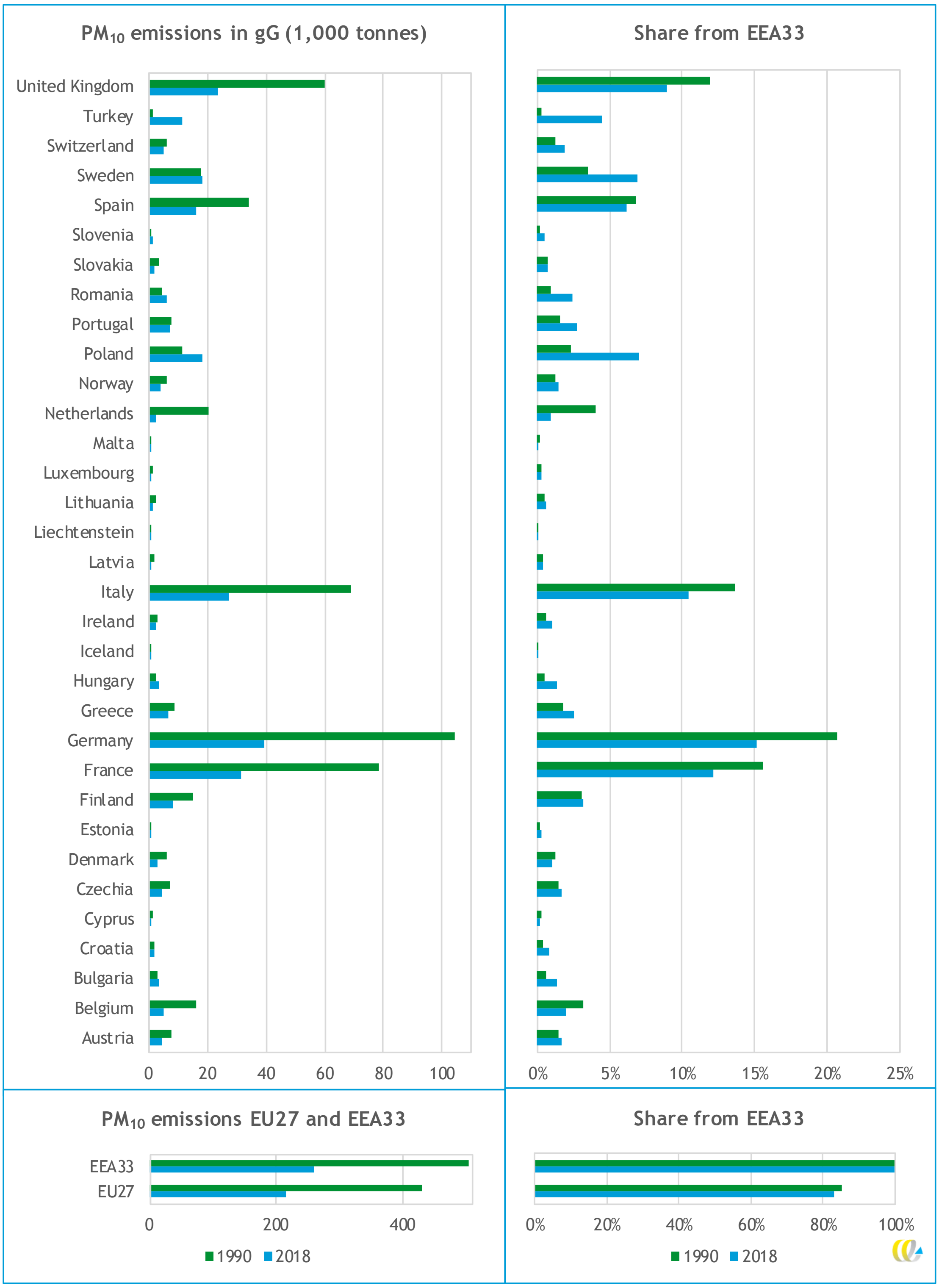
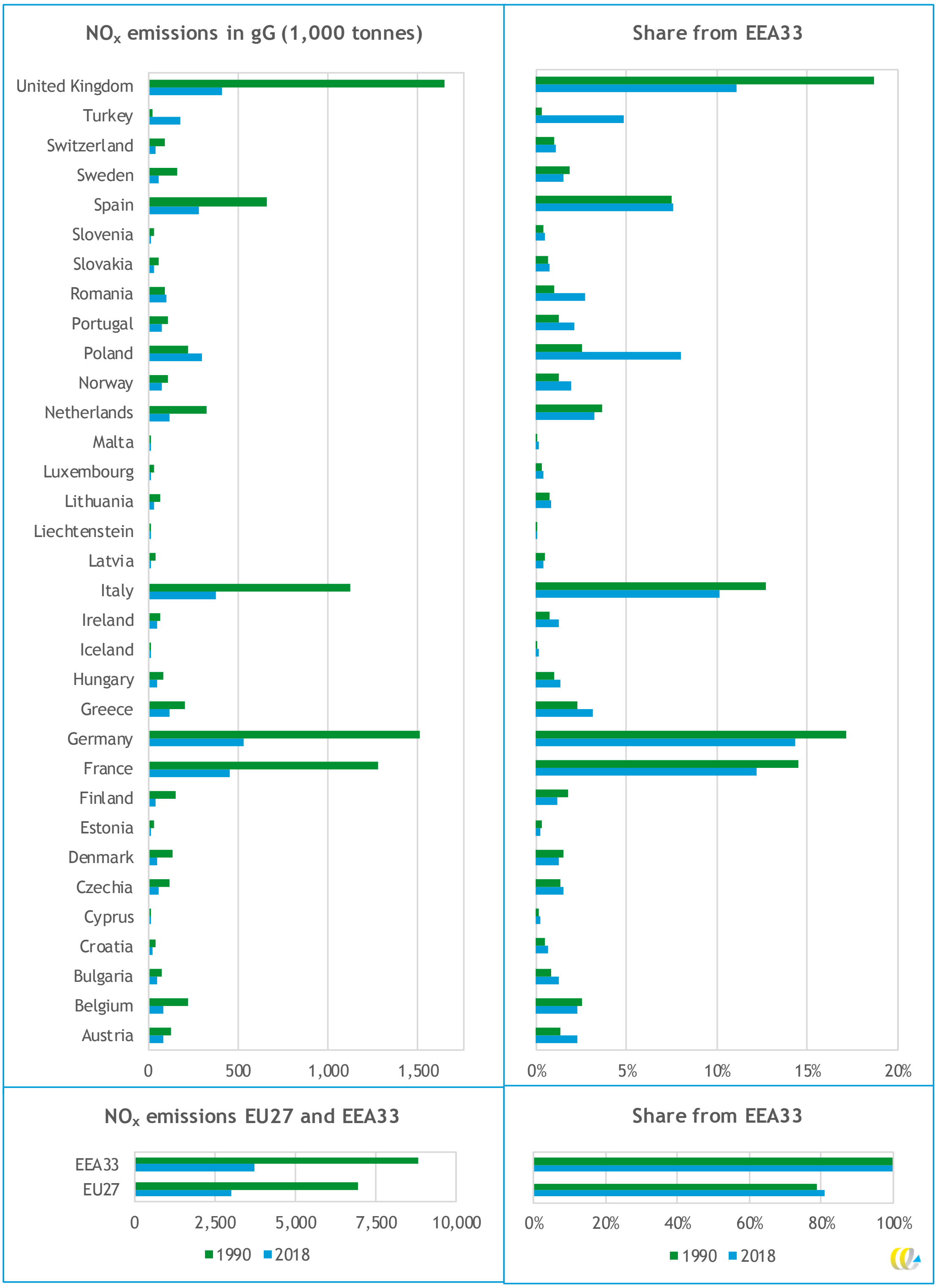


Figure 10 - NO_x emissions from transport sector per country in Europe 1990 and 2018. Data obtained from: (EEA, 2020a)



2.3 Shares of different modes of transport

In this paragraph we present an overview of the emissions in the transport sector, divided by mode of transport. Figures 11 and 12 show that both for NO_x and PM_{10} emissions road transport dominate total emissions from transport[3]. The shares of road transport in 2018 are 83% for PM_{10} and 82% for NO_x. Additionally, emissions from road transport are the main cause of pollution from transport in urban areas. Therefore, we will focus on emissions from road transport in the rest of this paragraph.

Figure 11 - Trends in PM_{10} emissions from 1990-2018 (EEA, 2020a)

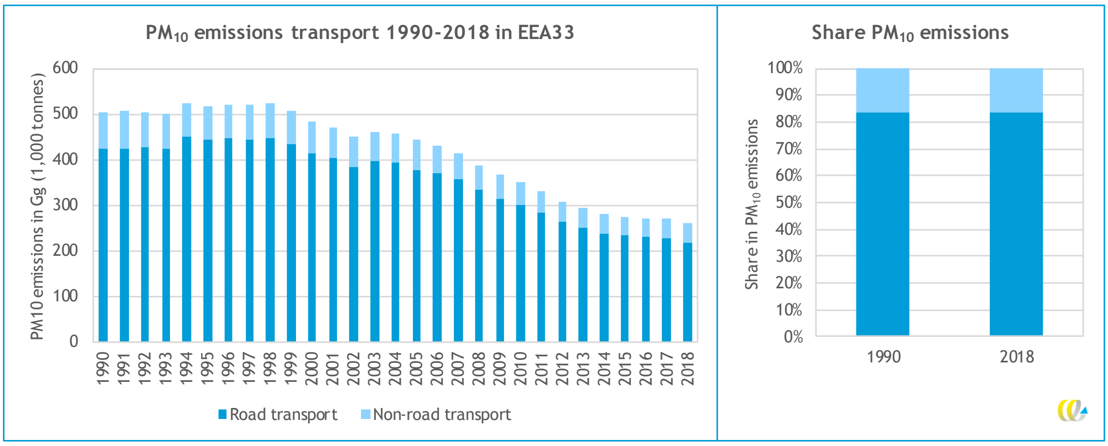
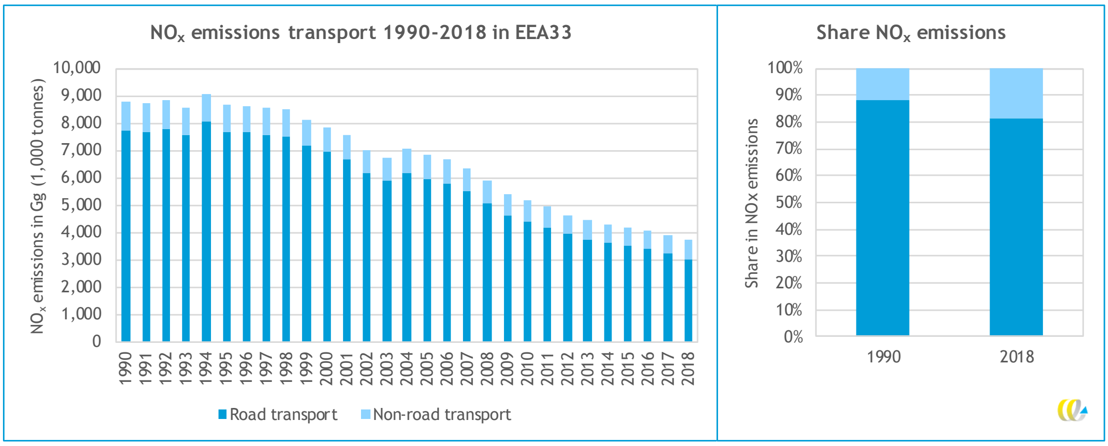


Figure 12 - Trends in NO_x emissions from 1990-2018 (EEA, 2020a)

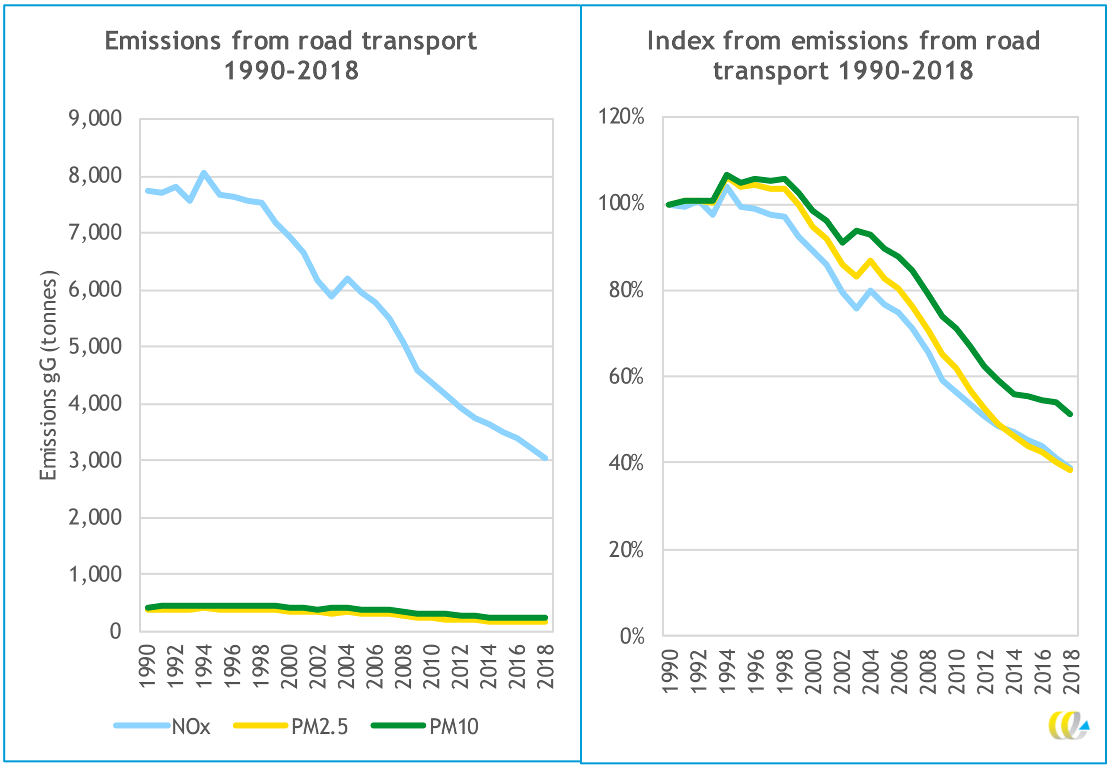


3 Road transport includes the following modes of transport: HDVs and buses, LDVs, moped and motorcycles, other road transport (Gasoline evaporation, automobile tyre and break wear, automobile road abrasion) and passenger cars. Non-road transport includes the following modes of transport: domestic aviation, international aviation, international inland waterways, national navigation, other transport and railways (diesel) (IPCC, ongoing; EEA, 2020a). Agricultural machinery and mobile combustion from construction and industry is not included in this dataset.

Trends in emissions between 1990 and 2018 per mode of transport

All emissions in road transport are reduced by at least between 1990 and 2018, see Figure 13.

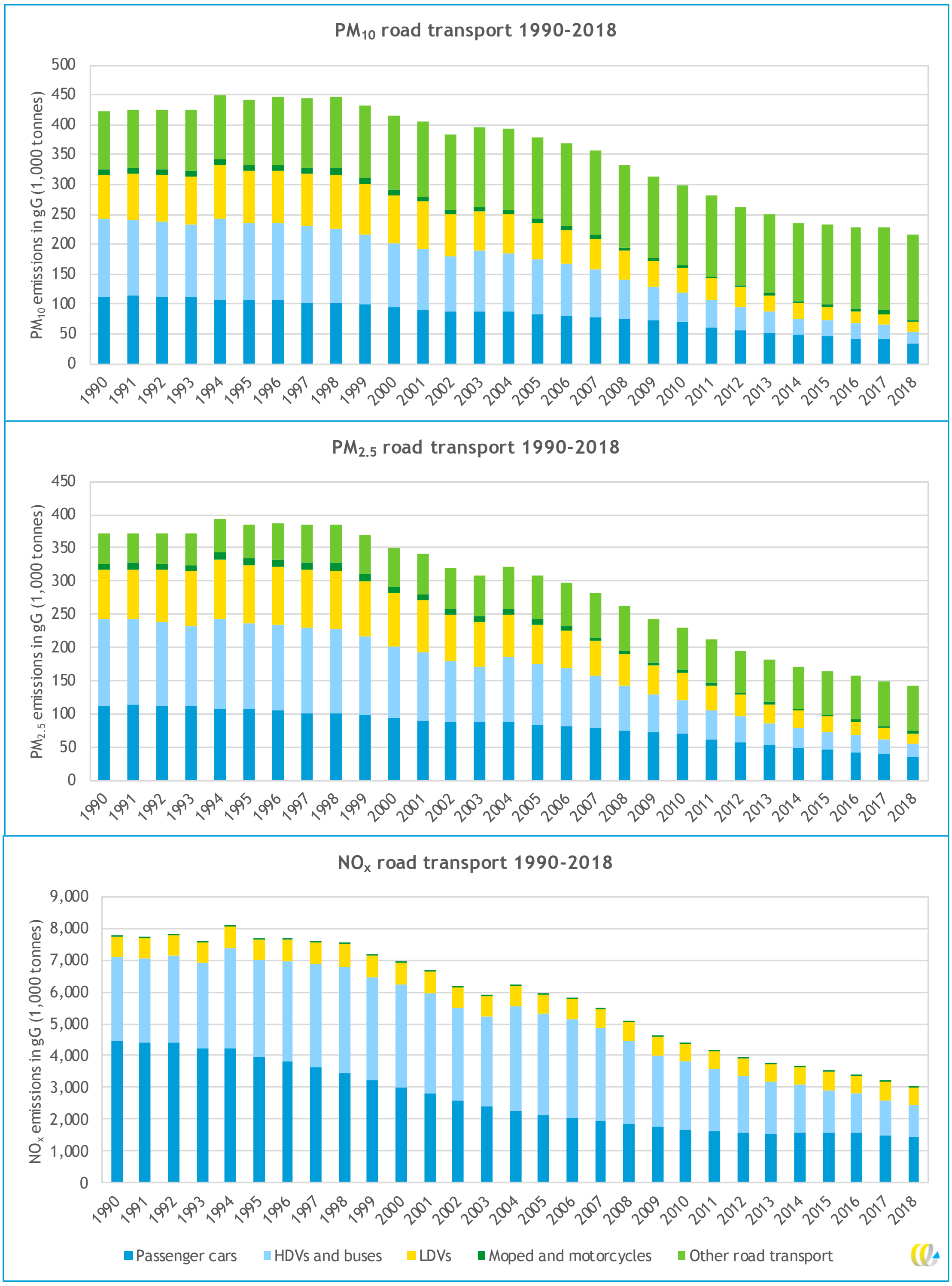
Figure 13 - Emissions from road transport in EEA33 between 1990 and 2018. Data obtained from: (EEA, 2020a)



In accordance with Figure 14, in 1990 PM_{10} and $PM_{2.5}$ emissions were mainly caused by **passenger car, HDVs and buses**. However, in 2018 the main source of PM emissions in road transport is ‘other road transport’. The PM emissions from other road transport have increased between 1990 and 2018 while PM emissions from passenger cars, HDVs, buses and LDVs are significantly reduced.

Both in 1990 and 2018, NO_x emissions in road transport were mainly caused by **passenger cars and HDVs and buses**, despite the fact that emissions from these modes were reduced by about 60% over time. Annually, NO_x emissions caused by LDVs have been about the same and NO_x emissions from moped, motorcycles and other road transport were hardly present.

Figure 14 - PM_{10}, $PM_{2.5}$ and NO_x emissions in EEA33 between 1990 and 2018 in road transport per mode of transport. Data obtained from: (EEA, 2020a)



2.4 Projected transport emissions

In the previous paragraphs we have shown that NO_x and PM emissions from the transport sector have decreased between 1990 and 2018. In this paragraph we will show how the trend will continue until the year 2030 based on current policy measures in road transport (e.g. measures that are already in place).

From CE Delft (2018) we know that the lion share of all air pollution costs from road transport is caused by diesel emissions, which is mainly caused by the PM emissions from diesel exhaust. This is harmful because the PM emissions from diesel exhaust mainly consist of (ultra)small particles that can penetrate deep into human tissue (CE Delft, 2018). Therefore, in our projections we distinguish costs from diesel exhaust and from petrol exhaust.

The projections in this paragraph are based on data from the GAINS database (IIASA, 2018). GAINS includes detailed data on emissions per vehicle type and country both for 2016 and 2030 (CE Delft, 2018). The results are presented in Figure 15. The analysis shows that $PM_{2.5}$ and NO_x emissions will continue to decrease between 2016 and 2030 due to new policy measures, while PM_{10} emissions from non-exhaust sources[4] will increase as the emissions from brake, wear and tear will remain more or less constant per vehicle-km but the number of kilometres driven in 2030, will increase (CE Delft, 2018).

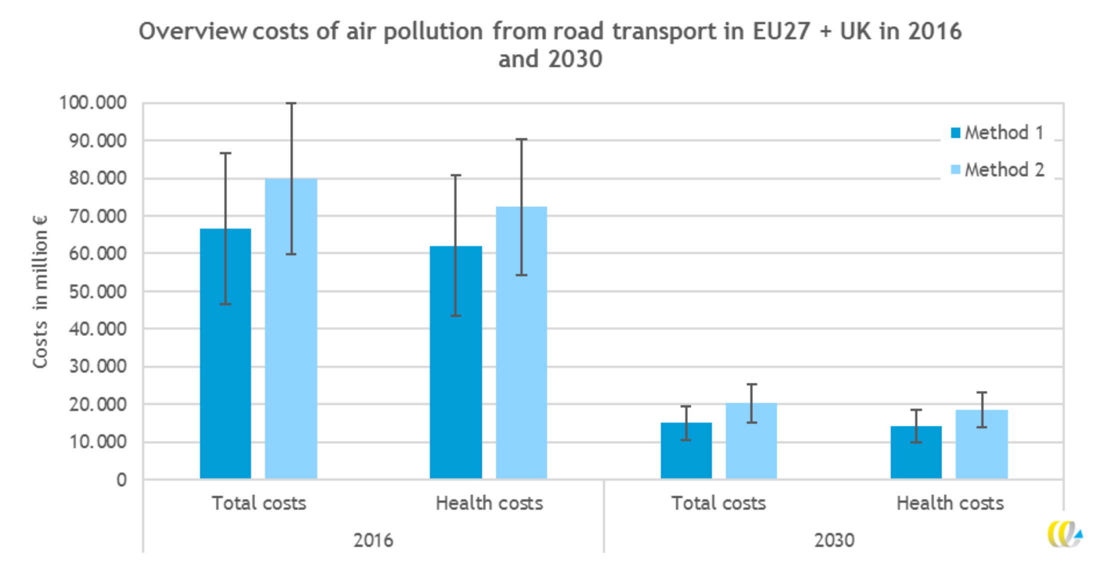
Both from the previous study and the current analysis, GAINS predicts a decline in PM and NO_x emissions from diesel and petrol exhaust between 2018 and 2030. This leads to a reduction of social costs in 2030.

All figures and trends presented in this paragraph are pre-COVID-19. The impacts of the pandemic and the measures that governments adopted to curb it are not yet visible in the emission databases nor in the emission projections. This will no doubt be done in the coming years. Depending on how long the measures will have to remain in place, the impact on future emission levels may be substantial. Text box 1 gives some information on the possible impact on NO_x and PM emissions.

4 Non-exhaust emissions = brake, wear and tear emissions.

Figure 15 – NO_x and PM projections in 2030 compared to 2016 based on Gains database (IIASA, 2018)

Figure 16 - Summary of costs from road transport in 2016 and in 2030 based on two methods



Source: Data obtained from (CE Delft, 2018).

Text box 1 - Impact from COVID-19 on emissions of air pollutants (EEA, 2020b)

In 2020 the COVID-19 virus changed the transport and mobility sector. Globally, countries have introduced lockdown measures which forced its inhabitants to stay at home and reduce their movements. In its annual report on air quality in Europe, in 2020 the EEA has adopted an assessment of the impact of these measures on air quality across Europe. The assessment is based on statistical data, satellite data and computer models during spring 2020, focusing on NO_2 and PM_{10}. The assessment of the impact of the lockdown is more uncertain for PM_{10} levels, because PM_{10} emissions vary due to a variety of factors, such as meteorology and emissions from natural sources. Emissions from natural sources are difficult to predict, which makes the outcome of the models more uncertain.

Nevertheless, it is certain that lockdown measures in European countries led to significant reductions in emissions of air pollutants. These reductions come particularly from road transport, aviation and international shipping. The transport of goods and its corresponding emissions of air pollutants were only little affected (EEA, 2020b).

NO_2

During April 2020, levels of NO_2 were reduced in all assessed locations. These reductions were highest at the most affected COVID-19 locations due to more severe lockdown measures (Spain, Italy and France) and in urban areas with high population densities. The reductions of NO_2 emissions was substantial in European agglomerations with more than 0,5 million inhabitants. Especially in Barcelona and Milan, where the reduction was over 50% (EEA, 2020b).

PM_{10}

The reductions of PM_{10} emissions are more homogeneous over Europe than emissions form NO_2. The overall magnitude of the change is similar, about 20% reduction. However, the largest reduction of PM_{10} is in urban and suburban areas in Spain (average 30%) and UK, Italy, Austria (about 20% reduction). Nationwide, the greatest reductions were in Spain and Italy (average almost 40 and 35%), France and Norway (approximately 25% reductions) (EEA, 2020b).

2.5 Ambient concentrations and share of transport

Although emission levels are an important indicator of air quality, the EU's air quality directive on Ambient Air Quality (2008/50/EC) deals with pollutant concentrations in the air measured in ug/m^3. The EEA's Europe's urban air quality report states (EEA, 2019b):

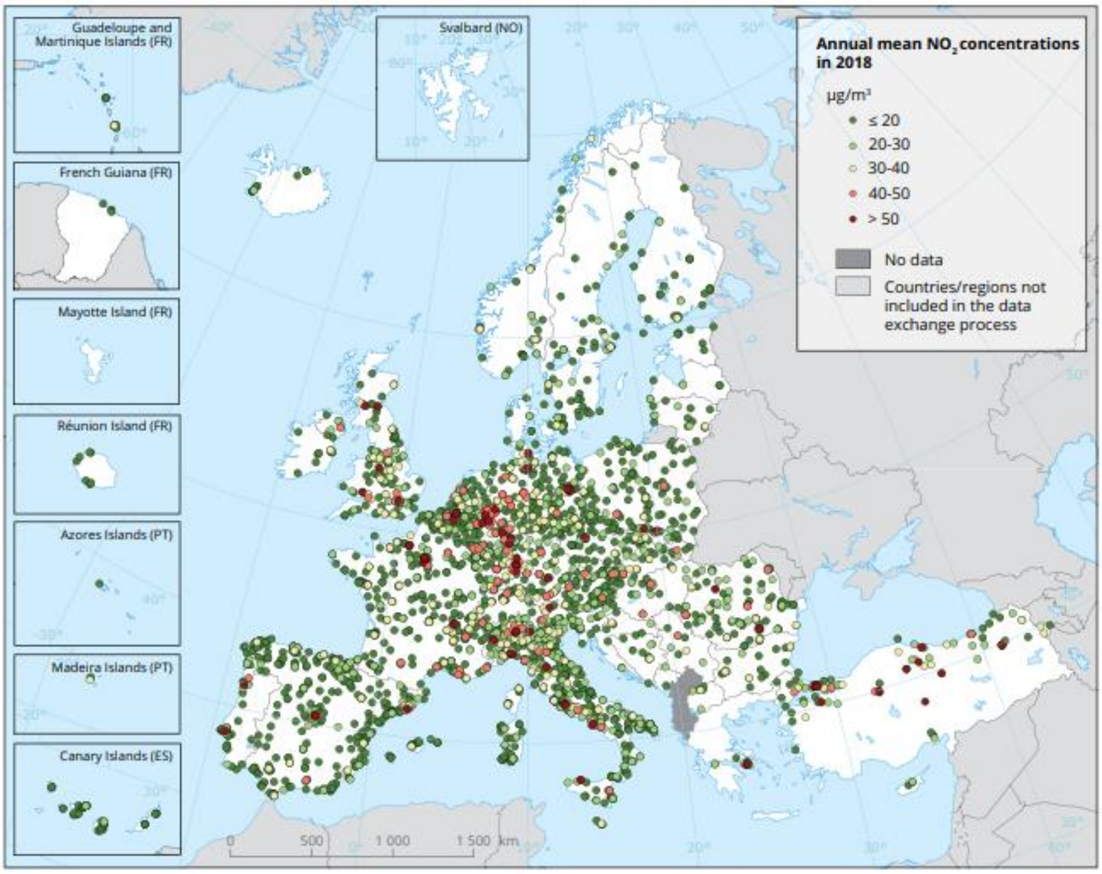
> *Air pollution, particularly in urban areas, is a public health concern, as clean air is vital for the quality of life and well-being of the public in Europe. Managing air quality is a common challenge for many of Europe's cities, where the population's exposure to high levels of air pollution can be considerable because of a mixture of urban activities, proximity to road traffic emissions and the difficulty of dispersing air pollutants away from highly urbanised areas. Cities can also be affected by poor air quality because of background concentrations caused by transboundary emissions from industrial and agricultural activities, as well as city-specific emissions from the transport and energy sectors.*

The spatial distribution of NO_2 and PM concentrations can be determined through measuring stations throughout Europe supplemented with dispersion models that calculate atmospheric reactions of different compounds and the impact of weather conditions as an average of monitoring stations. In reality, stations may already underrepresent pollution in a city as local governors may also have an impetus to limit the measurement of air pollution to allow for greenwashing the city pollution. The actual level of pollution should be significantly higher in some areas and therefore be subject of more study in the future. Figures 17 and 18 illustrate the dispersion of PM_{10} and NO_2 concentrations in 2018 based on measurements (all sources, not just transport) (EEA, 2020b). Concentration levels exceeding the European limit values are depicted in red.

A keen eye can see quickly that high NO_2 concentrations are dominantly located in densely populated areas (Northern part of Italy, the 'Ruhrgebiet' in Germany and the ports of Rotterdam and Antwerp and all major capital cities such as London, Paris, Madrid, etc. This is confirmed in the annual "Air quality in Europe" report by the EEA which says (EEA, 2020b):

> "*The highest concentrations, as well as 95 % of all values above the annual limit value, were observed at traffic stations, including two rural traffic stations, the only rural stations with concentrations above the annual limit value. Traffic is a major source of NO_2 and nitrogen monoxide (NO) (which reacts with ozone (O^3) to form NO_2).*"

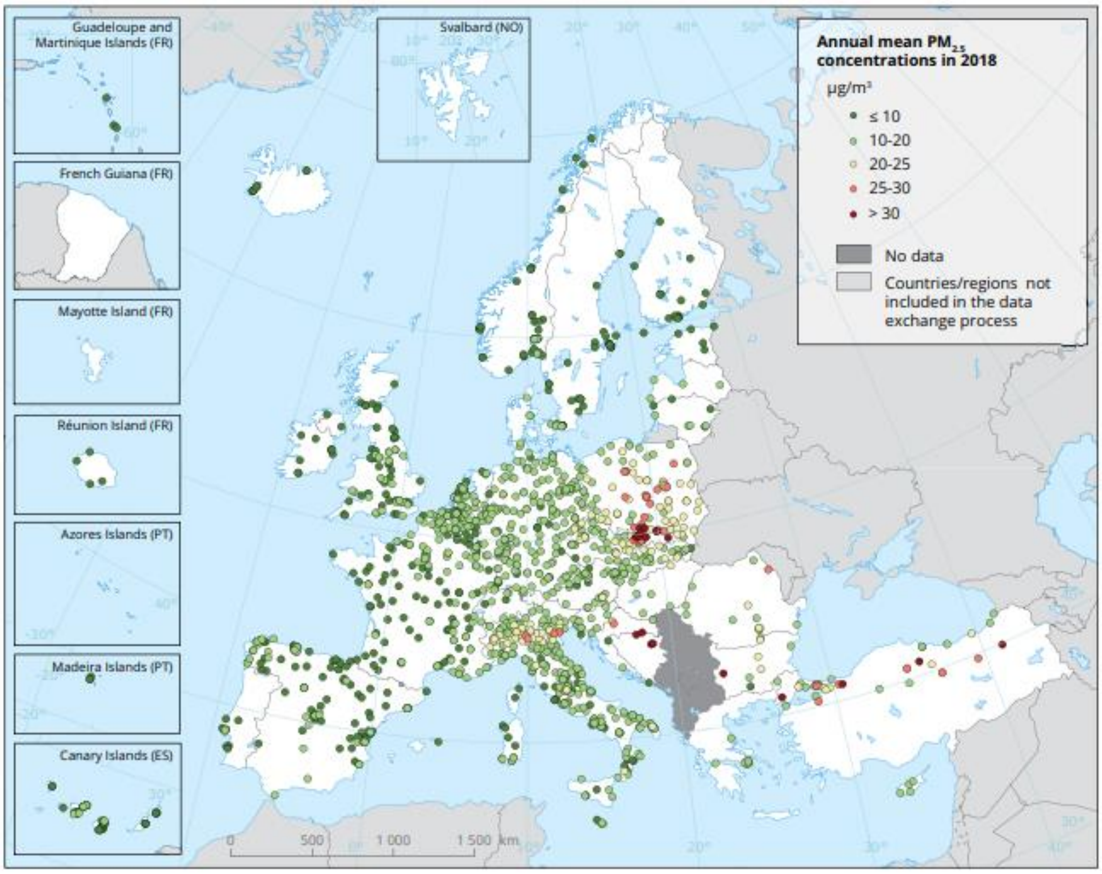
Figure 17 – Concentrations of NO_2 in 2018



Source: (EEA, 2020b).

For $PM_{2.5}$ exceedances of the EU annual limit value were less numerous in 2018. Nevertheless higher $PM_{2.5}$ concentrations occur primarily in urban areas (EEA, 2020b).

Figure 18 - Measured $PM_{2.5}$ emissions in Europe in 2018



Source: (EEA, 2020b).

Although the correlation between urban density and concentration hot spots seems obvious, determining the precise contribution of the transport sector to (local) concentrations remains very challenging. The contributions from the various emission source sectors to ambient air concentrations and air pollution impacts depend not only on the amount of pollutant emitted but also on the proximity to the source, the emission conditions (e.g. height and temperature) and other factors such as dispersion conditions and topography (EEA, 2018).

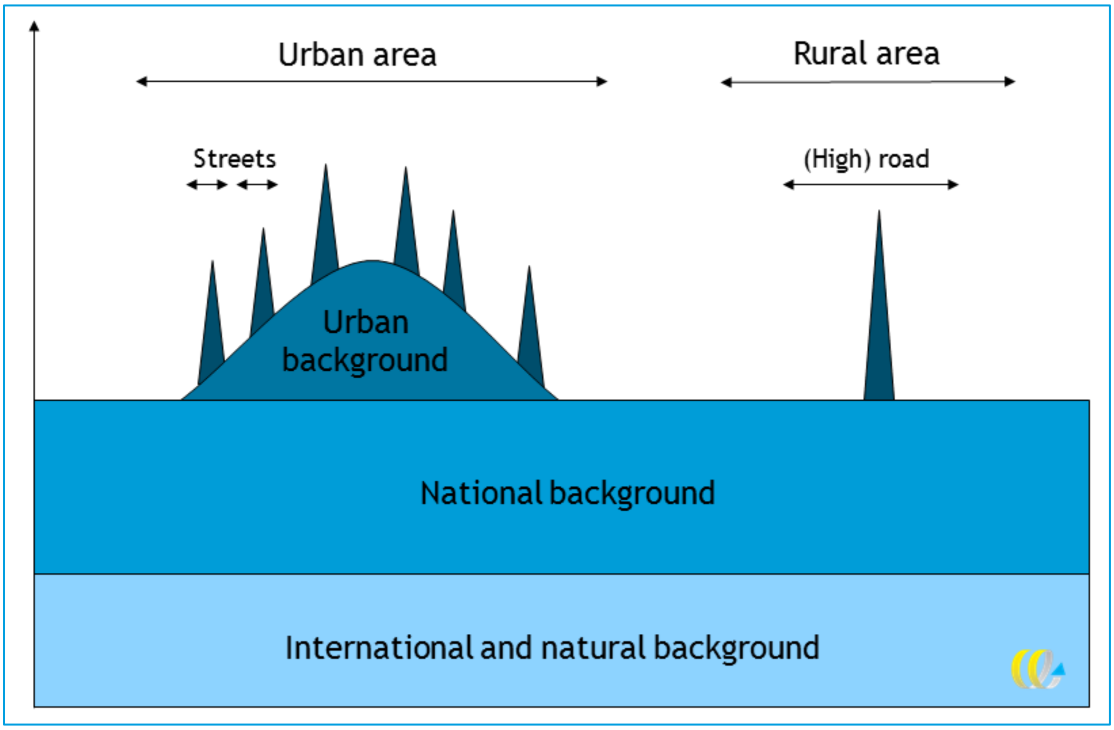
Figures 17 and 18 show concentrations of $PM_{2.5}$ and NO_2 for all sources combined (industry, households, agriculture, etc.) not only the transport sector. Although there is a clear link between urban density and the level of concentrations, and traffic intensities are higher in more populated areas, the contribution of transport to the total concentration level cannot be precisely derived from these figures. **It is important to note that the share of transport in ambient concentrations will vary greatly from location to location, from street to street**. This can be illustrated by looking at Figure 19. It gives a schematic overview of the local concentration and a crude division of its origins which will describe in short:

- **International and natural background**. This level contains (for a specific location) emissions that are non-domestic in nature. These are emissions from other countries that are carried through the atmosphere and stem from all kinds of sources and also include emissions from international shipping and emissions from natural sources, such as sea salts.

- **Domestic background.** This is the part of the total concentration level of all domestic emitting polluting sources.
- **Urban background.** This is comprised of the combined emissions within the urban area.
- **Local spikes.** These are caused by local sources which in urban areas are mostly busy road with motorised traffic. Spike can also occur in close proximity of (large) agricultural facilities.

It is known that on average transport (due to its emissions on street level) generally makes a larger contributions to surface concentrations and health impacts in urban areas than emissions from, e.g. high industrial stacks (EEA, 2020b).

Figure 19 - Schematic overview of the build-up of ambient concentrations



Source: Translated from RIVM **(2020)**.

A study by the Joint Research Centre (JRC) identifies the main current sources of NO_2 pollution for 30 major European cities (Degrauewe, et al., 2019). The average contribution of transport to overall nitrogen oxides (NO_x) emissions was 47%. The report also shows that the shares of road transport in total local NO_x emissions differ considerably across Europe. They show that in Athens and Milan over 70% of emissions comes from transport, while in Lisbon, where shipping emissions are high, road transport is only responsible for 20% of NO_x pollution. This shows that the impact of policy measures to reduce NO_x emissions will also differ significantly from city to city.
Karagulian et al. (2015) estimate the share of transport to $PM_{2.5}$ emission in cities at 25% but also state that significant differences occur between regions and cities. Differences in the contribution from various sources from country to country and city to city are also found by IIASA (Kiesewetter & Amann, 2014).
Nevertheless, scientific literature evidences that the share of transport emissions to health related social costs is larger than the share of the emissions for two reasons: First, transport

emissions are mostly (except for aviation) emitted at ground level implying that intake fractions in the human body can be substantially increased (Humbert, et al., 2011). Second, most transport is taking place in areas where many people live — both for passenger and freight transport and hence the exposure of population to transport related emissions is higher than to emissions of industry or electricity plants.

3 Policy intervention

This chapter gives general information on the possible policy interventions and the points of engagement policy makers can aim for. Also a long list of measures that have the potential to reduce transport emissions in cities is presented including a qualitative assessment of their costs and effectiveness.

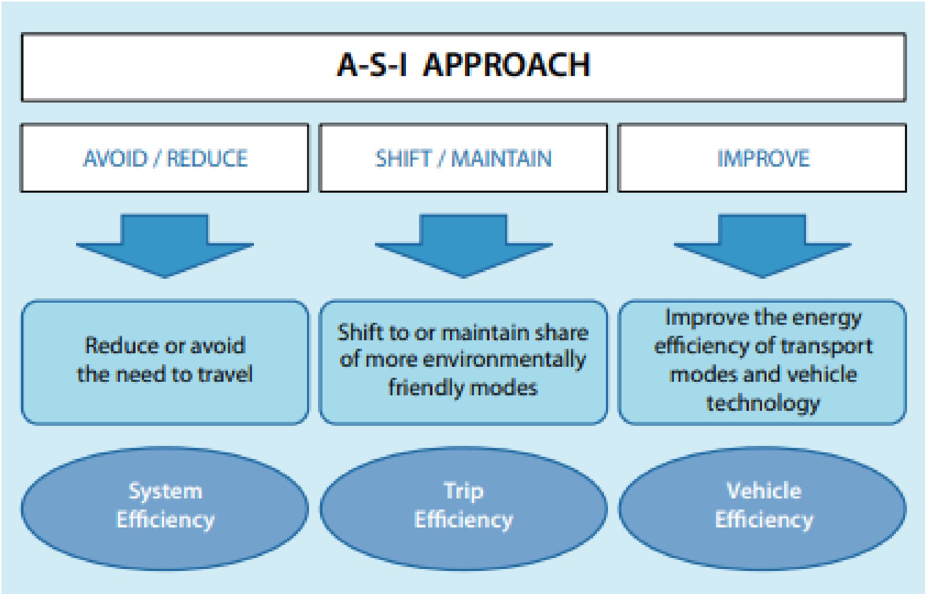
3.1 Avoid, Shift, Improve

Recently the World Health Organisation (WHO) has advised governments to promote more healthy and green economic activities. With regard to air pollution it calls on governments to (WHO, 2020b):
- protect nature and preserve clean air;
- invest in clean energy to ensure a quick healthy energy transition, which will also bring co-benefits in the fight against climate change;
- build healthy, liveable cities, focusing on mobility issues, such as public transport, and promotion of walking and cycling;
- stop using taxpayer's money to subsidise the fossil fuels that cause air pollution.

In Chapter 2 we have seen that the transport sector contributes substantially to air pollution plus that exposure to transport emissions is more prominent than in other sectors. It stands to reason therefore that adopting measures to reduce transport emissions can improve air quality to a relatively large extent (EC, 2021), particularly in cities were exposure is relatively high. Finding out which measures can be effective is what we will look at in this chapter.

Reducing the impact of transport emissions can be done in many different ways. To increase our understanding of the numerous policy interventions available we adopt the Avoid, Shift and Improve (ASI) framework from the EEA (see Figure 20). This framework has three basic levels in which the transport system can be transformed in order to achieve lower emission levels (and consequently improved air quality). We will first describe shortly the three elements of the ASI framework. Below that we give a long list of measures for the three ASI elements.

Figure 20 - Avoid, Shift, Improve framework



Source: (SUTP.org, 2011).

3.1.1 Avoid

Avoiding or reducing transport refers to options that increase the efficiency of the transport *system*. This can be attained by managing transport demand, avoiding unnecessary trips and increase the occupancy of vehicles.

Reducing the distance travelled per capita leads to an immediate reduction in emissions and can therefore be very effective to improve air-quality. Research has proven that there is great potential to reduce environmental pressures from transport through the avoidance of unnecessary trips, especially in the urban context (JRC, 2013). It will require changes in everyday practices, but not necessarily a change in current lifestyles (Givoni & Banister, 2014). Nevertheless, altering mobility behaviour through policy measures may also trigger some resistance, particularly if mobility demand is restricted in some way.

Many avoid measures are within reach of local governments. Parking policies, environmental or congestion zones, car sharing schemes in the EU are typically implemented and/or managed at local government level.

3.1.2 Shift

Instruments that shift mobility from less environmentally friendly (and harmful to health) to more environmentally friendly can also contribute significantly to the reduction of transport emissions and lead to more active mobility. Particularly a shift to non-motorised, active modes of transport (walking and cycling) and public transport can contribute to a reduction in emissions.

Shift measures can be encouraged by spatial and city planning, for example by investing in cycling infrastructure at the cost of car/vehicle infrastructure. Also dedicated infrastructure for public transportation can promote a shift to more environmentally friendly (and in case of walking and cycling) healthier modes. Such measures, sometimes also referred to as 'micro-mobility' are typically within reach of local/city governments.

3.1.3 Improve

The Improve component of the ASI framework deals with the use of cleaner vehicles with lower emissions per kilometre driven. Newer cars with more stringent European emission standards, other fuel types (petrol instead of diesel) and the adoption of zero emission vehicles (ZEVs) have proven to be very successful in reducing (among other components) NO_x and PM emissions from transport.

Cities and/or local governments can encourage the use of cleaner vehicles by introducing environmental/low-emission zones in which older, less environmentally and health friendly vehicles are not allowed to enter. There have also been examples of local fiscal incentives such as scrapping schemes that promote the adoption of cleaner vehicles and simultaneous scrapping of other older more polluting vehicles.

3.1.4 Combining measures

An effective policy approach will not focus on a single measure nor on a single pillar of the ASI framework. In fact, many measures will have Avoid, Shift *and* Improve elements. For example, increasing parking fees in a city area will reduce the amount of car traffic entering the city (Avoid) and at the same time will lead to a Shift towards other transport modes such as public transport, cycling and walking. Introducing an Improve measure such as electric car sharing system might also reduce car ownership which leads to a reduction of car use (Avoid).
It is also important to note that although it is possible to combine measures to increase the total emission reduction, due to interactions between measures the total impact will be smaller than the sum of each part.

Also, policy interventions will need to be tailor made taking into account the city characteristics, political willingness and commitment, public acceptance, the need and desire to tackle health inequalities, etc. We will discuss this in more detail in Chapter 4, where we focus on five specific measures to improve air quality. Before that, we recommend to read about two interesting cases of local air quality programmes in the German Bundesland Baden-Württemburg and the Brussels metropolitan region. For Baden-Württemburg, a five year integral policy approach was adopted with substantial impacts on air quality. For the Brussels region, a comprehensive plan of modal shift and fleet renewal in parallel with a regional-wide *Low-Emission Zone* was implemented. See Text box 2:

Text box 2 - Experience on air quality measures from Baden-Württemberg and Brussels capital region

Baden Württemberg

Over the past decades, cities in the state Baden-Württemberg (Germany) dealt with serious air pollution. The post-war design of the cities infrastructure facilitated the use of automobiles, which caused many monitoring stations to report air quality levels among the worst of the country. Even after the introduction of Low-emission zones in medium to large cities, banning the use of the oldest and most polluting cars, the level of NO_x in many cities was still above the EU norms (for a large number of days per year) for what is considered healthy air quality. From 2015 onwards, the state authority and local governments agreed that stricter measures had to be implemented in order to improve air quality to an acceptable level. However, they realised the timeframe of implementation and the measures to have an effect would be 3-5 years.
A major barrier was that public awareness and political willingness were relatively low. Therefore, an awareness campaign was held throughout the state, announcing the critical state of the air in cities. There was

a lot of attention for the '*fine dust alarm'* campaign ('feinstaubalarm') and as a reaction people adjusted their transport behaviour leading to a 5% decrease of car use in some areas.

After that the authorities gained confidence that stricter measures could be proposed as opposition against these plans would be lower than before the campaign. A diesel ban was considered in the centre of larger cities, causing a fierce debate locally and even at the national level. As this ban was not widely supported, the transport ministry introduced a package of several complementary measures in order to reduce transport borne air pollution. Among the measures were speed limits in cities at major roads, traffic management in and around the city, ambient air filters at most heavily trafficked streets, increase of public transport options and lowering fees, and local changes to infrastructure and road capacity to influence road usage locally. For the speed limits to have a maximal impact, speed limits at main access roads to the city were implemented along the entire length. This enabled through traffic to circumvent city centres and spread traffic more evenly throughout the city, resulting in a quick drop of emissions at the roads. With the adjustments of traffic lights, fluidity was increased and congestion was pushed outside the city borders. Also, streets were redesigned with roads further away from the houses and giving more space for slower modes, thus reducing road capacity for motorised traffic. At a main entrance road in Stuttgart with 2x3 lanes, on lane on each side was transformed into a bus lane, reducing capacity for cars significantly. As a consequence, these roads could handle less cars through which was a strong incentive for cars to change routes, resulting in a decrease of air pollution at critical areas. In consultation with manufacturers of car filters plans were made for ambient air filters to be placed at roadsides of road with heavy traffic and very bad air quality.

In order to facilitate the change of peoples' change in car use behaviour, public transport was improved (greater accessibility, diesel buses phased out) and intensified in the (larger) cities and neighbouring agglomerations. The aim was to supply a complete package of measures that would not only bring restrictions but also provide alternative solutions, as the authorities realised this would enhance the chances of a measure to be successful. Overall, these measures brought concentrations of NO_x down by roughly 60% locally. Besides, the number of air pollution monitoring stations throughout the state that reported exceedances of the EU norms dropped from approximately 600 to about 30 in a few years' time.

From a legal perspective, the state is responsible for the air quality in an area while city authorities are having power over implementation of transport related measures. The transport ministry and city policy makers worked cooperatively rather than in a hierarchical fashion in order to implement the measures. The package of measures was presented as a large sum (~ 400 million EUR) of all transport and urban mobility related measures which would have an effect on air pollution to some extent. Actually, the sum of public spending on the abovementioned measures was around 20 million EUR. As a whole, these measures have proved the authorities at these levels to be very effective at the local level. These measures reach to shift traffic in most cases in order to shift air pollution emissions and to a lower degree reduce the number of trips taken within a city, which in the end is the most effective to reduce air pollution and GHG emissions.

Brussels capital region

The Brussels capital region has coped with severe air pollution over the past decades, and was legally obliged to increase air quality to meet European legislation. Car use was high, and the main cause of air quality problems in the region, even though cycling has slowly been adapted by people in the Belgium capital region. To encounter air pollution problems, the comprehensive *plan air-climate-energie* for Brussels was proposed and gradually implemented. The Brussels regional authority has a regional mobility plan called *Good Move*. Policies in this plan are promoting people to use alternative modes such as cycling, walking, public transport and sharing mobility. There is a target to reduce kilometres driven by private car by 25% by 2030, compared to 2015.

The Brussels authority was brought to court by local action groups and had been warned by the European Commission with respect to its air quality. This has led to the adoption of the Brussels *Low Emission Zone* (LEZ) which entered into force in 2018. The success of the LEZ in the reduction of on-street air pollution levels can be attributed to the limited number exceptions for vehicles (only Oldtimers and handicap vehicles may enter the zone without complying to the Euro standards). An ANPR[5] system is used to monitor traffic and fines automatically. Several complementary measures were also implemented such as the reduction of traffic speed to 30 km/h on a large majority of streets since 2021. Also parking policies (supply of public parking lots and permit legislation around office areas) encourage public transport and bike use. Parking lot regulation in office districts entails maximising the number of spots at each permit renewal or extension, based on the floor area of offices (m^2), and public transport accessibility at the location.

Aided by the success of the LEZ, Brussels has decided to gradually phase out of diesel and petrol cars in the region in respectively 2030 and 2035 effectively resulting in a zero-emission zone (ZEZ). Also, local authorities are considering a kilometre charge in the Brussels capital region, called *Smart Move,* which can regarded as a form of congestion charging with higher charges at peak-hours[6]. Increasing cycling infrastructure (dedicated lanes, shortcuts and crossings), initiatives such as guiding people to cycle safely and platforms to show the best way to reach the workplace by bike are also part of the plan. Moreover, several parts of neighbourhoods have been changed into 'car-free blocks/zones' (*quartiers appaisés*), redirecting fast through traffic, making inner streets more attractive for active modes. This is accompanied by a thorough communication plan.

A significant barrier for regional transport measures in the Brussels capital region is the legislative power that lies with the municipal and regional authorities. For communal roads, municipalities have the power to implement changes in rules and infrastructure, while regional roads, connecting the several urban areas of the municipalities in the capital region, are within the jurisdiction of the regional authority. This requires additional effort from policy makers at all levels as interests differ. Parking related measures are even more difficult to get consensus on, as they provide an important income stream for the municipalities. There is also oppositions to measures restricting car use from commuters to Brussels, which are generally less concerned about air quality in Brussels since they live elsewhere. A major barrier for a modal shift can be attributed to large presence of the fiscal benefits for company cars in Belgium. A relatively high part of employees in Belgium uses company cars, resulting in low willingness to change to different modes. Since company car benefits are a federal policy, no policy changes can be made easily to influence car use and eventually air quality.

The obligatory EU air quality norms are seen as the most important enforcement mechanism that drive measures to encounter air pollution. There may well not have been a LEZ in Brussels if there were no norms to enforce measures to reach these goals. However, as more and more cities reach the norms, the guidelines need to be updated, based on scientific reasoning to continually improve air quality.

The first part is partially based on an interview with Christoph Erdmenger, Head of Division Sustainable Mobility, Ministry of Transport Baden-Württemberg. The second part is partially based on an interview with Louise Duprez, Sustainable Mobility Project Manager at the Brussels department of Environment.

3.2 Long list of measures

In this paragraph we give a non-exhaustive long list of measures that can potentially reduce emissions and improve air quality. The list contains measures that are often found in literature and have proven to be or may potentially be effective to reduce emissions.
The main focus of the long list of measures is not necessarily to reduce air pollution. In some cases, measures are taken for other purposes and a reduction of air pollution is a co-benefit (e.g. 'congestion charge' main purpose is to reduce congestion in cities).
Table 3 presents the 28 measures that comprises the long list. We provide additional information on each measure concerning type, whether it is an Avoid, Improve or Shift

[5] Automatic Number Plate Recognition.

[6] See https://smartmove.brussels/en for further details on the *Smart Move* kilometre charge plan.

measure, a qualitative assessment of the effectiveness (in terms of reducing air pollutants) and an estimate of the up-front investment costs.

The qualifications presented in Table 3 should be interpreted with some caution for several reasons. First, the design of a particular measure will have a significant impact on its effectiveness and costs. A large congestion or environmental zone covering a large surface area of a city is obviously more effective in reducing emissions than a relatively small zone. Large fiscal incentives or parking fees will have a bigger impact on mobility (and thus emission reduction) than smaller ones.
Second, the particular situation of a city affects the potential impact of a measure. A city with a proper functioning cycling infrastructure will benefit less from improvements in cycling infrastructure. Also the geographical layout of a city may hinder the instalment of some measures.
Third, the table excludes political support base and social acceptance as a criteria, but it is not difficult to see that this will be a very important condition. As a general rule of thumb, effective measures tend to have a relatively large impact on mobility patterns and travel behaviour and thus require behavioural changes which often come with public or political resistance.

The qualifications in Table 3 thus give a rough idea of the potential effectiveness but it is adamant that local/city governments tailor each measure to the specific characteristics of the city. In Appendix B an extended version of this table can be found with some additional information.

In the Chapter 4 we focus on five measures from the long lost that were selected in light of the in-depth analysis of their effectiveness in consultation with the client (EPHA and its national partners). We also provide some more information on the conditions which determine their success, including lessons learned from cities/countries where these measures have been implemented. The criteria for selection were based on a combination of effectiveness, available experience from implementation (in other words, availability of sufficient ex-ante evaluations) and a mix of different types of measures (not focussing on a single mode).

Table 3 – Long list of measures

#	Measure	AIS	Type	Effectiveness [a)]	Up-front investment costs
1	Congestion charge	Avoid/Reduce	Spatial planning/TOD	Very effective (++++)	High (++)
2	Diesel ban	Avoid/Reduce	Norms	Very effective (++++)	High (++)
3	Environmental/(ultra) LEZ zone	Avoid/Reduce	Pricing/fiscal incentive	Very effective (++++)	High (++)
4	Parking policies (pricing)	Avoid/Reduce	Spatial planning/TOD	Effective (+++)	Low (--)
5	Parking policies (availability)	Avoid/Reduce	Spatial planning/TOD	Effective (+++)	Medium (+/-)
6	Respacing road infrastructure/capacity reduction	Avoid/Reduce	Spatial planning/TOD	Effective (++)	High (+)
7	Speed limits	Avoid/Reduce	Spatial planning/TOD	Effective (+++)	Low (-)
8	ZE city busses	Improve	Norms	Effective (+++)	High (++)
9	ZE city logistics - clean vehicles	Shift	Spatial planning/TOD	Effective (+++)	High (++)
10	Cycle logistics	Shift	Spatial planning/TOD	Moderately effective (++)	Medium (+/-)
11	Increase public transport capacity	Shift	Pricing/fiscal incentive	Moderately effective (++)	High (++)
12	Promote cycling/cycling infrastructure	Shift	Norms	Moderately effective (++)	High (++)
13	Scrapping subsidy	Improve	Spatial planning/TOD	Moderately effective (++)	High (++)
14	Subsidy ZEVs	Improve	Subsidy	Moderately effective (++)	High (++)
15	Traffic management/ITS	Improve	Spatial planning/TOD	Moderately effective (++)	Medium (+/-)
16	Subsidy/regulation micro mobility	Shift	Spatial planning/TOD	Slightly effective (+)	Medium (+/-)
17	ZE privileges (dedicated lanes)	Improve	Norms	Slightly effective (+)	Low (--)
18	Shared e-scooters	Shift	Norms	Slightly effective (+)	Medium (+/-)
19	Air filters at hotspots	Improve	Spatial planning/TOD	Slightly effective (+)	Medium (+/-)
20	Car free (sun)day	Avoid/Reduce	Spatial planning/TOD	Slightly effective (+)	Low (--)
21	Car sharing schemes	Shift	Norms	Slightly effective (+)	Medium (+/-)
22	Green Public Procurement (GPP)	Improve	Subsidy	Slightly effective (+)	Medium (+/-)
23	Subsidised (or free) public transport	Shift	Pricing/fiscal incentive	Slightly effective (+)	High (++)
24	Increase charging infrastructure	Improve	Spatial planning/TOD	Neutral (0)	High (++)
25	15 minute city	Shift	Spatial planning/TOD	Unknown (?)	High (++)
26	Mobility as a Service (MaaS)	Shift	Spatial planning/TOD	Unknown (?)	Unknown (?)
27	ZE city logistics - spatial planning such as hubs	Improve	GPP	Unknown (?)	High (++)
28	ZE construction sites – (Non Road Mobile Machinery)	Improve	Norms	Unknown (?)	High (++)

a) In case of adequate, optimised policy implementation. Effectiveness in terms of potential to reduce NO_x and PM emissions.

4 In-depth analysis of five measures

In this paragraph we highlight five measures which were selected in consultation with the client (EPHA) and focus on some of the conditions that determine the success of these measures, including lessons learned from cities/countries where these measures have been implemented.The measures discussed are:

- congestion charge;
- environmental (low emission) zone;
- car sharing;
- parking policies; and
- cycling/walking policies.

The measures highlighted in this Chapter are not mutually exclusive. City/local governments in principle can decide to implement a single, or a combination of these measures. It is important to be aware that combining measures will lead to interactions effects. In general, the sum of the combined effects of two (or more) measures is smaller than the sum of each measure individually.

For each measure we focus on the following elements:

- a description of the measure;
- examples of implementation;
- conditions for implementation;
- effectiveness and impact on social costs;
- governance issues.

With respect to the effectiveness and impact on social costs we would like to stress in advance that an 'exact' quantification of the reduction of social costs as a result of implemented transport measures was beyond the scope of this study. In practice, measures will need to be customised to the specific characteristics of a city or urban area. Given the vast differences in city size, layouts, mobility patterns and behaviour, etc., there are no one-size-fits-all solutions and very different effects of measures. The presented effects and impact on social costs should be interpreted as indications of the possible effects. For a short description of the way the social cost reduction were calculated we refer to Annex C.

4.1 Congestion charge

Cities that have adopted this measure: London, Stockholm, Singapore, Gothenburg, Milan.

4.1.1 Description of the measure

A congestion charge is a pricing mechanism policy (tax/toll) with the aim to influence the demand of traffic in a certain time period and/or area. The main concept considers a zone within a city or a road that is highly congested. Often, this zone is a city centre district or (ring) road that handles a significant share of the city traffic. To enter the zone (or road), a charge can be levied by the local government. By charging vehicles entering the dedicated congestion charge zone (CCZ), congestion can be reduced significantly in case the price of entry is set at an optimal level. There are several design options for a congestion charge system. A local authority can use a real-time monitoring system to check which vehicles are entering the CCZ. Cameras (or electronic devices) register vehicles that enter the zone and afterwards the system automatically bills the owner of the vehicle. Another design requires the driver to buy a toll pass or vignette that acts as a ticket to enter the CCZ. The entrance points of the zone can be guarded by roadside enforcers or cameras that check whether for the entering vehicle a toll has been paid (US Department of Transport, 2017). By setting a price on the entry of a designated (congested) area, a reduction in traffic can be expected.

4.1.2 Examples of implementation

Since the beginning of the 21st century, several large cities around the world have experimented or eventually implemented a congestion charge. Singapore was the first to implement the Electronic Road Pricing (ERP) system in 1998. In London (2003), Stockholm (2007), Milan (2008) and Gothenburg (2013), similar schemes were introduced (Eliasson, 2014). The main reasons for introducing these use-related charges are to improve accessibility in heavily congested urban area and to improve air quality (Hajer, et al., 2012). The range of traffic reduction amounts 12-20% in all cities (Börjesson, 2018; Eliasson, 2014; Cornago, et al., 2019; Transport for London, n.d.). Use of public transport increased substantially. The congestion charge in London amounts £ 15 (€ 16) for every vehicle entering the CCZ during one day between 7 am and 10 pm, every day of the year (Transport for London, 2020). The price for entering the CCZ in Milan is a flat fee of € 5 for one day (Cornago, et al., 2019). The congestion charges for the CCZ's in Sweden are varying with the time within the day, ranging from € 1-2 with a maximum of € 6 per vehicle per day (Eliasson, 2014).

4.1.3 Conditions for implementation

There are several design options and conditions that impact the level of effectiveness of a congestion charge. These conditions can be at policy making level or at the practical details of the system and communication by the local authority.
If congestion charges are set, the optimal design involves a fluctuating in price according to the severity of congestion during the day. At time periods in which congestion is high, the charge should be higher in order to reach an optimal level of congestion reduction. However, a simple charge zone toll can still create significant effects on traffic reduction within a (large) area. The congestion charge should be implemented in a highly congested area, to obtain sufficient public support for road pricing. Roads that give entry to the CCZ should be monitored. To avoid excessive system costs, the design of the zone should be by drafting the size and shape such that the number of entry points (roads) are kept to a minimum (Eliasson, 2014). Besides, if reduction of health-damaging emissions at a detailed level is aimed for, the pricing system could be extended by a differentiation of the charging levels such that older and more heavily polluting vehicles pay higher charges (Börjesson, 2018).

The design of the CCZ should provide a good balance between effectiveness of the system and ease of understanding for users and policy makers. If the measure is framed as a means for tax collection, public support can decrease significantly. Implementation depends highly on political support which is determined by the institutional setting and who gets the power over the generated revenues, and to a lesser extent by public support and benefits from congestion reduction (Börjesson, 2018). The goal of the CCZ and the use of generated revenue should be communicated in a clear and transparent way by authorities from the start (Eliasson, 2014). A clear and focused goal for a CZZ is to reduce traffic and air pollution within the dedicated zone. An active monitoring policy of ex-ante and ex-post situation of the air quality and congestion situation at the street- and city-wide level can be important for transparent communication of policy implications.

To obtain a highly effective CCZ that maximally reduces air pollution at the city level, the following elements should be considered:
- Revenue generated from the CCZ is best used by investing in improvement of public transport and (highly developed) infrastructure for other transport modes within and to and from the CCZ.
- Increased walkability and infrastructure for slower modes (cycling and micro mobility) within the area, compact spatial planning, restraints on car traffic.
- The system should be automatically charging the owners of the vehicles by registration of the number plates. A monthly invoice works best for easy use for local citizens and regular users (Eliasson, 2014).
- When public transport is increased within the area, the vehicles used should comply to strict emission rules in order to maintain lasting benefits of the CCZ (Transport for London, n.d.).
- Design wise, the borders should ideally lie within main cordon road(s) that are able to handle relatively high traffic flows around the CCZ. In this way, heavy congestion at the borders of the CCZ is avoided, and through traffic can find its way to destinations at other sides of the city.
- In case the CCZ is designed for inner-city area (non-highway congestion charge), (vehicles of) inhabitants residing in neighbourhoods located in the CCZ should be granted exemption permits or high discounts. Also well-thought exemptions for other groups should be provided (e.g. blue card handicapped, emergency/civil service vehicles[7]).
- In case a high share of workplaces are located within a (proposed) CCZ area, proper parking and transferring facilities (e.g. Park & Ride) should be provided to avoid disruption at borders of the CCZ.

City characteristics

The cities in which a CZZ has been implemented were facing highly congested infrastructure in the inner-city area, with high concentrations of air pollution. The size of the congestion charge zones in these cities range between 8 and 35 km^2. The zones have a high population density and high number of workplaces providing employment, with a high share (up to two thirds) of employees commuting from outside the area. The cities with a CCZ have a population of at least one million inhabitants. The smallest city in which a CCZ is implemented is Gothenburg with approximately 500,000 inhabitants (Börjesson, 2018). Depending on the situation and shape of the infrastructure of the city, part of a highway or ring road is also appointed as part of the CCZ.

4.1.4 Effectiveness and impact on social costs

A CCZ is supported by literature as a very effective measure to combat air pollution in relatively large and dense urban areas. For London, the reported emission reductions of NO_x and PM_{10} are between 8-12% and 7-12% respectively (Beevers & Carslaw, 2005; Transport for London, 2008a). In Stockholm, NO_x emissions decreased by 8.5% as a consequence of the CCZ (Eliasson, 2014). After implementation of the CCZ in Milan, PM_{10} emissions decreased by 17% city-wide (Cornago, et al., 2019). We estimate the overall range in emission reduction of NO_x at 8 to 12% and the reduction of PM at 7 to 17%.

[7] See Transport for London : Discounts and exemptions for examples of CCZ exemptions in practice.

The initial investment and system costs are high. The use of an Automatic Number Plate Recognition (ANPR) system can result in lower operational costs. In large cities, if revenue is well spent (active modes infrastructure development, public transport) there are large potential benefits (in terms of social costs reduction).

Table 4 shows some rough estimates of the impact of a congestion charge on the social costs for three different city types and across the Northern, Western, Southern and Eastern part of Europe. We see that the change is in the range of 1 to 3% decrease. For metropoles this results in an expected range of social cost reduction of 30 to 70 mln euro in Western European cities, and 40-95 mln euro in Southern and Eastern metropoles. For small cities the expected range of social cost reduction is between 1 and 3 mln euro.
The impacts are likely to be somewhat larger in Southern and Eastern cities because the concentration levels will on average be higher.

Table 4 – Estimate of the change in social costs of congestion charging in 2020

	Metropolitan (> 1 mln inhabitants)		Big cities (200,000-1 mln inhabitants)		Small cities (< 200,000 inhabitants)	
	Social return	% change	Social return	% change	Social return	% change
North	-	-	3.7-8.7 € mln	1.2-2.7 %	1-2.3 € mln	1.2-2.8 %
West	30.8-71.7 € mln	1.1-2.6 %	4.4-10.2 € mln	1.1-2.6 %	1-2.4 € mln	1.1-2.7 %
South	39-90.9 € mln	1.1-2.6 %	3.1-7.1 € mln	1.1-2.7 %	1.3-2.9 € mln	1.2-2.7 %
East	40.8-95.7 € mln	1.2-2.8 %	5-11.8 € mln	1.2-2.8 %	1.4-3.2 € mln	1.2-2.8 %

4.1.5 Governance issues

A major barrier for the local authority to implement a CCZ at city level is often the fact legislative power for such pricing measures is not within their juridical control. In many countries, local authorities should perceive permission from national or federal governments to establish a CCZ (Poland Institute for Sustainable Development, 2021).

The announcement of plans for a CCZ may initially face low public support, resistance from local entrepreneurs, commuters, and car owners. However, if authorities have a clear campaign in which they bring forwards the benefits for each stakeholder group, and overall benefits, public opinion might be changed drastically. If alternatives are provided, public support may increase too. Changes made to the system as implemented may harm public support, especially in higher car dependent urban areas (Börjesson, 2018).

In Stockholm, a long and fierce political debate preceded implementation of the CCZ. Finally, after a several months trial of the CCZ, a public referendum was held in which the local public voted in favour of establishing a permanent CCZ. In this case, a trial followed by a referendum may be a transparent means to execute this type of far-reaching measure. Also, the allocation of power over revenues raised by the CCZ at the local authority level (the final decision maker) is considered to enhance the political willingness and is therefore an important factor for the level of success of CCZ implementation (Börjesson, 2018).

The Greater London Authority Act 1999 defined the new Greater London Authority (GLA) and gave the mayor of London the power to provide guidance and directives to London's transport body, Transport for London (TfL). At the end of the 1990s, congestion levels in London had reached extraordinary proportions and public transport funding was insufficient to provide proper alternatives. Studies assessing the viability of a congestion charge in London had been conducted since the mid-1960s. In 2000 a new mayor was elected, with the plan to implement a CCZ in central London. With pricing technology readily available at that time, the political way towards the implementation of a CCZ was paved. The mayor was able to gather sufficient support from business community and raising public awareness by pointing out the economic costs of congestion and benefits to local residents, of which a large proportion was highly dependent on public transportation services. The new legislation permitted the mayor to implement congestion charging in London, without reference to a higher level of government. Another factor that might have helped is the political stability. No organised opposition to the proposal sustained. Furthermore, the fact that congestion charging was implemented early in the Mayor's term of office gave it more chance to succeed (US Department of Transport, 2017).

4.2 Low-Emission Zone/Environmental Zone

Cities/regions that have adopted this measure: Germany, The Netherlands, Italy, Milan, London, Malmö, Stockholm, Brussels (region).

4.2.1 Description of the measure

A *Low-Emission Zone* (LEZ), also known as *Ultra-Low Emission Zone* (ULEZ) or *Environmental Zone* (EZ) in city centres is a widely used policy instrument in European cities with the aim to reduce emissions of pollutants by regulating vehicles. A LEZ is a designated area in a city where access is restricted for vehicles with a certain emission standard set by the (local) authority. In practice, vehicles that emit a higher amount of NO_x and PM than the set threshold allows, are banned from driving within the zone. Depending on the design and strictness of the LEZ, warnings or high fines are given to vehicles that enter the LEZ with emissions that exceed the set boundaries (Sadler Consultants, 2020). The rationale here is that by banning the most polluting vehicles, a significant amount of air polluting emissions can be avoided. Emission remote sensing technologies can be useful prior to policy drafting. Authorities can apply specific thresholds or upper boundaries for the pollutant emitting vehicles allowed in the proposed LEZ, based on the data of monitored vehicle emissions. Also, emission remote sensing technology can be used as a permanent monitoring system for vehicles entering a LEZ, as pollutants from any type of vehicle can be monitored precisely and fined if rules are violated accordingly[8].

4.2.2 Examples of implementation

In the last decades, many European cities have implemented a LEZ, banning the oldest, most polluting vehicles from their city centres. There are different ways in which local authorities shape their LEZ policy. In Milan, besides the congestion charge zone (Area C), a LEZ (Area B) has been in place since 2009 covering a larger circle of the inner city (Municipality of Milan, 2020). In Lisbon, a LEZ was implemented in 2011, banning all vehicles lower than level EURO 2 in the city centre and EURO 1 in the rest of the LEZ that covers the city (Ferreira, et al., 2015). In several Dutch cities, the limitations of the LEZ only apply to heavy duty vehicles for EURO 2 from 2010 onwards whereas zones in German cities allow only vehicles above the EURO 4 emission standard (Pestel & Wozny, 2019; Jiang, et al., 2017). In London, ULEZ has been implemented since early 2019, restricting the access to the ULEZ area other than EURO 6 diesel vehicles and EURO 4 petrol vehicles 24 hours a day, every day of the year. High fines are charged in case vehicles enter the area but do not meet the emission standards (GLA, 2019). The Brussels regional authority has

[8] See also Hager Environmental & Atmospheric Technologies (HEAT): Today, EDAR is Monitoring in Cities Throughout Europe

implemented a LEZ which entered into force in 2018 and covers the whole Brussels region comprising an area of several municipalities of about 160 km^2 (Duprez, 2021). The Brussels LEZ prohibits most polluting vehicles from entering the LEZ progressively over time, leading to a gradual phase out of older, heavily polluting vehicles[9] and eventually to the establishment of a *Zero-Emission Zone* (ZEZ). This means that diesel and petrol vehicles will be prohibited in the zone, respectively in 2030 and 2035.

4.2.3 Conditions for implementation

The policy design of a LEZ is critical for the level of effectiveness. A clear, well drawn territory should be aligned, the level of stringency, legal enforcement of the policy, strict exemptions rules to be granted to users and above all, the policy should be communicated in a clear manner. Ideally, the legal framework of the policy should be set in line or by national or EU authorities, to avoid large variation between cities in thresholds and limit values for the LEZ (Pestel & Wozny, 2019). A LEZ is regularly implemented in highly congested and large, densely populated urban areas. The total size of a LEZ is dependent on the city size and infrastructure characteristics, but often the (inner) city centre or city within the ring road is declared as a LEZ. An advantage by appointing the city ring road as the border of the LEZ is the clear demarcation for road users and road enforcers. In almost all instances of the LEZ, city authorities gradually increased the stringency in EURO standard prohibition. For example, in Milan a ban on all diesel vehicles up to EURO 4 will be in place from 2020 onwards. In the coming decade, the emission standards for vehicles that are allowed will be set at a higher level every other year (Municipality of Milan, 2020).

To obtain a highly effective LEZ that maximally reduces air pollution at the city level, the following elements should be considered:
- Clear demarcation of the area of the LEZ.
- Clear communication of the conditions and requirements of vehicles banned from and allowed to the LEZ.
- The biggest improvements in air quality can be achieved in case a high-EURO emission standard (low emission levels) is required for vehicles to enter the LEZ.
- However, to maintain public support and avoid barriers for the less affluent for which is more difficult to purchase a new vehicle, the increase of strictness of allowed vehicles according to the EURO standard should be gradual over time.
- Effectiveness and signal of the LEZ can be stronger if regulations are more uniform across cities and regions. This can be a national framework or when regulations are set in cooperation with other cities with a LEZ.

City characteristics

The cities in which a LEZ has been implemented are usually busy inner-city road traffic, resulting in high concentrations of air pollution. The sizes of a cities that have implemented them is on average smaller than those that implemented congestion charge. In some cases, the LEZ and CCZ are implemented parallel and work in tandem. Also, smaller cities (<100.000 inhabitants) can benefit from air quality improvements through LEZ’s.

[9] See In practice: Everything you need to know about the LEZ in the Brussels-Capital Region for an example of gradual prohibition of the EURO standards over the years 2020-2025.

4.2.4 Effectiveness and impact on social costs

In Lisbon, the introduction of the LEZ caused the PM and NO_2 levels to drop by 23 and 12% respectively. An important sidenote with these numbers is that over time, the vehicle fleet undergoes natural renewal in which old, high polluting vehicles (EURO 2) are replaced by new, less polluting vehicles (increase in share of EURO 4 and EURO 5 vehicles) (Ferreira, et al., 2015). In case the EURO emission standard for banning vehicles is set (too) low, the reduction of pollutants and consequent health benefits may be low (Pestel & Wozny, 2019; Goudappel Coffeng; Buck Consultants International, 2010). This is seen in the first phase of the LEZ in German cities. The restriction of vehicles of EURO 1 standard resulted in a significant but rather small reduction of NO_x, on average a reduction of 4% (Morfeld, et al., 2014).

In an evaluation of the Dutch LEZ, the first phase of LEZ in five major cities banning EURO 0 and EURO 1 diesel vehicles, there was no significant reduction in city level air pollutants concentrations (Boogaard, et al., 2012). In a number of Dutch cities, the PM_{10} levels have reduced with 2-7% compared to pre-LEZ levels, with the second phase ban of vehicles up to EURO 3 emission standard. However, a high number of violations of the policy was observed, which has led to a lower-than-expected impact of the measure. Also, a relative high proportion of transport operators will try to seek ways to obtain exemption permits (Goudappel Coffeng; Buck Consultants International, 2010). Stringent targets and enforcement mechanism are therefore necessary for effective functioning of the measure, with a strict policy concerning (temporal) exemptions . In German cities with a LEZ, a significant lower number of days of PM_{10} exceedance compared to cities without a LEZ was observed (Pestel & Wozny, 2019; Jiang, et al., 2017). In London, the *Ultra-Low Emission Zone* has proved to be highly effective: 36% lower levels of NO_2 were monitored in the first six months after implementation at the street level (GLA, 2019). Given the fact that the ULEZ covers the same area as the congestion charge zone in London, these numbers should be noted as a best-case scenario of a LEZ, including other traffic limiting measures.

In the 2019 evaluation of the Brussels regional LEZ, emission levels of NO_x and $PM_{2.5}$ from cars were estimated to be 11% lower for both pollutants compared to levels in early 2018. The reduction of NO_x and $PM_{2.5}$ for delivery trucks 3.5 and 21% respectively. Monitored concentration levels of NO_x is 10% lower and for $PM_{2.5}$ also lower (no specific levels of monitored $PM_{2.5}$ reduction are reported). One cannot ascribe the full reduction to the LEZ alone (e.g. also weather conditions are of influence), but the LEZ can be expected to have a very significant impact on the level of the street level pollutants (Brussels Environment, 2019). Altogether, the LEZ is perceived to be a very effective measure to encounter air pollution at the city level. We estimate the overall range in emission reduction of NO_x at 2 to 23% and the reduction of PM at 2 to 36%.

Table 5 gives some rough estimates of the impact of a LEZ/environmental zones on the social costs for three different city types and across the Northern, Western, Southern and Eastern part of Europe. We see that the change is roughly a 0.5 to 4% decrease. For metropoles this results in an expected range of social cost reduction of 10 to 100 mln euro in Northern Europe and 12 to 130 mln in Southern and Eastern metropoles. For small cities the expected range of social cost reduction is 0.5 to 4.5 mln euro.
The impacts are likely to be somewhat larger in Southern and Eastern cities because the concentration levels will on average be higher.

Table 5 - Estimate of the change in social costs of LEZ's/environmental zones in 2020

	Metropolitan (> 1 mln inhabitants)		Big cities (200,000-1 mln inhabitants)		Small cities (< 200,000 inhabitants)	
	Social return	% change	Social return	% change	Social return	% change
North	-	-	1.1-12 € mln	0.4-3.8 %	0.3-3.1 € mln	0.4-3.8 %
West	9.4-99.9 € mln	0.3-3.7 %	1.3-14.3 € mln	0.3-3.7 %	0.3-3.3 € mln	0.3-3.7 %
South	11.9-126.5 € mln	0.3-3.7 %	0.9-9.9 € mln	0.3-3.7 %	0.4-4.1 € mln	0.4-3.8 %
East	12.4-130.9 € mln	0.4-3.8 %	1.5-16.1 € mln	0.4-3.8 %	0.4-4.3 € mln	0.4-3.8 %

4.2.5 Governance issues

The policy design is critical for effectiveness of the LEZ in terms of air pollutants reduction. Factors that should be taken into account concern the size of the area, the level of stringency (banned vehicles), enforcement and fining of violations, exemptions granted to users, clarity of policy and communication prior to operation and permanent signalling.

The legal framework is an important aspect for the local policy maker for enforcement of a LEZ, which depends on national regulations. Preferably, thresholds and limit values for allowed vehicles are set at national or European level, which improves clarity and consistency in policies. Consensus on the level of strictness and requirements of a LEZ on both local and national level is critical for successful implementation (Poland Institute for Sustainable Development, 2021). Friction between interests should be solved in order to reach an effective LEZ policy.

The literature and best practices show that in case a LEZ is set up with strict emission standards, this policy measure can be effective and precise instrument to reach a significant reduction of air pollutants on the local level. If authorities decide to allow some groups of vehicles to be exempted from the ban, this may lead to more groups advocating to be excluded. In the end, the legitimacy of the proposed LEZ may have become weakened and public support may decrease. In the past, some cities finally have discontinued the LEZ.

If local authorities propose the implementation of a LEZ, they may face fierce opposition from inhabitants and local businesses. Primarily in high car dependent areas citizens may have fierce opposition arguing a LEZ is a limitation of freedom. This can be encountered if proper alternatives are provided (Poland Institute for Sustainable Development, 2021). Business owners may resist, as in most cases the majority of vehicles with high levels of pollutant emissions are the ones supplying these businesses. As in practice deliveries are often bound to certain time frames, exemptions for certain time periods or (charged) exemptions could be arranged. Besides, authorities could present best-practices of cases where business thrived more because of improved air quality, which attracted more costumers. This can reduce resistance and increase willingness from the public.

4.3 Car sharing

Cities/regions that have adopted this measure: Paris, Amsterdam, Cologne, other major cities in Europe/US.

4.3.1 Description of the measure

Car sharing is the use of a (passenger) car by several people where the cars are owned by a (public or private) provider for which the users pay for each ride separately. Local governments can stimulate the use of shared cars by means of regulation, targeted facilities and price incentives (by subsidies or discounts on parking permits). Regulation can be done by setting requirements for emission standards for the vehicles (e.g. electric drive instead of combustion engine). The vehicle may be collected, returned and (if applicable) recharged at dedicated parking spaces for the electric shared car (including charging infrastructure), depending on strategic and policy design.

There are several variants of car sharing: one-way/free-floating car sharing (e.g. ShareNow), round-trip car sharing, peer-2-peer car sharing (online/via an app sharing a private car, e.g. Snappcar), company and organisation car sharing, car rental and private car sharing. A car sharing system can either be commercially operated or as a platform between consumers (using privately owned cars). The provision of large-scale business to consumer (B2C) shared cars is currently dominant in large urban areas with high population density. Both free-floating and round-trip car sharing are the most prominent forms in operation.

In addition, it can be a means of improving the quality of life in streets by reducing the number of parking spaces. Existing parking spaces can be reduced and/or used for car sharing, including existing or new charging infrastructure.

The concept of car sharing is not a measure actively promoted by authorities with the aim to directly target air quality. Rather, in several cities local governments have supported and regulated car sharing initiatives as there are potential benefits in reduction of city traffic and subsequent improvement of air quality. Also, car sharing can decrease car ownership in urban areas, depending on the local situation and presence of viable alternative modes in addition to car sharing. This may lead to reduction of air pollutants, as car sharing users generally make a lower number of trips compared to the situation in which they own a private car **(PBL, 2015)**.

4.3.2 Examples of implementation

In 2011, the joint union of municipalities in the greater Paris region launched the first publicly operated free-floating car-sharing service. However, due to high operational costs, low demand, and the rapid development of alternative low-emission mobility options (e-scooters and privately operated car-sharing initiatives), the service was ended in 2018 **(Municipality of Paris, 2018)**. No monitoring and reporting on the air quality impacts of the scheme was executed, therefore actual impact remains unknown. Many other cities have since followed suit with B2C and C2C initiatives. Often the car sharing schemes have been commercial in nature, and in some cases supported by local governments often by facilitation of dedicated parking areas.

4.3.3 Conditions for implementation

Urban areas with high population density increase the feasibility of a car sharing system to be a durable transport alternative **(Agapitou, et al., 2014)**. In a number of North American cities, a private operator ceased their operations as the profitability of the car sharing operations were under pressure (rising operational costs, competitive market and lack of supporting infrastructure for EVs) **(ShareNow, 2020)**. This raises the question whether the supply of such car sharing systems are bounded to specific (market) conditions to be a suitable alternative for the use of privately owned vehicles. One suggestion is that under a certain level of population density the operational costs to maintain a smoothly running system of free-floating vehicles is an unsustainable business case. Conditions for successful operation of car sharing schemes are among others:
— high-income level areas, which enhances the scalability of car sharing;
— high-urban densities and large presence of alternative mobility options;

— areas with well-established safety regulations.

City characteristics
There are no particular city characteristics that impede the instalment of C2C car sharing schemes. For B2C there is the requirements of sufficient demand to be able to break-even. Typically larger cities (> 250,000 inhabitants) are moist suitable for B2C car sharing initiatives.

4.3.4 Effectiveness and impact on social costs

The presence of a B2C car sharing system can lead to a reduction in private ownership (7-11 vehicles sold and purchase avoided per shared car) and number of trips by car (6-16% of the trips are shorter than with private cars) as observed in five major North-American cities where a B2C car sharing system is (was) operational **(Martin & Shaheen, 2016)**.They make the implication that emissions of air pollutants at the city level will be reduced as well. If B2C initiatives offer new or even electric vehicles, this claim is plausible, although there may also be adverse effects of car sharing. If people are currently walking, cycling or using public transport and shift to using a car with an internal combustion engine, there may not be a net gain in air quality. This adverse effect is even more likely with C2C initiatives where the average shared car on offer is relatively older and therefore more polluting.

The effects on air quality improvements as a consequence of modal shift from private to shared car use are expected to take place after approximately one year as behaviour of transport users changes slowly. The adoption rate depends highly on the city infrastructure.

Moreover, in many European cities local authorities require car sharing firms to operate the fleet with only zero emission vehicles (mostly electric vehicles). This could lead to an additional reduction of air pollutants. However, no dedicated assessments of the direct impact on the reduction of pollutants are yet known. We estimate that the overall impact on the emission of NO_x and PM emission is in the range of -5 to +5%, meaning that, depending on the design of the car sharing scheme, the possibility of an increase in emissions cannot be dismissed.

Table 6 gives some rough estimates of the impact car sharing schemes on the social costs for three different city types and across the Northern, Western, Southern and Eastern part of Europe. We see that the change is roughly a 1% decrease. For metropoles this results in an expected range of social cost reduction of 20 to 30 mln euro. For small cities the expected range of social cost reduction is almost 1 mln euro.
The impacts are likely to be somewhat larger in Southern and Eastern cities because the concentration levels will on average be higher.

Table 6 - Estimate of the change in social costs of car sharing schemes in 2020

	Metropolitan (> 1 mln inhabitants)		Big cities (200,000-1 mln inhabitants)		Small cities (< 200,000 inhabitants)	
	Social return	% change	Social return	% change	Social return	% change
North	-	-	~ 2.6 € mln	~ 0.8 %	~ 0.7 € mln	~ 0.8 %
West	~ 21.5 € mln	~ 0.8 %	~ 3.1 € mln	~ 0.8 %	~ 0.7 € mln	~ 0.8 %
South	~ 27.2 € mln	~ 0.8 %	~ 2.1 € mln	~ 0.8 %	~ 0.9 € mln	~ 0.8 %
East	~ 28.3 € mln	~ 0.8 %	~ 3.5 € mln	~ 0.8 %	~ 0.9 € mln	~ 0.8 %

4.3.5 Governance issues

To avoid excessive increase of vehicles and to prevent a monopolistic market situation, authorities can use market entry rules and operation licenses to maximise the social benefits of these schemes. Regulation of car sharing are well suited to promote good practices or require minimum performances from the operators that are active in the market of shared vehicles. This can be the earlier mentioned requirement of zero emission vehicles, but also a minimum or maximum number of cars, free curb parking licences, dedicated parking spots, and operating fees. Public awareness, support and ultimately use can be increased in this way.
Interviews performed in the Netherlands with entrepreneurs and policy makers revealed that free-floating concepts, particularly those using smaller vehicles (electric bikes, scooters, and autopeds) can cause nuisance. It is not always clear if (in the case of autopeds) they can be used on sidewalks, and vehicles are not always left at the designated parking areas. Some local governments struggle with the balance between allowing alternative clean modes through sharing systems, and keeping cities organised and accessible for everyone (CE Delft, 2020b).
In some cities, like Paris **(6t, 2014)**, taxi services experienced a vast decrease in demand when car sharing schemes became operational. This may lead to resistance by employees in this sector especially in urban areas where car sharing is being initiated, and where taxis are already heavily affected by the rise of on-demand driving services (such as Uber, Bolt and Lyft).

4.4 Parking policies

Cities/regions that have adopted this measure: common in (large) cities in Europe.

4.4.1 Description of the measure

Parking policies were initially a measure to manage congestion and recover costs of public space for local governments. Parking policies with the aim to reduce congestion and air pollutants can manage the public parking spaces in such a way that traffic is reduced or avoided from entering certain parts of the city. Also, specific parking zones and routes are able to manage traffic flows within a city thereby preventing congestion in areas where exposure to pollutants is more critical.

Fiscal incentives can be used to influence parking demand at times of the day or distribution between certain locations. Distributional effects in the city can also be achieved by altering the supply of parking spaces or creating parking hubs outside the city centre (combined with public transport access/routes to the city centre). Local authorities can provide exemptions or permits for residents if desired. Parking policy can have a significant impact on car ownership of residents in an urban area.

4.4.2 Examples of implementation

In most densely populated cities throughout the world, parking policy has been implemented at a sophisticated level (Russo, et al., 2019). The implementation of parking fee increases, and parking space availability has impacted car use behaviour and resulted in a decline of car ownership in European and American cities (Litman, 2020).

4.4.3 Conditions for implementation

There are no particular conditions and/or city characteristics that prevent the implementation of parking schemes. In general, it is seen that if parking space is scarce, free space in cities is limited and traffic volumes are high, there is stronger incentive for cities to control traffic with parking policies.

4.4.4 Effectiveness and impact on social costs

Only recently, this measure is viewed upon as a way to encounter air pollution in cities. Therefore, not much empirical evidence on the effects on the emission of air pollutants can be found. It is known however that restriction of parking spaces can have a substantial impact on car ownership (which will in turn decrease car use). In Paris the number of privately owned cars was reduced by almost 40% in the past 15 years, partly due to reallocation of parking spaces. Also clear is that the availability of parking space nearby resident buildings has a significant influence on the rate of car ownership and the use for commuting. The limitation of parking spaces in city areas and financial barriers by higher parking fees and permits can influence the size of the vehicle stock in an area (Russo, et al., 2019). A study on the effects of parking management on air pollution in Belgrade found that if on-street and off-street parking prices are balanced, with time restrictions for on-street parking, the level of NO_x emissions would decrease with 14.2% (Simićević, et al., 2013). This impact we feel should be seen as extreme case which probably is limited to a particular area. In case cities set right prices for the on-street curb side parking lots, cruising can be reduced leading to a decrease of air pollutants surveys indirectly show (Shoup, 2007). All in all, we estimate that the overall impact on the emission of NO_x and PM emission is in the range of 5 to 10%.

The Brussels regional authority has a permit legislation in place which aims to reduce the number of parking in vicinity of office spaces in order to encourage workers to change their home-work-home commute to other modes. At renewal of parking permits, a maximum number of parking spaces is defined according to two factors: the floor area of offices (m^2) and the accessibility of the location by public transport (Brussels Environment, 2021).

Measures on parking pricing and management of the supply of public parking lots are relatively inexpensive instruments for local authorities to implement and has a high impact regarding the reduction of air pollutants.

Table 7 gives some rough estimates of the impact of a parking policies on the social costs for three different city types and across the Northern, Western, Southern and Eastern part of Europe. We see that the change is roughly a 1% decrease. For metropoles this results in an expected range of social cost reduction of 22 to 42 mln euro in Western Europe and 28 to 56 mln euro in Southern and Eastern Europa. For small cities the expected range of social cost reduction is between 1 and 2 mln euro.
The impacts are likely to be somewhat larger in Southern and Eastern cities because the concentration levels will on average be higher.

Table 7 – Estimate of the change in social costs of parking policies in 2020

	Metropolitan (> 1 mln inhabitants)		Big cities (200,000-1 mln inhabitants)		Small cities (< 200,000 inhabitants)	
	Social return	% change	Social return	% change	Social return	% change
North	-	-	2.6-5.1 € mln	0.8-1.6 %	0.7-1.4 € mln	0.8-1.6 %
West	21.5-42.4 € mln	0.8-1.6 %	3.1-6 € mln	0.8-1.6 %	0.7-1.4 € mln	0.8-1.6 %
South	27.2-53.7 € mln	0.8-1.6 %	2.1-4.2 € mln	0.8-1.6 %	0.9-1.7 € mln	0.8-1.6 %
East	28.3-56.2 € mln	0.8-1.6 %	3.5-6.9 € mln	0.8-1.6 %	0.9-1.9 € mln	0.8-1.7 %

4.4.5 Governance issues

As local authorities have in most counties jurisdiction over the local roads and curb sides (parking), implementing changes to the tariffs and allocation of the parking lots would not be a large challenge. Raising parking tariffs and removing parking lots in cities can initially result in resistance from car-owning citizens, shop owners and costumers. Resistance may be tempered in case proper alternatives for costumers and business visitors are supplied. This could be P+R spaces, more frequent public transport between parking lots and city centres, and support of active modes such as bicycle infrastructure and bike sharing systems. Transparent communication about the use of revenues from parking charges may increase willingness.
Very high tariffs of on-street parking may have a regressive effect regarding the socio-economic situation of inhabitants and visitors. In cities where tariffs are changed to very high hourly tariffs for on-street parking (5+ EUR/h), only the highest incomes may be unaffected in their parking behaviour, while middle- and lower-income groups may not afford these fees and are more restricted to use parking facilities further from their destination or make use of alternative modes.

4.5 Cycling and walking policies (active modes)

Cities with ambitious cycling policies in place: Copenhagen, Rotterdam, Antwerp, Strasburg, Paris, Vienna, Berlin, London.

4.5.1 Description of the measure

In many cities policies have been implemented with the aim to increase the share of active modes of transport. With an increase of the share of active modes local authorities aim to achieve a cleaner, less congested city infrastructure and higher level of air quality and thus a healthier city. Active modes also benefit a person’s health because of the activity itself, addressing physical inactivity, one of the key risk-factor of non-communicable diseases and can therefore reduce associated social costs (WHO, 2020a).For this, walking and cycling schemes, often accompanied by vehicle restricted roads or zones and bike sharing systems are adopted in cities around the world. Specific biking infrastructure (separate lanes) and bike friendly intersections in cities are other interventions which may impact other modes if space in cities is limited. Such infrastructure can be complemented by dedicated fast-lane bike infrastructure outside cites which makes it more interesting to bike for longer distances, including the commute. Apart from funding a bicycle sharing system, (national) governments can provide fiscal incentives to make cycling (to work) more appealing.

4.5.2 Examples of implementation

Many large cities in Europe, North America and Asian countries have implemented a form of bike sharing hiring schedule in the last decade. The cities of London, Paris and Barcelona have a bike sharing scheme with several thousands of bikes that can be picked up and returned in docking stations that are evenly spread across the city (Rojas-Rueda, et al., 2012; Midgley, 2011). Besides the provision of the bikes, cities have put large efforts in the development of cycling infrastructure, comprising separate bicycle lanes, bypasses and routes through cities. This has been established at an advanced level in the Netherlands (Utrecht, Rotterdam, Eindhoven), Belgium (Antwerp, Brussels), Denmark (Copenhagen, Aarhus), and France (Paris, Bordeaux, Strasbourg)[10]. Brussels has implemented a speed limit of 30 km/h in the majority of their streets since the beginning of 2021, with exception of few major roads where 50 km/h is allowed (Brussels Environment, 2019). The change of the norm was implemented to enhance road safety but a side effect is people may be more prone to change to active modes, as traffic safety is increased and difference in travel times on short distances are minimal between car and e.g. bike (or e-scooter). Therefore, the application of city-wide speed limits can be an indirect measure to increase air quality at the local level.

In Ireland and the UK, a cycling-to-work scheme provides commuters to buy a bicycle via their employer by purchasing from their gross salary, obtaining a tax benefit.

4.5.3 Conditions for implementation

The adoption of cycling is observed to be significant when cycling infrastructure (at the street level) and a bike sharing system is realised (Ballinger, et al., 2017). City infrastructure and topology is of importance for the potential adoption rate of active transport. Dedicated off-road cycle paths or separated lanes as well as clean air zones (LEZ) are important conditions for a change in behaviour of commuters. Separate lanes are also important to increase road safety/reduce traffic incidents.

For a significant adoption rate of cycling as a logical and attractive alternative, the city topology should preferably be a plane surface, with slopes up to 4% maximum (Midgley, 2011). This argument however has become of less importance with the introduction of the electric bike. Even steep inclinations can be overcome with most electric bicycles. Active mobility requires the provision of extensive, safe infrastructure, such as walkways and cycle lanes. Areas with safe, integrated transport systems where walking and cycling is encouraged, health and quality of life can be enhanced (CPME, 2020).

Another condition is to convey the benefits of active modes to citizens. Citizens who are committed to be active, are more likely to be healthier.

4.5.4 Effectiveness and impact on social costs

The impact of the measure can be expected to be gradual as behavioural change to active modes of transport is not immediate. The evaluation of the cycle scheme in London states that the impact on air pollution is ambiguous. In London, the modal shift caused by the bike-sharing scheme observed a shift from car to cycling of 4% of the participants, while a large majority changed from public transport to the active mode (Transport for London, 2008b). The impact on air quality is therefore ambiguous. This was, however, before a LEZ and congestion charging zone was implemented and local air pollution was still at high levels in London.

Although implementing bike infrastructure, and in particular separate bike lanes in densely populated and already congested areas can be challenging and costly, it should be noted that compared to car infrastructure, bike infrastructure is generally much cheaper to achieve similar improvements in accessibility.

In Paris, Lyon, Montreal and Barcelona, the implementation of a bicycle sharing system resulted in a 2-10% lower number of car trips (Midgley, 2011). Again, there was a major shift from public transport to bicycle sharing observed. An evaluation at the policy cost effectiveness of the Paris bike sharing scheme (which had been operated by a private party under contract) showed this measure to be relatively expensive as there are high operational costs and risks for recuperation of initial investments. All in all, we estimate that the overall impact on the emission of NO_x and PM emission is in the range of 0 to 5%.

[10] See also Copenhagenize Index 2019 : The Most Bicycle- Friendly Cities of 2019 for example cities and best practices.

The use of active modes of transport also implies increased physical activity which has additional health benefits and may reduce social costs. When encouraging individuals to engage in active mobility, such as by walking or cycling, it is important to address both the health and the transport-related benefits and challenges, including the risks of physical inactivity, and the problems of air pollution, noise (also an important environmental risk factor for health) and congestion.

Table 8 gives some rough estimates of the impact of cycling and walking policies on the social costs for three different city types and across the Northern, Western, Southern and Eastern part of Europe. We see that the change is roughly a 0 to 1% decrease. For metropoles this results in an expected range of social cost reduction of 0 to 22 mln euro in Western Europe and 0 to 28 mln euro in Southern and Eastern Europa. For small cities the expected range of social cost reduction is between 0 and 1 mln euro.
The impacts are likely to be somewhat larger in Southern and Eastern cities because the concentration levels will on average be higher.

Table 8 - Estimate of the change in social costs of cycling and walking policies in 2020

	Metropolitan (> 1 mln inhabitants)		Big cities (200,000-1 mln inhabitants)		Small cities (< 200,000 inhabitants)	
	Social return	% change	Social return	% change	Social return	% change
North	-	-	0-2.6 €.mln	0-0.8 %	0-0.7 €.mln	0-0.8 %
West	0-21.5 €.mln	0-0.8 %	0-3.1 €.mln	0-0.8 %	0-0.7 €.mln	0-0.8 %
South	0-27.2 €.mln	0-0.8 %	0-2.1 €.mln	0-0.8 %	0-0.9 €.mln	0-0.8 %
East	0-28.3 €.mln	0-0.8 %	0-3.5 €.mln	0-0.8 %	0-0.9 €.mln	0-0.8 %

4.5.5 Governance issues

One of the main barriers for successful implementation of cycling schemes is the limited expertise of local policy makers and policy officers. Car use and ownership have been the dominant factor in city mobility planning and introducing (substantial) cycling (and walking) infrastructure often competes with space for cars and other road vehicles, particularly in older cities with a dense building.
The dominance of car mobility in (city) planning is also reflected by public opinion on cycling: there are many examples worldwide where public acceptance of bike travel is low as it is associated with low status compared to car travel. In such situations public awareness campaigns might be beneficial to increase the public willingness to embrace cycling and/or walking policies. An aspect that can greatly benefit the public acceptance is the involvement of a key figure or ambassador that promotes these policies. Besides, if no widespread dedicated infrastructure is yet in place, people may be reluctant to choose cycling as their way to move through the city due to safety concerns. Next to separate cycling or walking infrastructure, traffic calming can be used to improve the safety situation of cyclists on the road. Speed reduction and physical obstacles on roads, speed bumps can be used to obtain a safer road situation.

Air quality and increasing physical activity of citizens is generally not the main policy driver for local/city governments to adopt cycling polices; policies aiming to tackle climate change and reducing CO_2 emissions is. Other factors that come into play is ‘active mobility’ and the health benefits with associated with increased physical activity. There is a trade-off with traffic safety (cyclists are more prone to be involved in traffic accidents) but also with air-quality: exposure to air pollutants is higher when cycling or walking. This poses a risk to promote cycling policies with air quality as the rationale despite that there are additional health benefits due to increased physical activity which could compensate that.

To increase the chances of success of cycling and waling policies, three elements are of crucial importance:
1. Hardware (a properly functioning and well-connected infrastructure).
2. Software (public awareness (including the health benefits) and willingness to adopt cycling/walking as an alternative for car travel).
3. A clear long-term perspective coupled with (long term) policy goals.

5 Overview of impacts of selected measures

In this chapter we give a resume of the most important findings and a comparison of the five selected measures in terms of effectiveness, costs and impact on social costs.

5.1 Resume of effectiveness and initial costs

Figure 21 shows the impact on PM and NO_x reductions of the five selected measures. It is clear that Congestion charging and Low-Emission Zones/environmental zones are (based on findings from literature) have the greatest potential to reduce PM and NO_x emissions from transport in cities. A 10 to 20% reduction is attainable based on evaluations of cities that have implemented these measures. It is also clear from Figure 21 however that uncertainties in particular for LEZ's are large. This illustrates among other things that the effectiveness depends largely on the strictness and size of the zone and therefore tailor-made solutions are required to benefit from its potential.
Parking policies can also be fairly effective and can reduce PM and NO_x emissions in the range of 5 to 10%. Car sharing and Cycling/walking policies are much less effective in terms of PM and NO_x reduction (and may even be negative). Not shown in Figure 21 however is that particularly Cycling/walking policies have other benefits such as increased health from active mobility and better liveability of cities if space car traffic is reduced simultaneously.

Figure 21 - Potential impact of the top 5 measures on PM and NO_x emission reduction

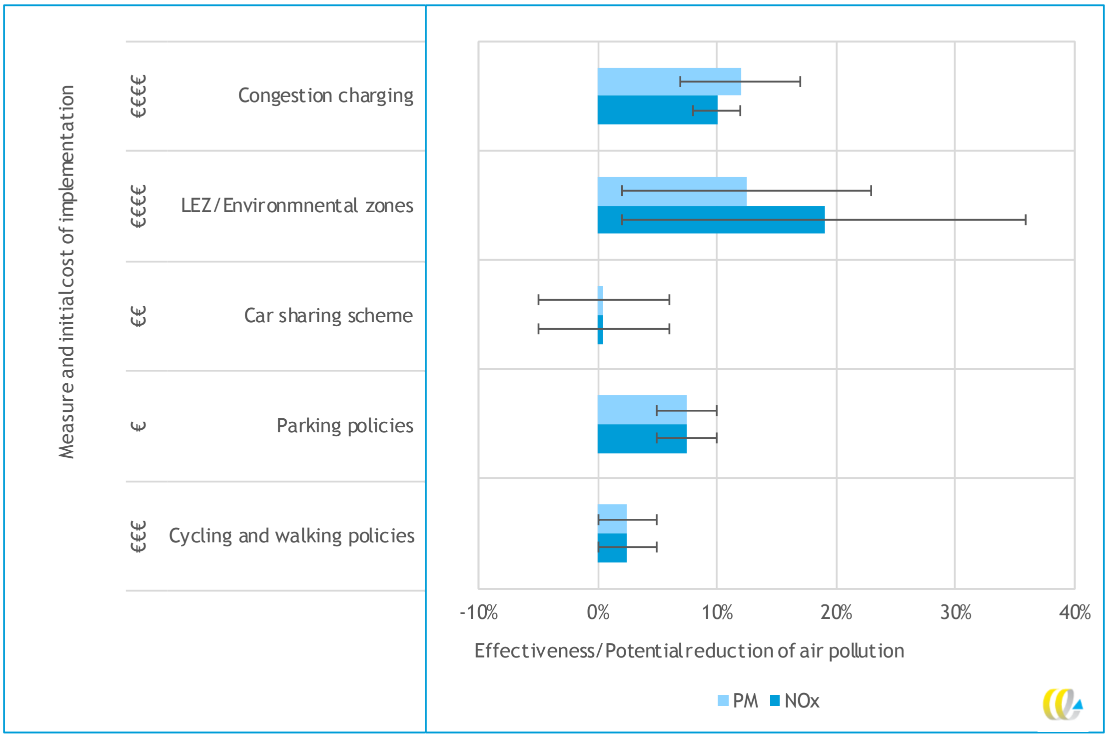


Figure 21 also shows that the initial investment cost of congestion charging, LEZ’s and to a lesser extent cycling and walking policies are relatively high. For congestion charging the bulk of these costs can recovered by the entry fees. Parking policies have fairly low up-front investment costs and additionally can generate a stable stream of income for local governments. Cycling policies are costly if infrastructural changes are required, particularly in dense cities areas where space is limited.

5.2 Resume of impact on social costs

Based on the data gathered and methodology developed in (CE Delft, 2020a) we have made estimates of the impact on social costs that each of the five selected measures may have. Social costs are only available for the current situation which is why we present impacts of measures only for the year 2020. Additional information on the calculation of these figures can be found in Annex D. The improvement in air quality/or reduction in ambient concentrations is (percentagewise) smaller than the reduction in emissions of NO_x and PM. This is as expected since transport is just one of the sources that contribute to overall ambient concentrations. Housing, agriculture and industry add to the total concentration of PM and NO_2 in the air, even though emissions may not be in close proximity of cities (background concentrations).

Table 9 - Estimate of the change in social costs of congestion charging in 2020 for 5 selected measures

	Metropolitan cities		Big cities		Small cities	
	Social return	% change	Social return	% change	Social return	% change
Congestion charge						
North	-	-	3.7-8.7 € mln	1.2-2.7 %	1-2.3 € mln	1.2-2.8 %
West	30.8-71.7 € mln	1.1-2.6 %	4.4-10.2 € mln	1.1-2.6 %	1-2.4 € mln	1.1-2.7 %
South	39-90.9 € mln	1.1-2.6 %	3.1-7.1 € mln	1.1-2.7 %	1.3-2.9 € mln	1.2-2.7 %
East	40.8-95.7 € mln	1.2-2.8 %	5-11.8 € mln	1.2-2.8 %	1.4-3.2 € mln	1.2-2.8 %
LEZ’s/environmental zones						
North	-	-	1.1-12 € mln	0.4-3.8 %	0.3-3.1 € mln	0.4-3.8 %
West	9.4-99.9 € mln	0.3-3.7 %	1.3-14.3 € mln	0.3-3.7 %	0.3-3.3 € mln	0.3-3.7 %
South	11.9-126.5 € mln	0.3-3.7 %	0.9-9.9 € mln	0.3-3.7 %	0.4-4.1 € mln	0.4-3.8 %
East	12.4-130.9 € mln	0.4-3.8 %	1.5-16.1 € mln	0.4-3.8 %	0.4-4.3 € mln	0.4-3.8 %
Car sharing schemes						
North	-	-	~ 2.6 € mln	~ 0.8 %	~ 0.7 € mln	~ 0.8 %
West	~ 21.5 € mln	~ 0.8 %	~ 3.1 € mln	~ 0.8 %	~ 0.7 € mln	~ 0.8 %
South	~ 27.2 € mln	~ 0.8 %	~ 2.1 € mln	~ 0.8 %	~ 0.9 € mln	~ 0.8 %
East	~ 28.3 € mln	~ 0.8 %	~ 3.5 € mln	~ 0.8 %	~ 0.9 € mln	~ 0.8 %
Parking policies						
North	-	-	2.6-5.1 € mln	0.8-1.6 %	0.7-1.4 € mln	0.8-1.6 %
West	21.5-42.4 € mln	0.8-1.6 %	3.1-6 € mln	0.8-1.6 %	0.7-1.4 € mln	0.8-1.6 %
South	27.2-53.7 € mln	0.8-1.6 %	2.1-4.2 € mln	0.8-1.6 %	0.9-1.7 € mln	0.8-1.6 %
East	28.3-56.2 € mln	0.8-1.6 %	3.5-6.9 € mln	0.8 -1.6 %	0.9-1.9 € mln	0.8-1.7 %
Cycling and walking policies (active mobility)						
North	-	-	0-2.6 € mln	0-0.8 %	0-0.7 € mln	0-0.8 %
West	0-21.5 € mln	0-0.8 %	0-3.1 € mln	0-0.8 %	0-0.7 € mln	0-0.8 %
South	0-27.2 € mln	0-0.8 %	0-2.1 € mln	0-0.8 %	0-0.9 € mln	0-0.8 %
East	0-28.3 € mln	0-0.8 %	0-3.5 € mln	0-0.8 %	0-0.9 € mln	0-0.8 %

The expected ranges in social cost reductions are shown in Table 9. We see that the impact of congestion charging and LEZ's/environmental zones contributes most to the potential to reduce social costs.

For congestion charging in metropoles the expected range of social cost reduction in 2020 is between 30 and 95 mln euro. For small cities the expected range of social cost reduction is between 1 and 3 mln euro. For LEZ's/environmental zones in metropoles the expected range of social cost reduction is between 10 to 120 mln euro. For small cities the expected range of social cost reduction is 0,5 to 4 mln euro.
For the other 3 measures (car sharing schemes, parking policies and promoting of cycling an walking) the expected range of social cost reduction is 0 to 60 mln euro in metropoles and 0 tot 2 mln euro in small cities in 2020.

These potential 'savings' in costs, in addition to other benefits more commonly quantified in impact assessments, might encourage local/city governments to implement these measures: even if the initial investment cost may be high there may be a large 'return on investment' in terms of a reduction of health related social costs. The findings in this study point to the fact that the relative contribution of an individual measure is rather limited: city governments aiming to reduce the social costs should consider more than just one measure.

It should also be emphasised that the reported potential social cost 'savings' are only a general indications of the expected benefits in terms of reduced social costs: individual authorities should carefully examine the local situation and determine the impact of any given measure on social costs for their specific circumstances. It is also important to note that transport NO_x and PM emissions will already decrease significantly between now and 2030 as a result of the Euro vehicle emission standards (Euronorms). This will also decrease the impact on potential social cost reductions. By how much however could not be determined in this study.

5.3 Resume on general governance issues

Several issues, barriers may arise as governments start to consider a certain (set of) measure(s). In this section we give a resume on common observed difficulties authorities may face when proposing policies regarding improvement of air quality and implementation.

One of the common issues concerning air quality improving policies is the resistance for change of the status quo by the public. This can be attributed in part to the lack of (public or political) awareness of the problem. What might help is that measures are introduced as a part of a wider set of policies that seek to address health inequalities and support communities most impacted to thrive in their cities. Awareness campaigns can increase peoples and businesses awareness of their contribution to the problem which may induce a shift in their perspective on the problem. An increase of public awareness in itself could result in a small reduction of in PM and NO_x emissions as was observed in Baden-Württemburg (Erdmenger, 2021).

Another general governance issue is that traffic/mobility and spatial planning departments at local governments are often predominantly focused on the 'car-user perspective' which limits the potential for non-car solutions or integral (multi-modal) solutions (Harms, 2021). In order to successfully combat local air quality problems, a 'package' of several measures is recommended as policies will enhance each other (Erdmenger, 2021). A clear overall vision of authorities on air quality improvement or (clean) transport in which a number of complementary measures are incorporated can contribute greatly to the impact of policies (Harms, 2021). Complementary measures may also lead to synergy. For example, a clear and strict LEZ in a city can lead to a higher share of travellers using active modes (Ballinger, et al., 2017). In order to increase political and public willingness, the authority should consider make clear the proposed measures are a means to increase attractiveness of the city in terms of quality of life, air quality, public health and welfare (Harms, 2021). However, this is more difficult in cities where coal mining is the main source of income for its inhabitants (for instance in the city of Rybnik).

At the implementation level, political support is a significant determinant for success or failure, as seen with cycling policies in major cities (London, Paris, Barcelona) (Harms, 2021). The same is true for the implementation of congestion charging zones in Swedish cities (Eliasson, 2014). In the end, three important aspects should be in line with each other:
1. The infrastructural aspects.
2. The behaviour and perception of the public.
3. The governance willingness, vision and goals followed by adequate implementation.

In order to further enhance policy implementation, legal responsibilities of authorities should be clear and certain. For large, general measures (like for example a diesel ban) national, federal or state law may be required for legal reasons (such as the mobility law in Spain). Authorities should be aware their efforts are in line with desires and perceptions of the national government with regard to air pollution solutions to avoid setbacks and struggle but rather have the support of other government bodies in the implementation phase (Erdmenger, 2021). Also, expected benefits and evaluated benefits should be communicated openly and regularly to the public.

Framing of policies with a fiscal or pricing aspect (e.g. parking, congestion zone, (U)LEZ) as a means to increase tax collection can reduce public support significantly (Börjesson, 2018). Also, the allocation of power over revenues from a pricing policy (e.g. CCZ, parking) is considered a very important factor of successful implementation. There may be low willingness if power of using those funds is not allocated at the authority (level) that implements the policy in the first place. Air quality policies that restrict the use of a type of mobility or infrastructure (certainly roads) should be accompanied by measures that provides proper alternatives in order to maintain public support (Erdmenger, 2021). Communication on the predicted effects of a measures as well as evaluated effect (post-implementation) is very important to justify to take (strict) measures.

The COVID-19 situation has led to a realisation of authorities that governmental bodies could and should take much bolder action in planning and implementing (drastic) measures in order to achieve (legally binding) targets. A reaction from employees was they actively started to stimulate to get their companies into air pollution reducing strategies and business practices (Erdmenger, 2021).

Emissions in Europe should not exceed the EU annual limit values set by the European Commission (EC, 2020a). However, the EU annual limit value for PM does not correspond with the WHO annual limit value for PM in the WHO guideline (WHO, 2018), which is two times lower than the EU annual limit value. The impact of the EU annual limit values should not be underestimated, as these are binding for all countries and cities in Europe. Adjustment of the EU annual limit values, which is expected in 2021, leads to a reduction of emissions in Europe as a consequence. Adoption of the WHO limit values is currently a matter of choice and depends on ambitions at state and city level. For instance, the city of

Bilbao aims to reach the WHO annual limit values as part of its own ambition to improve air quality at the city level.
The measures in this report focus on reducing air pollution and to improve air quality in cities. It is good to be aware of the fact that this is not always the main reason why measures are implemented everywhere in Europe. For instance, in some areas these measures are implemented to improve the accessibility of certain areas and villages, such as in Poland. Public transportation has not been available to all Polish inhabitants and thus improvements are made to make public transportation available to everyone. Investments are made with EU funds in sustainable public transportation, such as electric buses. The development of certain areas in Europe may therefore be an opportunity to invest in sustainable mobility and transportation.

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A Emissions in 1990 and 2018

Table 10 - Transport emissions in 1990 and 2018 per country

Country Name	NO_x 1990	NO_x 2018	PM_{10} 1990	PM_{10} 2018
Austria	120	84	7	4
Belgium	222	83	16	5
Bulgaria	73	47	3	3
Croatia	40	25	2	2
Cyprus	9	7	1	0
Czechia	119	57	7	4
Denmark	130	47	6	3
Estonia	29	9	1	1
Finland	154	41	15	8
France	1,278	452	78	32
Germany	1,508	531	105	39
Greece	198	116	9	7
Hungary	83	48	3	3
Iceland	7	4	0	0
Ireland	60	46	3	3
Italy	1,119	377	69	27
Latvia	39	15	2	1
Liechtenstein	0	0	0	0
Lithuania	64	29	2	2
Luxembourg	26	14	1	1
Malta	3	4	1	0
Netherlands	319	119	20	2
Norway	110	72	6	4
Poland	220	295	12	18
Portugal	106	77	8	7
Romania	87	99	5	6
Slovakia	57	28	3	2
Slovenia	30	16	1	1
Spain	660	281	34	16
Sweden	159	55	18	18
Switzerland	88	41	6	5
Turkey	25	178	1	11
United Kingdom	1,645	410	60	23

B Extended long list of measures

#	Measure	AIS	Type	Effectiveness [a)]	Up-front investment costs	Implementation effort (gov)	Cost-effectiveness	Example cities
1	Congestion charge	Avoid/Reduce	Spatial planning/TOD	Very effective (++++)	High (++)	High (++)	High (+++)	Gothenburg, Jurmala (LV), London, Milan, Palermo (IT), Singapore, Stockholm, Valetta
2	Diesel ban	Avoid/Reduce	Norms	Very effective (++++)	High (++)	High (++)	High (+++)	Athens, Brussels, Berlin, Madrid, Paris
3	Environmental/(ultra) LEZ zone	Avoid/Reduce	Pricing/fiscal incentive	Very effective (++++)	High (++)	Medium (+/-)	High (+++)	Athens, Berlin, Munich, Brussels (region-wide), Copenhagen, Krakow, London, Lisbon, Milan, Palermo, Prague, Utrecht, Rotterdam
4	Parking policies (pricing)	Avoid/Reduce	Spatial planning/TOD	Effective (+++)	Low (--)	Medium (+/-)	Very high (++++)	Amsterdam, Belgrade, Bucharest, Krakow, Paris
5	Parking policies (availability)	Avoid/Reduce	Spatial planning/TOD	Effective (+++)	Medium (+/-)	High (++)	Very high (++++)	Amsterdam, Bucharest, Belgrade, London, Paris
6	Respacing infrastructure	Avoid/Reduce	Spatial planning/TOD	Effective (++)	High (+)	High (++)	High (+++)	Antwerp, Bucharest,

#	Measure	AIS	Type	Effectiveness a)	Up-front investment costs	Implementation effort (gov)	Cost-effectiveness	Example cities
	Road capacity reduction							Ljubljana, Nuremberg, Stuttgart, Paris, Riga
7	Speed limits	Avoid/Reduce	Spatial planning/TOD	Effective (+++)	Low (-)	Low (--)	Very high (++++)	Antwerp, Brussels, Stuttgart, Paris
8	ZE city busses	Improve	Norms	Effective (+++)	High (++)	High (++)	Moderate (++)	Amsterdam, Bilbao, Ljubljana, Warsaw, Zielona Góra
9	ZE city logistics - clean vehicles	Shift	Spatial planning/TOD	Effective (+++)	High (++)	High (++)	Moderate (++)	Bilbao
10	Cycle logistics[11]	Shift	Spatial planning/TOD	Moderately effective (++)	Medium (+/-)	Medium (+/-)	Moderate (++)	Amsterdam, Cambridge (UK), Berlin, Hamburg, San Sebastian (ES), Vienna, Vicenza (IT)
11	Increase public transport capacity	Shift	Pricing/fiscal incentive	Moderately effective (++)	High (++)	High (++)	Moderate (++)	Brussels, Gdansk, London, Paris, Warsaw, Stuttgart,
12	Promote cycling/cycling infrastructure	Shift	Norms	Moderately effective (++)	High (++)	High (++)	Moderate (++)	Antwerp, Brussels, Budapest, Bucharest, Gdansk, Ljubljana, London, Paris, Rotterdam, Warsaw
13	Scrapping subsidy	Improve	Spatial planning/TOD	Moderately effective (++)	High (++)	High (++)	Moderate (++)	*National policy*
14	Subsidy ZEVs	Improve	Subsidy	Moderately	High (++)	Medium (+/-)	Moderate (++)	*National policy:*

[11] See https://ec.europa.eu/transport/themes/urban/cycling/guidance-cycling-projects-eu/cycling-measure/cycle-logistics_en for cases of cycling logistics city projects.

#	Measure	AIS	Type	Effectiveness [a)]	Up-front investment costs	Implementation effort (gov)	Cost-effectiveness	Example cities
				effective (++)				*Poland, the Netherlands,*
15	Traffic management/ITS	Improve	Spatial planning/TOD	Moderately effective (++)	Medium (+/-)	Medium (+/-)	High (+++)	Gdansk, Ljubljana, Paris, Stuttgart
16	Regulation micro mobility	Shift	Spatial planning/TOD	Slightly effective (+)	Medium (+/-)	Medium (+/-)	Moderate (++)	Berlin, London, Paris
17	ZE privileges (dedicated lanes/bus lanes)	Improve	Norms	Slightly effective (+)	Medium (+/-)	Medium (+/-)	Moderate (++)	*National policy; Norway, Poland*
18	Shared e-scooters	Shift	Norms	Slightly effective (+)	Medium (+/-)	Medium (+/-)	Moderate (++)	Budapest, Bratislava, Rome, Bucharest, Riga, Stockholm, Vilnius, German, French, Polish cities,
19	Air filters at hotspots	Improve	Spatial planning/TOD	Slightly effective (+)	Medium (+/-)	High (++)	Moderate (++)	Stuttgart
20	Car free (sun)day	Avoid/Reduce	Spatial planning/TOD	Slightly effective (+)	Low (--)	Medium (+/-)	High (+++)	Barcelona
21	Car sharing schemes	Shift	Norms	Slightly effective (+)	Medium (+/-)	Medium (+/-)	Moderate (++)	Amsterdam, Berlin, Cologne, Ljubljana, London, Milan, Paris, Vienna
22	Green Public Procurement	Improve	Subsidy	Slightly effective (+)	Medium (+/-)	Medium (+/-)	-	-
23	Subsidised (or free) public transport	Shift	Pricing/fiscal incentive	Slightly effective (+)	High (++)	High (++)	Moderate (++)	Budapest, Krakow, Ljubljana, Luxembourg
24	Increase EV charging infrastructure	Improve	Spatial planning/TOD	Neutral (0)	High (++)	High (++)	Low (+)	Amsterdam, Brussels, Paris
25	15 minute city	Shift	Spatial planning/TOD	Unknown (?)	High (++)	High (++)	Unknown	Barcelona, Paris
26	Mobility as a Service	Shift	Spatial planning/TOD	Unknown (?)	Unknown (?)	Medium (+/-)	Unknown	-

#	Measure	AIS	Type	Effectiveness [a)]	Up-front investment costs	Implementation effort (gov)	Cost-effectiveness	Example cities
	(MaaS)							
27	ZE city logistics - spatial planning such as hubs	Improve	GPP	Unknown (?)	High (++)	High (++)	Moderate (++)	-
28	ZE construction sites - (Non Road Mobile Machinery)	Improve	Norms	Unknown (?)	High (++)	High (++)	Moderate (++)	-

Overview of interviewees

Table 11 – Overview of interviewees

Country	Organisation	Job title	Name
Germany	Ministry of transport in Baden-Württemberg	Head of sustainable mobility department	Christoph Erdmenger
The Netherlands	Dutch Cycling Embassy	CEO	Lucas Harms
Poland	The city of Rybnik	Advisor to the mayor of Rybnik on integrated transport	Bartosz Mazur
Poland	Institute for Sustainable Development (ISD) Foundation	Specialist and CEO	Wojciech Szymalski
Belgium	Bruxelles department of Environment	Sustainable Mobility Project Manager	Louise Duprez
Spain	The city of Bilbao	Mobility counsellor	Alfonso Gil

C Calculation of Social cost reduction

The calculations of the social cost reduction as displayed throughout the report (see Chapter 4 and Section 5.2) are based on a previous study by CE Delft from 2020. In that previous study, the health impact of air pollution has been calculated for a total of 432 cities in Europe, spread over 30 countries (EU27 plus the UK, Norway and Switzerland). In these calculations, sixteen human health-related endpoints are distinguished, caused by the inhalation of particulate matter, NO_2 and ozone. These calculations are done based on the level of pollution concentration in 2018 for each city. Furthermore, city characteristics such as age distribution, income level, and total number of inhabitants are used to determine a specific cost for each city.

To give a general idea of the possible health benefits the proposed measures in this report might have, the results from the CE Delft study in 2020 have been used as the basis for the calculation. The 432 cities are distributed over eleven groups, where we distinguish between geographical location (North, East, South or West Europe), and between city size (metropolitan, big, and small cities)[12]. This renders the following ‘sample sizes’ for each group of cities:

Table 12 – Sample size per city type and geographical area

	Metropolitan (> 1 mln inhabitants)	Big cities (200,000-1 mln inhabitants)	Small cities (< 200,000 inhabitants)	*Total*
North	-	13	10	*23*
West	10	66	127	*203*
South	4	32	79	*115*
East	6	31	54	*91*
Total	***20***	***142***	***270***	***432***

The city size grouping is done based on the following definitions:
- metropolitan: more than one million inhabitants;
- big cities: between 200,000 and one million inhabitants;
- small cities: less than 200,000 inhabitants.

The reason for this size distribution is that it results in a fairly even distribution of our sample of 432 cities over the categories, considering the representativeness of the sizes for cities in Europe (there are much fewer metropolitan cities than cities of a ‘big’ size).

The distribution of cities over the geographical locations has been done based on the location of the country the cities are in. Below an overview of the countries that are included in each geographical area is displayed.

[12] Eleven groups, since there are no Northern metropolitan cities in our sample.

Table 12 – Countries per geographical category

North	East	South	West
Denmark	Bulgaria	Cyprus	Austria
Estonia	Croatia	Greece	Belgium
Finland	Czech Republic	Italy	France
Latvia	Hungary	Malta	Germany
Lithuania	Poland	Portugal	Ireland
Norway	Romania	Spain	Luxembourg
Sweden	Slovakia		Netherlands
	Slovenia		Switzerland
			United Kingdom

For each of the eleven city groups, the median total social costs is determined, based on the results of the previous study. Moreover, the median contribution of health endpoints caused by particulate matter and NO_2 is also given. The contribution of ozone is neglected in this calculation, since the average contribution of ozone is no more than 2.5%.

Next, we determined the range of potential social returns from implementing the proposed measures. To this end, we took the range of potential PM and NO_2 concentration reduction and applied them to the median contribution of PM and NO_2 to the total median social cost respectively, per group of cities. For each group of cities the formula for one end of the range therefore looks as follows:

Social cost gains (€) = median total social cost (€) × (median contribution PM(%) × concentration reduction PM(%) + median contribution NO_2(%) × concentration reduction NO_2(%)).

The results indicate the potential social returns in terms of monetised health benefits for each of the measures. For the purpose of giving a broad indication of the possible social returns, this method is a fair approximation, since the relationship between the level of pollution concentration is almost linear to the social costs, given the number of inhabitants. To arrive at a more precise estimate, the specific city characteristics should be taken into account, such as age distribution and income level.