Blue Sky Recovery

How to keep lockdown low levels of air pollution in European cities

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Executive Summary

Tuesday 9 March 2021 marked one year since the first country-wide ‘lockdown’ policy was imposed in Europe to contain the spread of Covid-19.[1] As a side effect, these policies triggered an unprecedented and rapid drop in traffic and air pollution.[2] Suddenly, the air in Paris was the cleanest it has been in 40 years[3], the inhabitants of Milan could clearly see the nearby Alps[4] and Berliners savoured remarkably clean air at even the busiest traffic hotspots.[5] Citizens got a glimpse of what living with and breathing cleaner urban air feels like.

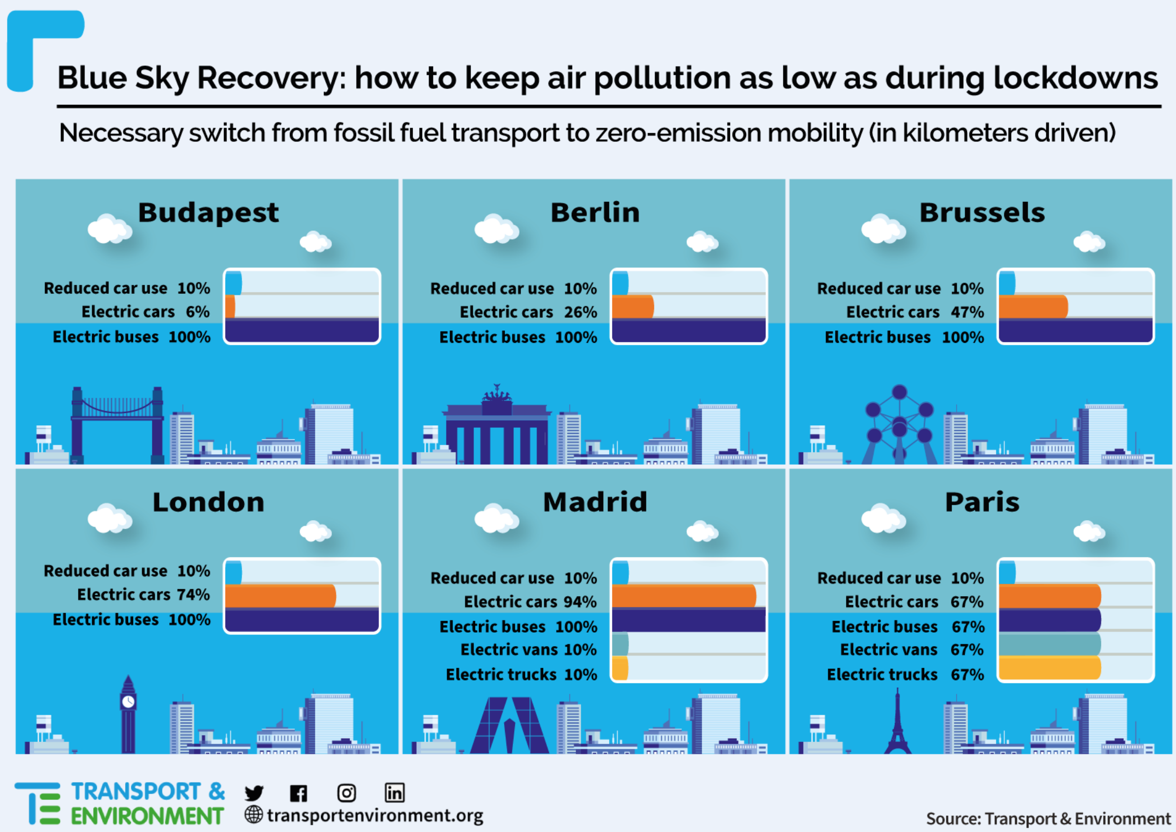
At the same time, they were warned that those living in polluted cities are probably more at risk from Covid-19[6], a realisation helping to trigger strong interest in clean air. A representative survey spanning 21 European cities showed that during the first lockdowns, when the air was at its cleanest, almost two out of every three respondents said they did not want to go back to pre-Covid pollution levels.[7]

The vaccines rolling out across Europe promise an end to lockdown policies. This is also a decisive moment for clean air. Road traffic and, consequently, congestion and air pollution in many cities has already risen to levels close to or at times above those observed before the pandemic[8], as subsequent lockdowns have been less strict and citizens started to use their car more. As a slow path to a post-pandemic world begins, will cities go back to a deadly ‘pollution as usual’, humanity’s foremost environmental health threat, or will they use the recovery and the EU stimulus funds to fast-forward the transition towards clean and healthy mobility? Of the €672.5 billion made available, 37 percent of each country’s spending must be used for green investments[9], though how this is defined is subject to dispute.[10]

This report uses the latest research on mobility trends to chart the changes in urban mobility needed for a rapid but realistic return and lock-in of the record low air pollution levels of March and April 2020. The analysis investigates the two most common strategies applied across Europe to clean up mobility: On the one hand, a roll-out of zero-emission vehicles whose sales surged across Europe in 2020 with Europe surpassing China for the first time[11]; on the other a wider overhaul of mobility relying also on a switch to active travel, public transport and teleworking. The results are presented in terms of percentage switch from fossil fuel transport to zero-mission vehicles and mobility; metrics designed to allow policymakers to adjust their mobility strategies, city budgets and investment programmes.

Air Quality Consultants Ltd., leading experts in the field, developed a methodology that can be applied to any city, assuming suitable air quality and traffic data can be identified. For this report, it was applied to a sample of six cities considered representative of major metropolitan regions in Europe: Madrid, Paris, London, Brussels, Berlin and Budapest.

The effects of the most stringent lockdowns on air quality from road traffic were determined for each city and different scenarios were run to estimate the changes in mobility necessary to expeditiously replicate the state of cleaner air seen during lockdowns. The following graph summarises the most important findings.



The most important findings are:

- During their most stringent phase, lockdowns reduced air pollution from road traffic in all six cities, but to varying extents. Reductions in nitrogen dioxide (NO2) from road traffic ranged from -16% in Budapest to -76% in Paris.
- In all six cities, lockdown low levels of air pollution can be replicated through mobility changes and readily available solutions. This is a 'yes we can' finding. Importantly, the fastest way to cleaner air requires both zero-emission vehicles and an increase in walking, cycling, public transport and teleworking.
- In Budapest, Brussels, Berlin and London, a switch to zero-emission vehicles alone would suffice, even assuming a limited supply of electric vans and trucks in the coming years. Between 42% (Budapest) and 92% (London) of all kilometers driven by car need to go zero-emission to replicate NO2 levels observed during the strictest lockdown phase.
- These four cities can however accelerate the path to lockdown-like clean air if they combine zero-emission vehicles with more walking, cycling, public transport and teleworking (shifting 10% of car travel). This would mean only 6% of all remaining kilometers driven by car in Budapest need to go zero-emission, and 74% in London.
- In Madrid and Paris that have seen particularly strong reductions of NO2 pollution, only a combination of zero-emission vehicles and reduced car use can replicate lockdown levels. In Madrid, 10% of all kilometers travelled by light and heavy-goods vehicles, as well as 94% of car-km, must go zero emission. In Paris, 67% of all kilometers driven need to be switched to ZEVs.
- The report also provides a longer-term outlook showing how fleets of only electric cars, vans, buses, motorcycles and trucks would affect air quality in the selected cities. NOx emissions from traffic would be eliminated completely and PM2.5 emissions reduced by 22% to 66%.

From the local to the European level, a wide range of policy options are available to drive the mobility changes needed to replicate the air quality effects of lockdowns:

- In T&E's view, cities and governments should focus on phasing out vehicles with internal combustion engines at the national and local level (e.g. through Zero-Emission Zones), reforming taxation to accelerate the uptake of emissions-free vehicles, rolling out the right charging infrastructure and reallocating public space to walking, cycling and public transport.

- The European Union could make the strongest contribution by setting an EU-wide phase-out date for sales of cars with internal combustion engines no later than 2035 and tightening the CO_2 standards for cars, vans, trucks and buses that enter into force after 2025.
- Even if lockdown air quality levels can be replicated across the six cities studied here, it is important to stress that according to the newest health evidence, there are no safe levels of air pollution. Further reductions will therefore be needed in line with the EU's announcement of a 'Zero Pollution Action Plan'. This strategy should only support mobility solutions that are capable of zero pollutant emissions, and EU clean air laws should be reviewed based on the latest scientific understanding and the upcoming revision of World Health Organisation guidelines.

It is clear that a return to clean air is both needed for health reasons and wanted by the population. This study provides mayors with a realistic roadmap to achieve this. With billions of Euros available specifically to 'build back better', what are we waiting for? Full details on the methodology, data sources and results can be found in the accompanying technical report by *Air Quality Consultants.* This report summarises the approach and results, as well as T&E's policy recommendations.

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1. Context and objective of the analysis

1.1 Context: cleaner air during Covid-19 lockdowns has stimulated the debate

The Covid-19 pandemic has provided a **new stimulus to the debate on urban air pollution**. 'Lockdown' policies adopted to contain the spread of the virus triggered, as a side effect of disrupted social and economic activity, a **strong reduction of pollution levels** in most major European cities.[2] The air in Paris, for example, was the cleanest in 40 years during the stringent phase of the lockdown[3] and inhabitants of Milan were suddenly able to clearly see the nearby Alps.[4]

Following this first-hand experience of cleaner air, interest in the health effects of polluted air increased significantly. A recent Pan-European YouGov survey across 21 of Europe's largest cities in May 2020 showed that two in three city dwellers didn't want to go back to pre-lockdown pollution levels. Almost three in four (74%) demanded effective protection from air pollution, even if this requires reallocating public space to walking, cycling and public transport.[7] At the same time, experts warn that **those living in polluted cities are probably more at risk from Covid-19.**[6]

As countries and cities emerge from the more stringent stages of their lockdowns, Europe is at a **decisive moment for clean air policies**. Many European cities have already seen a rebound of pollution, with some cities experiencing levels that exceed pre-lockdown concentrations.[8] The newest data from the European Environment Agency confirms that **air pollution still is the principal environmental factor driving disease**, with around 400,000 premature deaths attributed to ambient air pollution annually in the EU.[12] Road transport, in turn, is the main source of NO_2 pollution and the joint second-largest source of $PM_{2.5}$.[12]

But the past year has opened a **window into a possible future** and triggered a process of reimagining urban mobility, as can already be observed in many cities. The questions now are: Will we go **back to 'pollution as usual'** or **fast-forward the transition** towards clean and healthy mobility that is already underway? And how to provide cleaner air while serving the mobility needs of our societies? This is what this report investigates with regard to road transport through a case study of six of Europe's largest cities.

1.2 Objective: Identify solutions to keep pollution at lockdown levels

This report has been designed to **inform the clean air debate** in Europe by providing **solid evidence** and policy recommendations. It aims at helping decision-makers at all levels set a course towards cleaner and eventually **zero-emission mobility** and provides estimations for changes needed to replicate the air quality effects of lockdown periods in normal times. It focuses on solutions that are **ambitious but realistic** and align with the objectives of the European Green Deal[13] for climate neutrality by 2050 and a 'zero pollution ambition for a toxic-free environment'. The report also makes concrete proposals for the spending of €750 billion in EU Covid recovery funds, Next Generation EU, a third of which is earmarked for green investments, including transport. By zooming in on six very different cities in Europe, conclusions that apply to many other cities can also be drawn.

The remainder of the report has the **following structure**: First, the scope and methodology of the analysis will be presented (chapter 2). Secondly, the actual impact of lockdown policies on urban air quality and the contribution from road traffic will be assessed, using official monitoring data and adjusting for meteorology and other external factors (chapter 3). Thirdly, the effects of selected mobility scenarios will be modelled for the selected cities in order to quantify scenarios that would replicate the clean air benefits of lockdowns (chapter 4). The report then provides an outlook on a future with only zero-emission vehicles and quantifies the air quality benefits that can be expected compared to the status quo (chapter 5). Finally, conclusions that apply beyond the selected cities will be drawn and policy recommendations for the local, national and EU level will be formulated (chapter 6).

2. Overview of the scope and methodology

This chapter presents the scope and methodology of the report. Transport & Environment commissioned the underlying analysis to *Air Quality Consultants Ltd.*, **one of Europe's leading consultancies** on air quality monitoring, modelling and assessment. The Company frequently provides expert evidence at public inquiries and it has staff who have acted as formal advisers in UK Government expert groups and European Commission working groups on air quality management and assessment. For the purpose of this project, *Air Quality Consultants Ltd.* have developed a **tailor-made methodology**. The approach is described in detail in the **accompanying technical report.** In this section, only an overview is provided to allow the reader to be able to interpret the main results. *Air Quality Consultants* has reviewed and approved the chapters that present the methodology and findings.

2.1 The scope: a closer look at six of Europe's largest cities

The scope of this report was to analyse a **sample of capital cities in Europe** and to draw both city-specific and more general conclusions from this analysis. Transport & Environment chose **six of Europe's largest cities**, aiming for **representativeness** as regards different types of cities, geographic regions, climatic conditions, policy approaches to the Covid-19 pandemic and starting points with regard to mobility and air pollution. Table 1 provides an overview of the exact geographic areas covered. The assessment methodology used in this study **could be applied to any city**, assuming suitable air quality and traffic data can be identified. It is important to stress that the **quality of local data** is decisive for the precision of the analysis, which also varies for the six cities analysed here (see section 2.5 and Annex 1 for).

Note that Milan was initially also included in this analysis but due due to issues with data from the identified urban background station, it was decided that the outputs for Milan were not suited to the methodology used in the analysis and so the results for Milan have not been included in this report.

Table 1: Overview of the cities covered by the analysis

Agglomeration	Exact area covered
Berlin	Region (Land) of Berlin
Brussels	Brussels Capital Region
Budapest	Budapest metropolitan area
London	Greater London
Madrid	Municipality of Madrid
Paris	Île-de-France

2.2 Methodology for the quantification of the effect of lockdowns

The first step in the analysis was to construct a baseline scenario, essentially determining the changes in air pollution from road traffic brought about by Covid-19 response policies.

Initially, the effect of the most stringent lockdowns on air pollution overall was determined. For each city the **'lockdown periods' were inferred** (see table 2 below)[1] and local nitrogen dioxide (NO2) measurements before and during this period were then compared. **NO2** was used as it is both a **pollutant of prime concern** for air quality policy and because there is a **strong correlation** between ambient concentrations in urban areas and traffic flow.[14]

Due to higher uncertainty[2], **particulate matter** is not used to define targeted reductions but the **effect of policies** on emissions of PM2.5 (Particulate Matter with a diameter smaller than 2.5 micrometers) is analysed

[1] The lockdown periods were identified based on the effect on air quality, which may differ from the legal mandates but best reflect the periods relevant from an air quality point of view. For example, in London, there was a drop in traffic a few days before the lockdown came into force.

[2] PM2.5 has many more sources, has a large secondary component and urban concentrations in Europe tend to be dominated by the regional background. Thus, the traffic "signal" is far smaller when compared to the total.

in the modelling of different scenarios. As urban ambient pollutant concentrations are significantly affected by meteorology, routine temporal factors (e.g. systematic differences in emissions on different days of the week) and also by regional background ozone concentrations, a '**de-weathering process'** was applied to remove the influence of these factors[3] and isolate the effect of lockdown policies, using Boosted Regression Tree (BRT) models developed by Carslaw and Taylor.[15]

The transport interventions explored in this report would all also reduce ammonia emissions from road traffic, which has the potential to reduce the formation of secondary PM2.5, but it has not been possible to include this additional benefit within the calculations. It would have also been very relevant for the public health debate to include Particle Numbers (PN) and further unregulated pollutants[16], but there is not enough data to do so. The results in this report can therefore be considered conservative estimates of the air quality effects.

Table 2: Overview of the most stringent lockdown periods in the selected cities

City	Pre-lockdown period	Most stringent lockdown period
Berlin	01/01/2020 – 15/02/2020	23/03/2020 – 20/04/2020
Brussels	01/01/2020 – 29/02/2020	18/03/2020 – 30/04/2020
Budapest	01/01/2020 – 29/02/2020	28/03/2020 – 30/04/2020
London	01/01/2020 – 29/02/2020	23/03/2020 - 30/04/2020
Madrid	01/01/2020 – 29/02/2020	14/03/2020 – 30/04/2020
Paris	01/01/2020 – 07/02/2020	17/03/2020 – 30/04/2020

Zooming in on the lockdown effect on road traffic emissions

The analysis subsequently looked **specifically** at the **effect of lockdown policies on air pollution from road traffic**. In order to isolate the road traffic component of air pollution, the monitoring sites in each city were separated into those which represent 'background' conditions, well away from any roads or other local emission sources, and those sited close to busy roads. The NO2 concentrations were then compared between these two categories of stations in order to determine the road traffic increment for NO2. This

[3] Other external factors were: wind speed, wind direction, air temperature, relative humidity, hour of day, day of week, week of year and background O3 (with O3 concentrations excluded from the PM2.5 models).

increment was then compared between lockdown and pre-lockdown policies, which showed the effect of lockdowns on NO2 pollution from road traffic. While there will undoubtedly have been changes to non-transport emissions caused by the COVID-19 lockdowns[4], the analysis assumes that the principal changes appear to have been to transport emissions (see the accompanying technical study for details on assumptions and uncertainty).

The calculated improvements at an individual site are subject to considerable variability. For this reason, it was considered most **appropriate to take the average improvements calculated across multiple monitoring sites within a city** (see also below). However, in the case of **Berlin, London and Paris**, a clear **spatial pattern** in these calculated improvements is evident; with larger reductions in the centre of each city and smaller reductions outside of the centre (see chapter 3). The decision was thus made to separate these three cities into inner and outer areas and calculate the average improvement seen at all monitoring sites within each of these zones. It should be noted that the absence of similar patterns in other cities is more likely to reflect the availability, and distribution, of monitoring sites, rather than a significant difference in activity patterns. It is thus also relevant to calculate the city-wide changes observed in Berlin, London and Paris without this additional spatial differentiation.

In order to allow for the testing of different mobility scenarios, it was first necessary to **calculate the relative contribution that different types of vehicles** make to emissions of NOx and PM in each city. This has been based on the **best available information for each city**. Discussions were held **with bodies responsible for air quality in each city**. In the case of Berlin and London, this resulted in the identification or provision of detailed city-specific traffic activity and emissions data. For other cities city-specific transport and activity data could not be provided or otherwise identified within the timescale of the data analysis and so the best available but less precise data was used. This was the urban portion of national-level traffic composition data held for each city by *emisia* as part of their COPERT model, that has been developed under the lead of the European Environment Agency.[17]

2.3 Modelling selected scenarios to replicate reductions equivalent to the baseline

It was then possible to **calculate the effect of specific transport scenarios** on emissions in each city, focusing on how the reductions observed during lockdown could be replicated through changes in mobility. The observed reduction in **NO2 concentrations during the most stringent lockdown period in each city were taken as the 'targets'** to be met by the different transport interventions. In order to link NO2 levels with emissions from cars, the observed improvements in the road traffic contribution to **NOx**

[4] For example, domestic heating emissions could increase as more people stay at, or work from, home. Satellite imagery suggests that NOx emissions overall decreased during this period (see https://ineris.shinyapps.io/cams-scen/).

concentrations were taken as a proxy for these NO2 targets. NOx is a precursor of NO2[5] and is released from the tailpipe of vehicles. It has been assumed that if the traffic increment to NOx concentrations can be reduced to the levels observed during lockdown, then the effects that the lockdowns had on NO2 concentrations will also be replicated. As explained in detail in Annex 1 and the technical study, this approach has certain limitations but does provide the **most practical means of linking traffic emissions with the observed reductions in NO2** concentrations (see the annex and the accompanying technical report for a detailed explanation).

Five scenarios were defined by T&E, consisting of either exclusively a **shift to zero-emission vehicles (ZEVs),** or a **mix between ZEVs** and more walking, cycling and public transport or teleworking where such a shift can reduce kilometers travelled. Chapter 4 provides a specification of the scenarios and the rationale behind them.

For each scenario, changes in the urban vehicle fleet were simulated that either meet, or attempt to meet, the air quality benefit seen in the baseline scenario. The **change that would replicate the cleaner air effects of lockdowns is expressed as a percentage change in vehicle kilometres, either through a shift to zero-emission vehicles, modal shift or demand reduction**. It is important to note that the current study is concerned with **area-wide changes** and did not look at reductions in concentrations by differentially targeting individual roads. As explained, particulate matter (PM) was not used to construct the baseline due to higher uncertainty, but it has been taken into account in modelling the effects of different scenarios. **Ambient PM2.5** concentrations are strongly influenced by air brought in from outside each city, have many more sources and a strong secondary component (meaning they are formed through chemical reactions in the ambient air). These processes are still far from being fully understood. All of which prevents the direct calculation of traffic emissions of PM2.5 from the roadside measurements. The approach for this pollutant has been to calculate the **reduction in emissions which would be caused by meeting the NO2 targets** under each of the scenarios.

2.4 Methodology for the outlook on a 100% ZEV fleet

In addition to the analysis of scenarios needed to deliver reductions in air pollution equivalent to lockdown levels, a longer-term outlook on the air quality effects of a fleet of **only zero-emission cars, vans, buses, trucks and motorcycles** is provided in chapter 5. The aim is not to replicate a baseline but to **estimate the resulting reductions in NOx and PM2.5** emissions from road traffic in the six cities compared to the status quo.

[5] To be precise, the NO component of NOx is one of the main precursors for NO2, alongside ozone.

2.5 Uncertainty and limitations

This study has **used the best available information** to provide an indication of how the reductions in traffic emissions caused by the Covid-19 lockdowns might be replicated using specific, managed fleet interventions. The **analysis is intentionally high-level** (estimating city-wide effects) and thus, while the results can be considered as reasonable best-estimates, they **should not be viewed as definitive or precise**. The principal sources of uncertainty and the strategies applied to manage those are **summarised in Annex 1** and analysed in detail in chapter 4 of the accompanying technical study. A careful assessment has shown that the data sources are **fit for the purpose** of providing high-level indications of how the air quality improvements experienced during the Covid-19 lockdowns can be replicated using managed transport interventions.

3. Quantification of lockdown effects on air quality

In this chapter, the **lockdown effects on the contribution of road traffic to air pollution** are presented. The analysis shows that in all selected cities NO2 and PM2.5 pollution was significantly reduced during the most stringent lockdown periods. But the **magnitude of the effects varies strongly between the cities**. Reductions in the traffic-component of NO2 levels range from -16% in Budapest to -76% in Paris (city-wide) (see table 3). This is **by no means to be read as an evaluation of the different lockdown policies** that were adopted for public health reasons, nor the level of disruption experienced by those living and working in the cities. The purpose of this analysis is solely to analyse how these reductions observed under exceptional circumstances can be replicated in normal times in the future through cleaner mobility. For this report, the cities can be classified in three categories according to the different levels of reductions.

Table 3: Reductions in NO2 levels and the traffic contribution during the most stringent lockdowns

Category	City	Observed mean change in NO2 levels (µg/m3) (city-wide)	% estimated reduction in traffic contribution to NO2
Limited reduction	Budapest	-3.2	-16%
Strong reduction	Berlin	-7.2	-39%
	Brussels	-6.2	-43%
	London	-12.7	-54%
Very strong reduction	Madrid	-14.6	-71%
	Paris	-20.6	-76%

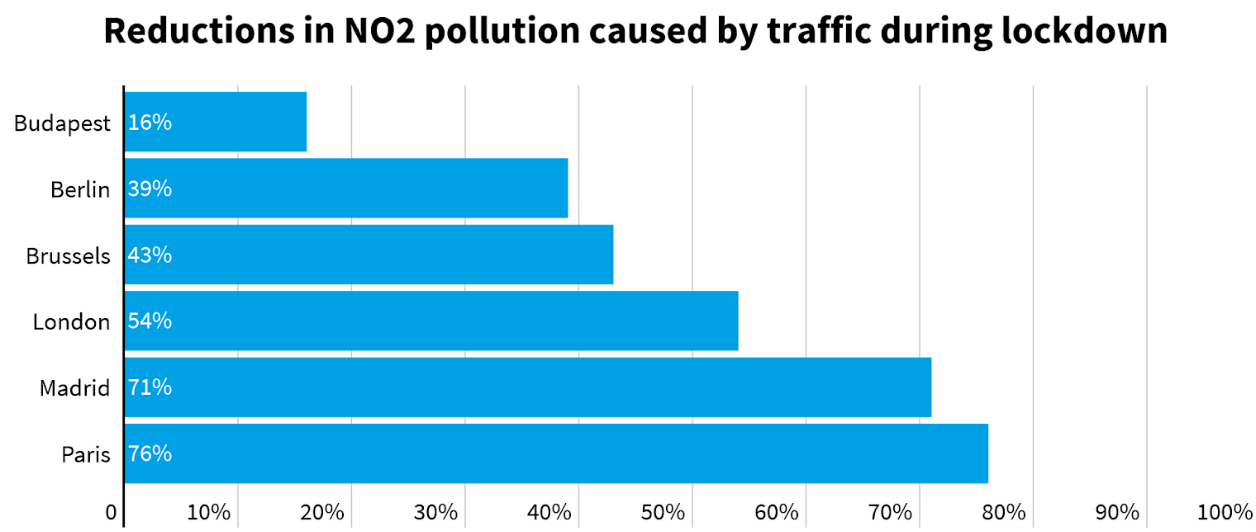

Figure 1: NO2 reduction from traffic during lockdown

Several **explanations** for this wide range of reductions seem likely:

- The **stringency of lockdown policies** adopted in response to Covid-19 varies greatly. Stricter lockdowns have led to a stronger reduction in road traffic and hence pollution from road traffic. Data from Dutch navigation and telematics company TomTom confirms a strong but varying effect of lockdown policies on traffic volumes.[18]
- At the same time, **public transport ridership has fallen significantly during lockdowns** due to contagion fears and many people travelled by car instead, which - to varying extents - will have offset those who stopped driving during lockdowns.[19]
- Cities with a **relatively cleaner vehicle fleet** (e.g. London) may have seen a more limited reduction as reduced use of these vehicles leads to lower reductions in emissions.
- The **number of monitoring stations** as well as the quality of official air quality data varies and may in part explain the variation observed (see also section 2.5).

Higher uncertainty in the results for Budapest

The reductions of the traffic component in Budapest may seem relatively low compared to data reported in the media. This may be due, on the one hand, to the fact that data previously discussed was not corrected for external effects - as is the case in the present study - as well as to the fact that often overall pollution, and not the traffic component, were used. On the other hand, it is important to note that the data for Budapest is prone to higher uncertainty due to the official monitoring data used (see Annex 1 for details). What is more, only two roadside monitors were operational in Budapest. One of these is adjacent to a road which was partially closed during 2019, which is likely to have skewed the BRT models. The other monitor is set back more than 30 metres from the main road, meaning that the effect of local traffic will be diminished. The two sites showed markedly different responses to the lockdown and it is not possible, from the ambient measurements, to determine which is most representative of the city-wide conditions.

Stronger reductions in central areas

In the **cities for which more granular data is available** (i.e. Paris, Berlin and London), the analysis shows that NO2 and NOx pollution levels have **fallen more strongly in the centre** compared to outer areas (see table 4). Possible explanations are that the road traffic component of air pollution is stronger in the denser city centres than in the outer areas. Moreover, economic and social activities which have been most affected by lockdowns are usually more concentrated in the centre (e.g. shopping streets, restaurants).

Table 4: Spatial patterns of the effects of lockdown policies in Paris, Berlin and London

City		**Paris**			**Berlin**			**London**		
Zone		central	outer	city-wide	central	outer	city-wide	central	outer	city-wide
% reduction in traffic compo-nent	NO_2	88	53	**76**	61	30	**39**	72	52	**54**
	NO_x	76	52	**68**	47	20	**28**	66	47	**49**

Lockdown effects vary strongly between cities

In summary, the results show that lockdown policies have caused a wide range of different reductions in air pollution from road traffic in the selected cities. For the purpose of this study this means that the **baseline** and hence the **extent of the reductions to be replicated** by changes in mobility also **differ significantly**. Replicating the 16% NO2 reduction observed in Budapest, for instance, is easier than attaining the drop of 76% seen in Paris. In consequence, the changes needed in different cities can only be compared with care, bearing in mind that the necessary changes will vary by definition.

Furthermore, it must be noted that **no city has seen a drop in air pollution from road traffic to close to zero**, as the EU's goal of 'a zero pollution ambition for a toxic-free environment' would require from a health point of view.[20] This means that for all cities analysed here, replicating the lockdown effects on air pollution can only be an intermediary step towards this target, and even more so for cities that have seen smaller reductions. The path towards zero-emission mobility will require more efforts. An outlook on the longer-term benefits of switching to zero-emission mobility is given in chapter 5.

4. Modelling of different mobility scenarios to attain lockdown low pollution levels

In this chapter, the **results of the modelling are presented**, looking at how the air quality improvements observed during lockdowns can be replicated through changes in mobility. For each scenario, **changes in the urban vehicle fleet were simulated** that either meet, or attempt to meet, the air quality benefit seen in the baseline scenario. The necessary change is expressed as the percentage change in vehicle kilometres required.

4.1 Definition and rationale of the scenarios: ambitious but realistic

Designing and implementing policies that improve air quality in the short to mid-term has proven **challenging in practice**. A wide range of mobility solutions is in principle available to curb urban air pollution. But the types of policies actually implemented in cities as well as their effectiveness has often been limited.

For this study to inform ongoing policy debates and decision-making processes in the post-lockdown context, it was important to focus on scenarios that are **ambitious enough** to replicate sufficient reductions while being **realistic for the short- to mid-term**. Based on existing research and good practice from leading European cities, several scenarios were defined by T&E that fulfil the criteria of both ambition and realism.

Two types of scenarios: zero-emission vehicles and a mix of modal shift and zero-emission vehicles

Two types of scenarios were selected, both of which have a **proven track record** of reducing air pollution, are **available today** and align with the EU's longer-term goal of a **zero emission and zero pollution** mobility: One type of scenarios relies exclusively on a shift to zero-emission vehicles and the other one consist of a mix between modal shift (to walking, cycling, public transport) and demand reduction (e.g. teleworking) with zero-emission vehicles. An overview of the scenarios is provided in table 5.

Table 5: Description and specification of the different scenarios

Type of scenario	Name of the scenario	Description of the scenario	Specification of the scenarios (in vehicle-km)				
			Modal shift/tele-working	Cars	Vans	Trucks	Buses
Shift to zero-emission vehicles	**SCENARIO A: shift to zero-emission cars**	This scenario analyses how many km travelled by cars with internal combustion engines (ICEs) need to be shifted to ZEVs to replicate the effects of lockdowns.	/	Shift to ZEVs until lockdown levels replicated	/	/	/
	SCENARIO B: shift cars, vans and trucks to zero-emission vehicles	This scenario analyses how many km travelled by cars, light-goods vehicles (LGVs) and heavy-goods vehicles (HGVs) need to be shifted to ZEVs to replicate the effects of lockdowns.	/	Shift to ZEVs until lockdown levels replicated	Shift 10% to ZEVs	Shift 10% to ZEVs	/
Mix of modal shift/reduced demand and ZEVs	**SCENARIO C.1: modal shift combined with zero-emission buses and cars**	This scenario assumes that part of the car traffic is shifted to walking, cycling and public transport or avoided by teleworking. It also assumes all buses go zero-emission. It then analyzes how many km travelled by cars need to be shifted to ZEVs.	Shift or avoid 10% of car-km	Shift to ZEVs until lockdown levels replicated	/	/	Shift all buses to ZEVs
	SCENARIO C.2: modal shift combined with zero-emission cars, buses, vans and trucks	This scenario assumes that part of the car traffic is shifted to walking, cycling and public transport or avoided by teleworking. It also assumes all buses go zero-emission and that part of the light-goods and heavy-goods traffic is shifted to ZEVs. It then analyzes how many km travelled by ICE cars need to be shifted to ZEVs.	Shift or avoid 10% of car-km	Shift to ZEVs until lockdown levels replicated	Shift up to 10% of km driven to ZEVs	Shift up to 10% of km driven to ZEVs	Shift all buses to ZEVs
	SCENARIO D: 10% modal shift and equal shift to zero-emission vehicles among cars, vans, buses and trucks	This scenario assumes that part of the car traffic is shifted to walking, cycling and public transport or avoided by teleworking. It then looks at how many km driven by all four-wheel vehicles - cars, buses, light-goods and heavy-goods vehicles - need to shift to ZEVs in order to replicate lockdown reductions.	Shift or avoid 10% of car-km	Shift to ZEVs until lockdown levels replicated	Shift to ZEVs until lockdown levels replicated	Shift to ZEVs until lockdown levels replicated	Shift to ZEVs until lockdown levels replicated

Rationale behind these scenarios

The rationale behind the scenarios listed above is the following:

- **SCENARIO A - shift to zero-emission cars:** The sales of electric cars are increasing faster than projected, namely as carmakers roll out new models needed to comply with the EU's CO2 targets. Despite the COVID-19 pandemic, electric mobility surged across Europe in 2020, as plug-in vehicles made up 10.5% of the market, compared to only 3% in 2019.[21]
- **SCENARIO B - shift cars, vans and trucks to zero-emission vehicles:** In addition to cars, shifting freight transport to zero-emission vehicles will also reduce pollution. A shift of 10% of vehicle-km for LGVs and HGVs is ambitious but not impossible according to T&E's modelling[22], especially when looking at cities that should lead the transition in Europe. Seven truck makers recently announced a joint pledge that by 2040 all their new commercial vehicles will be 'fossil free'.[22, 23]
- **SCENARIO C.1: modal shift combined with zero-emission buses and cars:** A 10% modal shift of car-km to walking, cycling, public transport or, alternatively, reducing traffic through teleworking is ambitious but possible. At the beginning of the pandemic, 44.6% of European employees said they worked from home.[24] Official estimates indicate that up to 37% of all jobs in Europe are suitable for teleworking.[25] When it comes to walking, cycling and public transport, many cities define more ambitious targets than a 10% reduction in car traffic in their Sustainable Urban Mobility Plans (SUMPs) but actual reductions in car traffic have in the past usually been more limited.[6] As regards urban e-buses, T&E currently expects that 100% zero emission bus sales across Europe are possible in the 2020s and hence a 100% zero-emission fleet in leading cities could be achieved in the next years.[7] A recent analysis shows that in Denmark, 78% of all new urban buses are already electric, and about two thirds of new sales in Luxembourg and the Netherlands run on zero-emission technology.[26]
- **SCENARIO C.2: modal shift combined with zero-emission cars, buses, vans and trucks:** See rationale for B and C.1. Vans and trucks are added, with a cap at 10% for the shift to zero-emission vehicles for these vehicles.
- **SCENARIO D: 10% modal shift and equal shift to zero-emission vehicles among cars, vans, buses and trucks:** This is a mid-term scenario. A shift to zero-emission vehicles across - cars, vans, buses and trucks - will be necessary to attain the EU's goals of climate neutrality and zero pollution.

The scenarios were run in the above order for each city, shifting vehicle-km until the baseline reduction in NOx was achieved or, if a scenario could not deliver this, the percentage change is expressed as more than 100%.

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[6] The Sustainable Urban Mobility Plan (SUMP) for Bremen (Germany), for example, aims for a reduction of a decrease of 4.2% in motor vehicle traffic for 2025. The SUMP of the Brussels Region, in turn, aims for reducing personal car use by 24% by 2030. But when it comes to actual modal shift achieved in the past, the results are often more limited. Vienna, one of Europe's leaders in this regard, has achieved a reduction of 6.3% between 2010-2015 on all roads and 11.2% in the city centre.

[7] Poland, for example, has also announced a shift to 100% electric public transport in large cities by 2030.

4.2 Results of scenario modelling for each city

The results of the modelling are presented in the table below. For each city, the most attainable scenarios of both the zero-emission and mixed scenarios that deliver the targeted reduction are presented. The main findings are:

- In all six cities, lockdown low levels of air pollution can be replicated through mobility changes and readily available solutions. This is a ‘yes we can’ finding. Importantly, the fastest way to cleaner air requires both zero-emission vehicles and an increase in walking, cycling, public transport and teleworking.
- In Budapest, Brussels, Berlin and London, a switch to zero-emission vehicles alone would suffice, even assuming a limited supply of electric vans and trucks in the coming years. Between 42% (Budapest) and 92% (London) of all kilometers driven by car need to go zero-emission to replicate NO2 levels observed during the strictest lockdown phase.
- These four cities can however accelerate the path to lockdown-like clean air if they combine zero-emission vehicles with more walking, cycling, public transport and teleworking (shifting 10% of car travel). This would mean only 6% of all remaining kilometers driven by car in Budapest need to go zero-emission, and 74% in London.
- In Madrid and Paris that have seen particularly strong reductions of NO2 pollution, only a combination of zero-emission vehicles and reduced car use can replicate lockdown levels. In Madrid, 10% of all kilometers travelled by light and heavy-goods vehicles, as well as 94% of car-km, must go zero emission. In Paris, 67% of all kilometers driven need to be switched to ZEVs.

An overview is provided in the following table and the full results for each city are presented on the factsheets in the Annex.

Table 6: Overview of the scenarios that would reduce NO2 pollution from traffic to lockdown levels

Category	City	Mean chang e in NO2*	% reduction in NO2 traffic compo-nent	First <u>zero-emission vehicle</u> scenario delivering the reduction (in vehicle-km)				First <u>mixed scenario</u> delivering the reduction (in vehicle-km)				
				Cars	Vans	Truck s	Buses	Cars	Vans	Trucks	Buses	Modal shift**
Both types of scenarios can deliver the reductions	Buda-pest	-3.2	-16%	42%	/	/	/	6%	/	/	100%	10%
	Berlin	-7.2	-39%	51%	/	/	/	26%	/	/	100%	10%
	Brussels	-6.2	-43%	72%	/	/	/	47%	/	/	100%	10%
	London	-12.7	-54%	92%	/	/	/	74%	/	/	100%	10%
Only mixed scenarios can deliver the reductions	Madrid	-14.6	-71%	ZEVs alone are insufficient to replicate lockdown levels if shift to zero-emission vans and trucks capped at 10%				94%	10%	10%	100%	10%
	Paris	-20.6	-76%	ZEVs alone are insufficient to replicate lockdown levels if shift to zero-emission vans and trucks capped at 10%				67%				10%
* in µg/m3 ** and teleworking												

5. Outlook: Quantification of clean air benefits of a 100% zero-emission fleet

In addition to the analysis of scenarios needed to deliver reductions in air pollution equivalent to lockdown levels, an outlook on the air quality effects of a fleet of **only zero-emission cars, vans, buses, trucks and motorcycles** is provided in this chapter. The aim here is not to replicate a baseline but to **estimate the resulting reductions in NOx and PM2.5** emissions from road traffic in the six cities compared to the status quo. This is the only scenario that includes motorcycles.

A complete switch to these zero-emission vehicles clearly represents a **mid- to long-term outlook** as fleet renewal takes time. But there is no doubt that this transition is indispensable to achieve the goals of the EU Green Deal on climate neutrality and zero pollution. T&E's own projections have shown that decarbonising the transport sector as a whole by 2050 implies for cars that the **last internal combustion engine car must be sold in 2035**.[27] From 2035 onwards, only zero emission vans and trucks (smaller than 26 tonnes) must be sold, **by 2040 all new trucks** (including above 26 tonnes) **must be zero emission**.

Figure 2 summarises the estimated reductions in the road traffic component of NOx and PM2.5 emissions. It is important to note that, as outlined in chapter 2, it was assumed that ZEVs have the same emission rate for non-exhaust PM2.5 as their ICE equivalents, which explains why reductions in PM2.5 are smaller than for NOx (see also Annex 1 for details).

The main findings are:

- The **contribution of different vehicle types** to pollution - and hence the reduction that can be expected from these sources - **varies considerably between the six cities**. The share of cars in total road emissions, for example, ranges from 33% of NOx in Budapest to 55% in Madrid; and PM2.5 contributions range from 13% in Berlin to 39% in Madrid.
- As regards **NOx emissions** from road transport, they will be **completely eliminated** once all cars, vans, buses, trucks and motorcycles go zero emissions.
- The expected **reduction in PM2.5 from road traffic compared to today is smaller** because zero-emission vehicles still produce non-exhaust emissions. **Reductions would range from 22% in London to 66% in Budapest**. In four of the six cities, PM2.5 emissions from road traffic could be cut by more than half.
- It should be noted that air pollution from other sources need to be addressed by other policies and will not be affected by the changes discussed in this study.

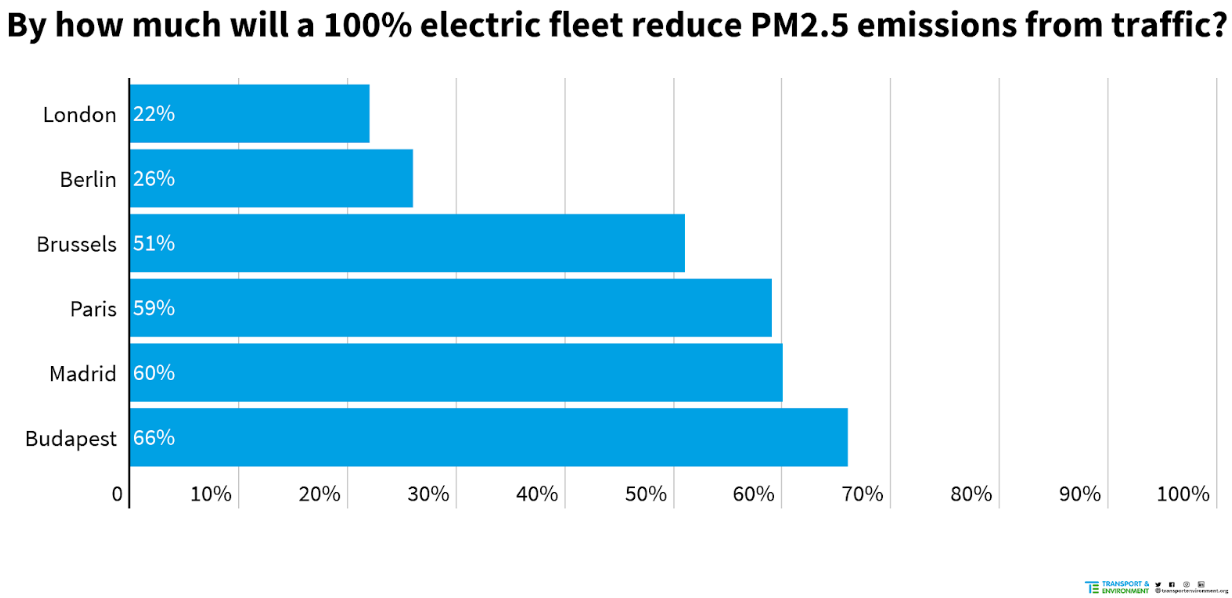


Figure 2: By how much will 100% electric fleet reduce PM2.5 emissions from traffic?

6. Summary & policy recommendations

6.1 Summary of the results

The most important results of the analysis presented above are:

- During their most stringent phase, lockdowns reduced air pollution from road traffic in all six cities, but to varying extents. Reductions in nitrogen dioxide (NO2) from road traffic ranged from -16% in Budapest to -76% in Paris.
- In all six cities, lockdown low levels of air pollution can be replicated through mobility changes and readily available solutions. This is a ‘yes we can’ finding. Importantly, the fastest way to cleaner air requires both zero-emission vehicles and an increase in walking, cycling, public transport and teleworking.
- In Budapest, Brussels, Berlin and London, a switch to zero-emission vehicles alone would suffice, even assuming a limited supply of electric vans and trucks in the coming years. Between 42% (Budapest) and 92% (London) of all kilometers driven by car need to go zero-emission to replicate NO2 levels observed during the strictest lockdown phase.
- These four cities can however accelerate the path to lockdown-like clean air if they combine zero-emission vehicles with more walking, cycling, public transport and teleworking (shifting 10% of

car travel). This would mean only 6% of all remaining kilometers driven by car in Budapest need to go zero-emission, and 74% in London.

- In Madrid and Paris that have seen particularly strong reductions of NO2 pollution, only a combination of zero-emission vehicles and reduced car use can replicate lockdown levels. In Madrid, 10% of all kilometers travelled by light and heavy-goods vehicles, as well as 94% of car-km, must go zero emission. In Paris, 67% of all kilometers driven need to be switched to ZEVs.
- The report also provides a longer-term outlook showing how fleets of only electric cars, vans, buses, motorcycles and trucks would affect air quality in the selected cities. NOx emissions from traffic would be eliminated completely and PM2.5 emissions reduced by 22% to 66%.

There are at least two interesting **general lessons** to be drawn from these results: First, the exceptional clean air effects of lockdown policies - which came as a side effect of profound disruptions in social and economic activities - can be replicated during normal times through mobility changes that are **not a distant hope** but seem attainable based on best practices and recent developments around e-mobility, modal shift and teleworking.

Secondly, even If lockdown air quality levels can be replicated across the six cities studied here, it is important to stress that according to the newest health evidence, **there are no safe levels of air pollution**.[20] Further reductions will therefore be needed in line with the EU's announcement of a 'Zero Pollution Action Plan' and replicating lockdown levels can only be an intermediary step.

6.2 Policy recommendations

To conclude, this last section looks at what policies are needed to drive the changes in mobility that would replicate the air quality effect of lockdown policies. All measures should align with the objectives of the European Green Deal, namely climate neutrality by 2050 and the 'zero pollution ambition for a toxic-free environment'.

Cities must be the frontrunners of a zero-emission future

The following table provides an overview and assessment of local and national policies that have a proven track record and can be implemented as of now, following the two categories of mobility changes analysed above (a switch to zero-emission vehicles and modal shift).

Table 8: Recommendations for local and national policies

Change in mobility	Policy	Necessary goals	Effect	Explanation
Shift to zero-emission vehicles	Zero-Emission Zones, phase-out vehicles with internal combustion engines	Banning the use of any car with pollutant or CO2 emissions from circulation in cities no later than 2030. Adopt national policies to phase-out the use of vehicles with internal combustion engines.	High	T&E's earlier research shows a high degree of effectiveness of Low- and Zero-Emission Zones.[28] A recent overview shows at least 8 cities have already planned to introduce such zones.[29] Recently, the Netherlands agreed on new rules to allow cities to create Zero-Emission Zones for freight transport as of 2025.[30]
	Roll-out charging infrastructure	Zero-emission transport can only happen with the right infrastructure. In cities, the focus should be on charging hubs for shared and electric mobility, chargers at business premises (or opportunity charging) and on fast chargers for urban deliveries and taxi-like services.	High	T&E has calculated that around 3 million public charging points will be needed for 44 million electric vehicles in 2030 if the EU is to decarbonise road transport.[31] Priority should be given to private charging at home, work and charging hubs for shared vehicle uses. In February 2021, carmakers, environmentalists and consumer groups called on the EU to turn the Alternative Fuels Infrastructure law into a Zero Emission infrastructure law to ramp up charging across the EU road network.[32]
	Focus regulations and financial incentives to ensure all new high-mileage public and private fleets & sharing services are electric from 2025	Public policy should target high-mileage fleets, like taxis, ride hailing and delivery vans and shared vehicles, including tax, financial support and ZEV mandates.	High	Replacing high-mileage vehicles by zero-emission alternatives has disproportionately positive effects on air quality as these vehicles are driven more. Electrifying fleets can accelerate the transition to zero-emission mobility, research shows.[33]

	Switch to zero-emission buses	All new Urban buses should go to zero emissions by 2025 and should lead the way.	Medium	T&E's analysis showed the high potential for a rapid switch to zero-emission buses, that already have a better total cost of ownership (TCO) than diesel buses when external costs like air pollution are included.[34] A recent analysis showed that in Denmark, 78% of all new urban buses are already electric, and about two thirds in Luxembourg and the Netherlands run on zero-emission technology.[26]
Modal shift and reduction of car traffic	Create pedestrian zones and bike lanes	Reducing or removing motorised traffic has direct significant effects on local air quality and also improves road safety, reduces noise and frees up public space.	High	Studies show closing streets to private traffic can reduce air pollution.[26, 35] The Belgian city of Ghent, for example has reduced NO2 levels by about 25% in residential streets after the introduction of a new traffic plan that prohibited motorised vehicles in parts of the city.[36] A tracking tool by the European Cyclists' Federation shows more than 1,100 km of cycle lanes have already been added in European cities since the beginning of the pandemic.[37]
	Reduce transport demand through measures such as teleworking	Teleworking should be used beyond the current pandemic as it reduces traffic and can help alleviate capacity issues during peak hours, which often are a main hurdle for modal shift to public transport. Private and public employers should allow teleworking were possible and desired by the employees.	Medium	Previous research showed that teleworking can reduce traffic and air pollution.[38] During the current pandemic, teleworking has increased to unprecedented levels and has probably played an important role in reductions of air pollution.[39] At the beginning of the pandemic, 44.6% of European employees said they worked from home.[24] Official estimates indicate that up to 37% of all jobs in Europe are suitable for teleworking.[25] In France, the Île-de-France Region has introduced measures to help employees change their commuting schedules.[40] Major companies, such as *Allianz SE*, have already announced that many of their employees will be able to continue teleworking beyond the pandemic (applying to 40% of employees).[41]

	Improve public transport	Public transport has significantly lower emissions per person-kilometer than individual motorised transport and accounts for a higher share of total transport volumes.	Medium	Studies show that re-organising public transportation significantly benefits air quality.[35]

The EU must define a clear pathway to zero-emission mobility

For the EU to deliver on climate neutrality by 2050 and the 'zero pollution ambition' - the world's most ambitious clean air target - a clear pathway to zero-emission mobility must be defined to provide predictability to citizens, policymakers and business. The following table summarises the most important and effective policies that the EU should adopt.

Table 9: Recommendations for EU policies

Category	Policy	Necessary goals	Effect	Explanation
Shift to zero-emission vehicles	Set an EU-wide end date for sales of internal combustion engine (ICE) vehicles	From 2035 onwards, only zero emission light-duty vehicles and heavy duty vehicles (smaller than 26 tonnes) must be sold. By 2040 all new trucks must be zero emission.	Very high	These dates are based on T&E's analysis on how to achieve zero emissions by 2050, in line with the EU targets.[27] A summary of the arguments can be found in a recent letter by consumers, companies, NGOs and health experts.[42]
	Review CO2 standards upwards (announced for 2021)	The 2021 review of the CO2 standards for cars and vans is timely. To ensure the regulation establishes Europe as an emobility leader, it should accelerate the transition to zero emission cars by increasing the 2025 target, set a long-term zero emission goal, improve the regulatory design and resist pressure from the oil & gas industry to weaken	Very high	Following the entry into force of the 2020/21 EU car CO2 target of 95 g/km, sales of electric cars (EVs) have surged beyond even the most optimistic forecasts. EV sales reached over 10% in 2020 and are expected to hit 15% in 2021.[21] This shows that once carmakers supply adequate models and market these effectively, consumers and companies alike are happy to purchase them. But the growing EV market masks many regulatory flaws and failures to cut emissions. The biggest risk is that the EV momentum could stagnate between 2022-2029

		the regulation via fuel credits for alternative fuels. For details see T&E's position paper.[8]		unless the current post-2020 standards are strengthened.[43]
	Zero Pollution Action Plan (announced for 2021)	The EU must translate its new 'zero pollution ambition' into binding legislation and concrete action. This mainly requires aligning the limits set in the Ambient Air Quality Directives with the available scientific evidence and the upcoming revised guidelines of the World Health Organisation (WHO).	High	New studies show that the health effects of air pollution have been underestimated and that no safe thresholds can be identified.[20]
	Use EU and national recovery plans to fast track the transition to zero emissions	Europe must use the economic recovery fund of an unprecedented scale to fast track the transition to zero emissions. No public money should be spent on gas, oil or diesel, and EU and national programmes should target incentives for zero-emission solutions, infrastructure and investments.	High	The EU has been under pressure to help Europe's economies recover from the pandemic. NGOs campaigned not to return to the 'old normal' and instead promote climate-friendly rescue funding. The agreement requires 37% of the fund to be spent on investments and measures that support climate objectives.The European Commission must take seriously the 'do no harm' principle, which is enshrined in the plan, if it is to stop fake green spending.[10]

[8] Transport & Environment (2021). Cars CO2 review: Europe's chance to win the emobility race. Retrieved from: https://www.transportenvironment.org/sites/te/files/publications/Car%20CO2%202021%20revision%20-%20position%20paper%20%28T%26E%29.pdf

	Review the Alternative Fuels Infrastructure Directive (announced for 2021)	Some 3 million public charging points will be needed for 44 million electric vehicles in 2030 if the EU is to become climate neutral by 2050. The European infrastructure law must be reviewed so it ensures seamless charging coverage in public and private buildings, in cities, across main EU roads as well as destination and public charging for commercial vehicles.	High	T&E has analysed the needs for charging infrastructure in line with the climate objectives and predictions for the scale-up of e-mobility.[31]
	Align any future Euro 7/VII standard with the pathway towards zero-emission mobility (announced for 2021)	Emission standards for cars have been the primary instrument to reduce pollutant emissions in the past but have so far failed to deliver significant reductions in the real world. The upcoming Euro 7/VII norm must be the last EU emissions standard, set the vehicle emission limits to the lowest level globally and define a clear roadmap to zero-pollution for cars, vans and light trucks by 2035 and for all trucks by 2040.	Medium	T&E has analysed the effectiveness of past standards, reductions that can be achieved in the short to mid-term as well as a pathway to zero emissions and zero pollution in a recent briefing.[44]

Modal shift	Use EU and national recovery plans to fast track the transition to zero emissions	National recovery plans should include, as a priority, support for modal shift and zero-emission public transport (buses, trams, metros and the related infrastructure). They should also help increase the amount of bike lanes, expand footpaths and grant support for bikes and e-bikes. Finally, investments in rail infrastructure and rolling stock on commuter lines should also be supported	High	T&E has analysed in detail the proposals for the recovery package and the EU budget and suggested concrete changes to make these investments sustainable.[45] Sadly, the 'Next Generation EU' package does not refer to the Taxonomy regulation screening criteria but simply to a generic 'Do No Harm' principle and to marginally revised Rio Markers for the 30% that is supposed to be 'climate friendly'. As a result, National Recovery plans could include measures that are not compliant with a low carbon and pollution-free transport sector.

7. Annexes

7.1 Assumptions and limitations of the analysis

As explained in detail in the technical study, this report has used the best available information to provide an indication of how the reductions in traffic emissions caused by the Covid-19 lockdowns might be replicated using specific, managed fleet interventions. The analysis is intentionally high-level and thus, while the results can be considered as reasonable best-estimates, they should not be viewed as definitive or precise. This section provides a short overview of the main uncertainties and limitations and the strategies applied to manage them.

Source of uncertainty	Strategy applied
Analyses of Ambient Measurements	
Air quality measurements: uncertainty and location-specific influences	For this study, the siting of stations and the official data have been checked for plausibility by the consultants. In its recent Fitness Check of the Ambient Air Quality Directive, the European Commission investigated the question of sampling sites and data quality, coming to the following conclusions: ' This, however, does not appear to amount to systemic shortcomings in the EU-wide monitoring network. Overall, the monitoring network by and large adheres to the provisions of the AAQ Directives, and ensures that reliable and representative air quality data is available.'[52]
Approach to weather normalisation: uncertainty from machine learning algorithms and uncertainty introduced by the measurements of the parameters used to normalise the NO2, NOx and PM2.5 concentrations	The approach taken has been to repeat each analysis three times and thus produce three separate sets of BRT-adjusted concentrations. A visual check of these three BRT-adjusted time-series has been carried out to confirm that the degree of variance is qualitatively small. The average from these three datasets has then been reported. Testing with alternative datasets has shown that while specific values at individual air quality monitors are affected by site choice, the overall conclusions of the study are unlikely to be affected.

Subtraction of Concurrent Regional Background Concentrations: It is not possible to measure the non-transport component directly and so the approach has been to rely on measurements made during lockdown at monitoring sites well away from roads.	To minimise the influence of traffic emissions on the measured background concentrations, the study has extrapolated the BRT-adjusted background concentrations measured during the Covid-19 lockdowns. This is appropriate because BRT-adjusted daily-mean concentrations are largely constant throughout a calendar year - as long as no significant, external events (such as the Covid-19 lockdowns themselves) cause a disruption. However, this approach assumes that non-transport emissions were unaffected by the lockdowns, which is unlikely to be the case. It seems likely, for example, that emissions from heating in the central areas of cities might have reduced during the lockdowns, while heating emissions in the suburbs increased, reflecting the redistribution of the population. This effect may have caused the extent of reductions in traffic emissions to be overestimated in the centre of cities and underestimated in the suburbs. In practice, this artefact is unavoidable, but the effect is likely to be small when compared with other sources of uncertainty. The outcomes of this study are dependent upon the ambient air quality measurements. They are constrained by both monitor siting and data ratification. In particular, the study relies on comparing roadside measurements against equivalent background data. Where this comparison considers a busy kerbside with a site well away from any roads, the effect of road traffic can readily be seen. **Remarks on the data for Budapest** There is additional uncertainty in the mean values for Budapest. Only two roadside monitors operated in Budapest. One of these is adjacent to a road which was partially closed during 2019, which is likely to have affected training of the BRT models. The other monitor is set back more than 30 m from the main road, meaning that the effect of local traffic will be diminished. The two sites showed markedly different responses to the lockdown and it is not possible, from the ambient measurements, to determine which is most representative of the city-wide conditions.

Emissions Calculations	
Activity Data: For five of the cities (all but London and Berlin), it has been necessary to rely on national-level fleet and speed data (for urban settings) held by Emisia. These data are primarily intended for national-level reporting (for example, to the European Commission). While still providing a robust basis for high-level emissions calculations, these activity data are less precise for the respective cities than those available in Berlin and London.	The consultants reached out to the competent authorities in each city in order to request the best available data and clarify potential questions. The results of the study have been shared with these authorities before the publication of this report and the consultants and T&E offered a direct exchange on these findings.
Emissions Factors: The emissions factors used for Berlin are derived from HBEFA, while for all other cities the COPERT emissions factors have been used	The different approaches have made the best use of the available information for each city. All road transport emissions factors are subject to uncertainty and, while both COPERT and HBEFA are ultimately derived from the same European Research for Mobile Emission Sources (ERMES) emissions database, each treats the data in different ways and is subject to different uncertainties. Overall, both emissions models provide equally valid results which can be considered as fit for purpose in terms of this study.
Emission Factors: non-exhaust emissions of PM2.5	Non-exhaust emissions of PM2.5 have been calculated within each model. The data which underpin the non-exhaust emissions factors is relatively old, and does not differentiate between different technologies and other features which might be expected to affect emissions (for example the use of regenerative braking). Given the uncertainties around the emissions factors, no attempt has been made to differentiate between non-exhaust emissions from conventional and electric vehicles. In other words, it has been assumed that switching from a conventional to electric vehicle will have no effect of non-exhaust PM2.5 emissions. In practice, electric vehicles may have lower emissions from brake wear, on average, than conventional vehicles, but there remains some uncertainty regarding the effect of electrifying the fleet on average vehicle weight, which is linked to road and tyre wear rates. Assuming equal non-exhaust

	emissions from electric and conventional vehicles is the most robust approach currently available.
Congestion Effects: It has been assumed that there is a linear relationship between the total vehicle-kilometres for a particular vehicle type on a given road and the NOx emissions from that vehicle type on that road	In practice, this relationship will be non-linear because altering the total flow of vehicles will affect driving characteristics. Put simply, reducing traffic will often reduce congestion and reduce emissions from all remaining vehicles. It has not been possible to take account of this effect in the study but the same air quality benefits could be seen with smaller reductions in vehicle-kilometres for those scenarios which relate to increased home working etc. It is also possible that changes to working patterns, allowing more flexible start and end times, might reduce congestion effects and emissions for the same nominal traffic volumes. These details fall outside of the scope of this study.
Primary NO2: The target reductions have been based on measurements of NO2 and NOx concentrations. The effects of managed fleet interventions have then been calculated in terms of NOx only.	Achieving the observed reductions in NOx emissions should also achieve the observed reductions in NO2 concentrations as long as the proportion of primary NO2 emissions does not change. However, in practice, the Covid-19 lockdowns, and the managed fleet interventions, are both likely to be associated with a change in the fleet-average proportion of primary NO2. This is because, for example, primary NO2 emissions from passenger cars tend to be very different to those from buses, and selectively removing one vehicle type without removing the other will alter the fleet-average emission proportion. So long as the managed interventions have a similar effect on primary NO2 proportions as occurred during the Covid-19 lockdowns (for example if the main effects were on car traffic), then it is still appropriate to assume a linear relationship between NO2 and NOx in terms of achieving the transport-emissions-derived targets. Where the interventions target an alternative part of the fleet, then this may introduce some error. NOx and NO2 at the roadside is curvilinear, with less available ozone to form NO2 at higher NOx concentrations. This means that the NO2 response to a nominal change in NOx should, all other things being equal, be highest at low concentrations. However, as

	well as ambient ozone concentrations, the quotient of NO2 in NOx is strongly influenced by the proportion of primary NO2 in local emissions. This can be particularly important where the relative make-up of the vehicle fleet is altered by an intervention or change (for example if passenger car activity changes but bus activity does not). Many models exist for predicting NO2:NOx quotients. However, it is not considered that any of them would add significantly to the overall accuracy of this study. It is clearly the case that the same reduction in NO2 concentrations might be delivered by multiple different reductions in NOx; and this is emphasised by the higher observed percentage improvements for NO2 than for NOx, which might be caused by a change to average fleet compositions during lockdown. This effect is, however, relatively small compared with other sources of uncertainty affecting this study. It is thus considered appropriate to assume that measures which deliver the NOx reductions observed during lockdown will also deliver the NO2 reductions observed during lockdown. In any event, this issue will only introduce error where the assessment scenarios target a different section of the vehicle fleet than that which was affected by the lockdown.
Secondary PM2.5: The calculations of PM2.5 emissions have focused solely on primary particles	The managed transport interventions explored would all reduce emissions of NOx and also ammonia from road traffic. This has the potential to reduce the formation of secondary PM2.5, but it has not been possible to include this additional benefit within the calculations, and the benefits to PM2.5 of the different scenarios will have been under-predicted

Lockdown Equivalence for PM2.5	
The effects of the interventions on PM2.5 emissions have been calculated, but it has not been possible to calculate the effect of the lockdowns on PM2.5 emissions.	In practice, the reductions to PM2.5 emissions during lockdown are likely to be very similar (on a proportional basis) to the changes in NOx emissions. Many of the managed intervention scenarios involve a switch from conventional to electric vehicles and while this removes all local NOx emissions, it is only expected to remove a portion of the local PM2.5 emissions. This means that, although the effects of the managed interventions on PM2.5 emissions have been calculated, these interventions would be unlikely to be sufficient to recreate the reductions in traffic-related PM2.5 emissions which occurred during lockdown.

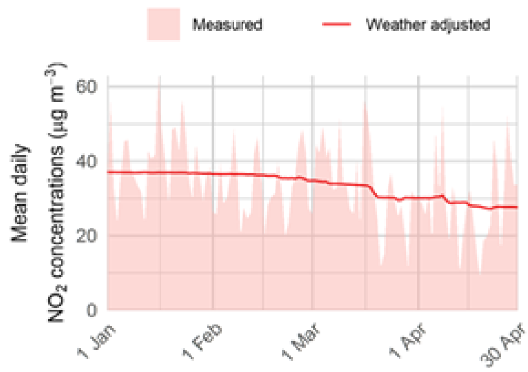
7.2 Factsheets with the results for each city

Replicating Covid-19 lockdown-related air quality benefits through green mobility policies in Berlin

TRANSPORT & ENVIRONMENT

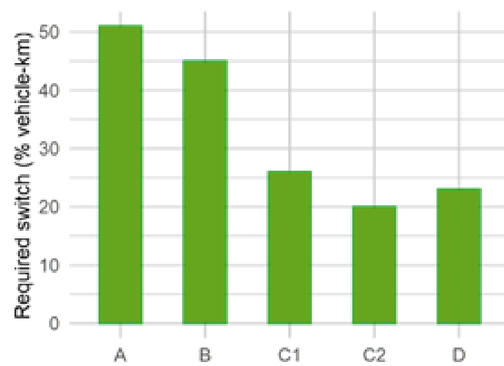
Air Quality

During lockdown many cities in Europe experienced a substantial improvement in local air quality. After adjusting for the influence of weather NO_2 concentrations at roadside monitoring stations in Berlin decreased on average by 20%. Can this positive change be replicated through green mobility policies after the pandemic is over?

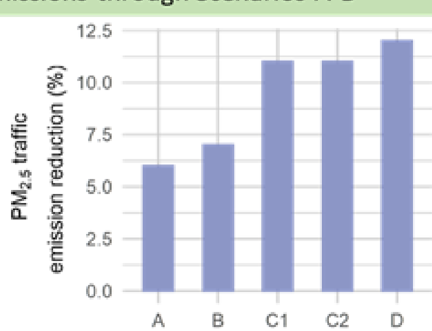


Estimated required switch from internal combustion engine to ZEV (zero exhaust vehicles) in passenger cars (in vehicle-km) if:

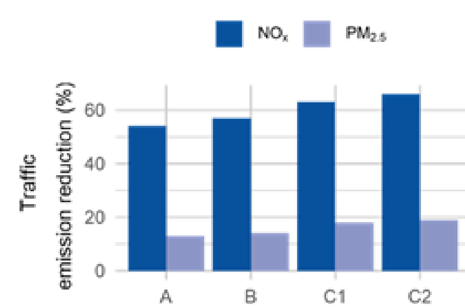
- SCENARIO A: shift to zero-emission cars
- SCENARIO B: shift cars, vans and trucks to zero-emission vehicles
- SCENARIO C.1: modal shift combined with zero-emission buses and cars
- SCENARIO C.2: modal shift combined with zero-emission cars, buses, vans and trucks
- SCENARIO D: 10% modal shift and equal shift to zero-emission vehicles among cars, vans, buses and trucks



Estimated reduction in traffic $PM_{2.5}$ emissions through Scenarios A-D



What if **all** passenger cars switch to ZEV?



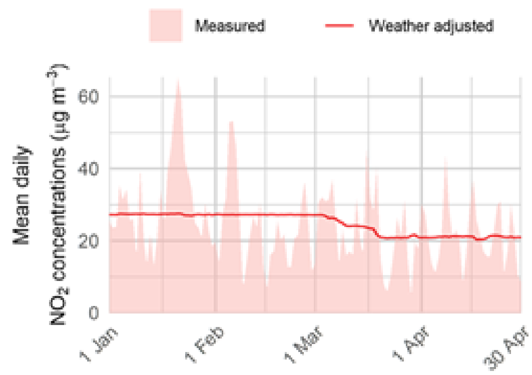
Replicating Covid-19 lockdown-related air quality benefits through green mobility policies in

Brussels

TRANSPORT & ENVIRONMENT

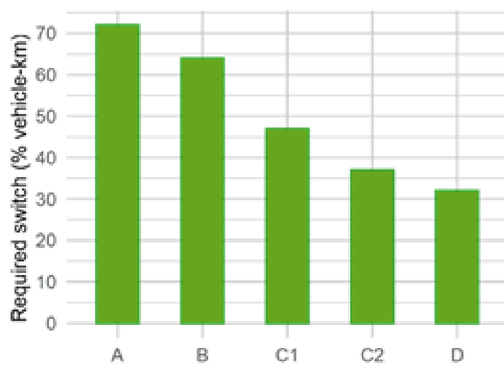
Air Quality

During lockdown many cities in Europe experienced a substantial improvement in local air quality. After adjusting for the influence of weather NO_2 concentrations at roadside monitoring stations in Brussels decreased on average by 23%. Can this positive change be replicated through green mobility policies after the pandemic is over?

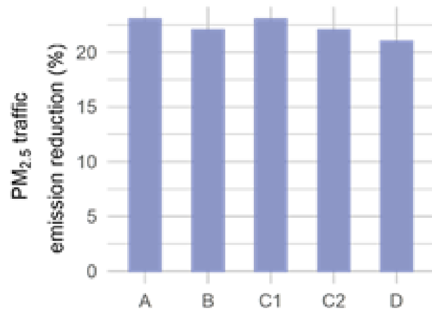


Estimated required switch from internal combustion engine to ZEV (zero exhaust vehicles) in passenger cars (in vehicle-km) if:

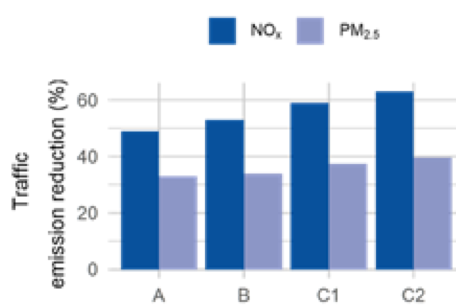
- SCENARIO A: shift to zero-emission cars
- SCENARIO B: shift cars, vans and trucks to zero-emission vehicles
- SCENARIO C.1: modal shift combined with zero-emission buses and cars
- SCENARIO C.2: modal shift combined with zero-emission cars, buses, vans and trucks
- SCENARIO D: 10% modal shift and equal shift to zero-emission vehicles among cars, vans, buses and trucks



Estimated reduction in traffic $PM_{2.5}$ emissions through Scenarios A-D



What if **all** passenger cars switch to ZEV?

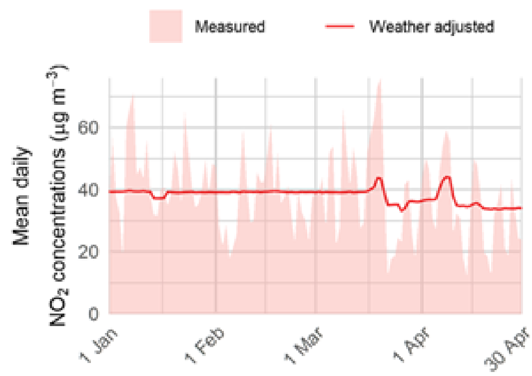


Replicating Covid-19 lockdown-related air quality benefits through green mobility policies in Budapest

TRANSPORT & ENVIRONMENT

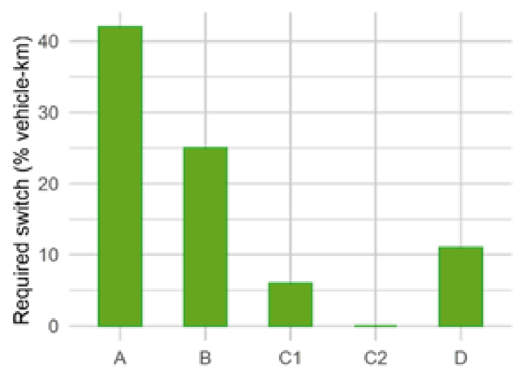
Air Quality

During lockdown many cities in Europe experienced a substantial improvement in local air quality. After adjusting for the influence of weather NO_2 concentrations at roadside monitoring stations in Budapest decreased on average by 8%. Can this positive change be replicated through green mobility policies after the pandemic is over?

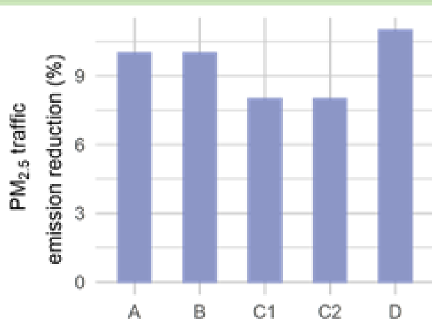


Estimated required switch from internal combustion engine to ZEV (zero exhaust vehicles) in passenger cars (in vehicle-km) if:

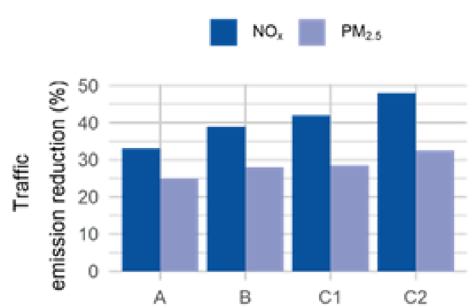
- SCENARIO A: shift to zero-emission cars
- SCENARIO B: shift cars, vans and trucks to zero-emission vehicles
- SCENARIO C.1: modal shift combined with zero-emission buses and cars
- SCENARIO C.2: modal shift combined with zero-emission cars, buses, vans and trucks
- SCENARIO D: 10% modal shift and equal shift to zero-emission vehicles among cars, vans, buses and trucks



Estimated reduction in traffic $PM_{2.5}$ emissions through Scenarios A-D



What if **all** passenger cars switch to ZEV?

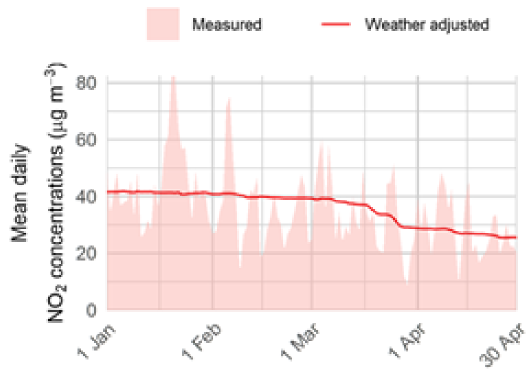


Replicating Covid-19 lockdown-related air quality benefits through green mobility policies in London

TRANSPORT & ENVIRONMENT

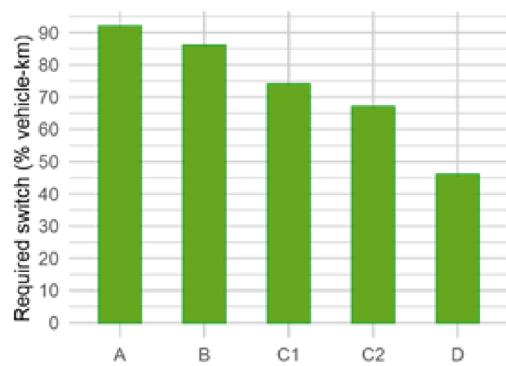
Air Quality

During lockdown many cities in Europe experienced a substantial improvement in local air quality. After adjusting for the influence of weather NO_2 concentrations at roadside monitoring stations in London decreased on average by 31%. Can this positive change be replicated through green mobility policies after the pandemic is over?

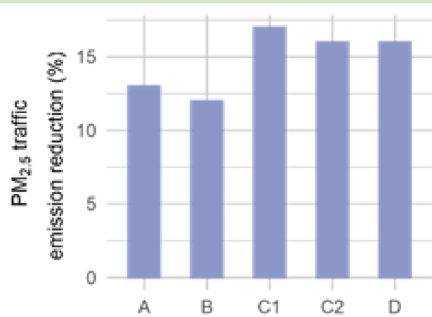


Estimated required switch from internal combustion engine to ZEV (zero exhaust vehicles) in passenger cars (in vehicle-km) if:

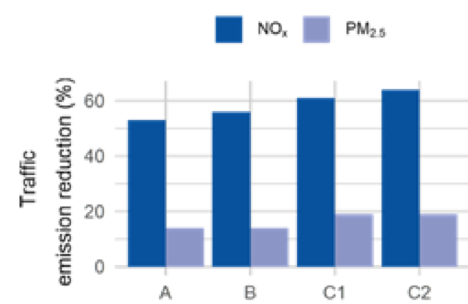
- SCENARIO A: shift to zero-emission cars
- SCENARIO B: shift cars, vans and trucks to zero-emission vehicles
- SCENARIO C.1: modal shift combined with zero-emission buses and cars
- SCENARIO C.2: modal shift combined with zero-emission cars, buses, vans and trucks
- SCENARIO D: 10% modal shift and equal shift to zero-emission vehicles among cars, vans, buses and trucks



Estimated reduction in traffic $PM_{2.5}$ emissions through Scenarios A-D



What if **all** passenger cars switch to ZEV?

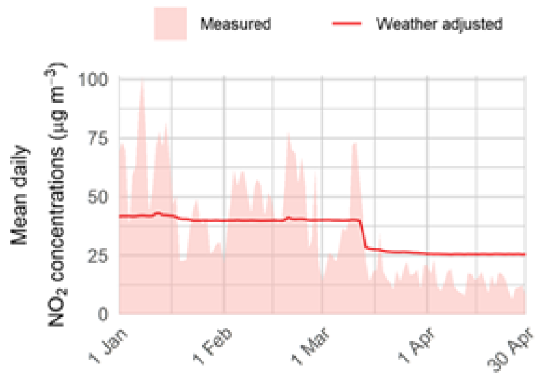


Replicating Covid-19 lockdown-related air quality benefits through green mobility policies in

Madrid

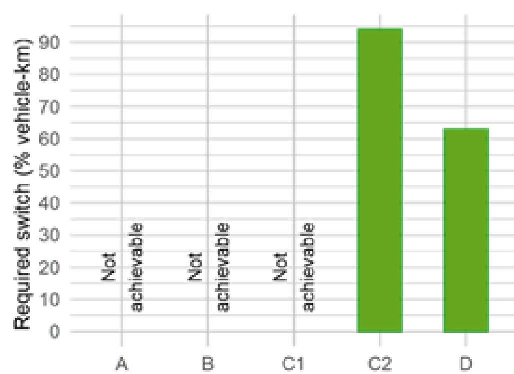
TRANSPORT & ENVIRONMENT Air Quality

During lockdown many cities in Europe experienced a substantial improvement in local air quality. After adjusting for the influence of weather NO_2 concentrations at roadside monitoring stations in Madrid decreased on average by 36%. Can this positive change be replicated through green mobility policies after the pandemic is over?

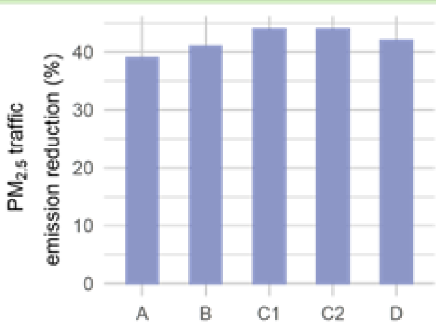


Estimated required switch from internal combustion engine to ZEV (zero exhaust vehicles) in passenger cars (in vehicle-km) if:

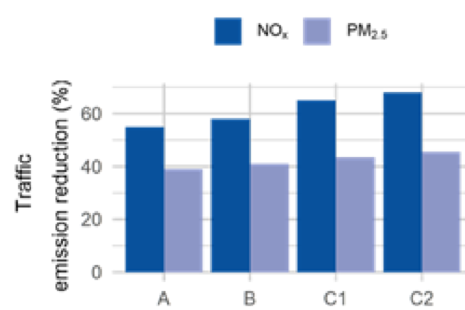
- SCENARIO A: shift to zero-emission cars
- SCENARIO B: shift cars, vans and trucks to zero-emission vehicles
- SCENARIO C.1: modal shift combined with zero-emission buses and cars
- SCENARIO C.2: modal shift combined with zero-emission cars, buses, vans and trucks
- SCENARIO D: 10% modal shift and equal shift to zero-emission vehicles among cars, vans, buses and trucks



Estimated reduction in traffic $PM_{2.5}$ emissions through Scenarios A-D



What if **all** passenger cars switch to ZEV?



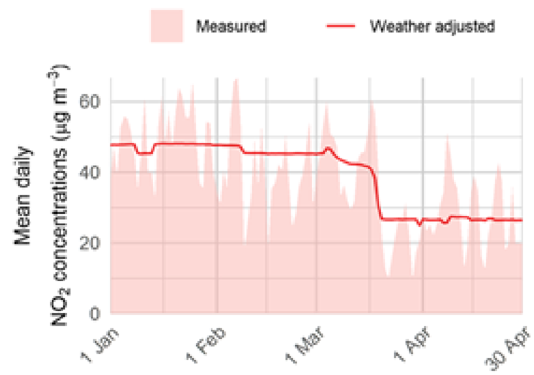
Replicating Covid-19 lockdown-related air quality benefits through green mobility policies in

Paris

TRANSPORT & ENVIRONMENT

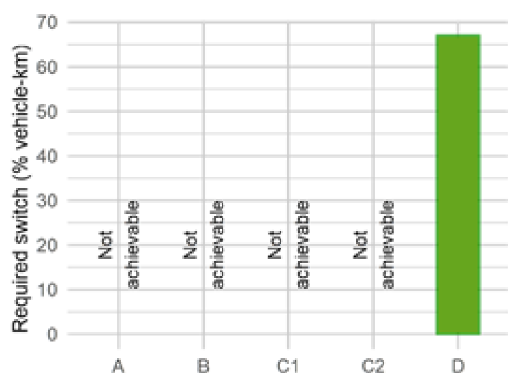
Air Quality

During lockdown many cities in Europe experienced a substantial improvement in local air quality. After adjusting for the influence of weather NO_2 concentrations at roadside monitoring stations in Paris decreased on average by 43%. Can this positive change be replicated through green mobility policies after the pandemic is over?

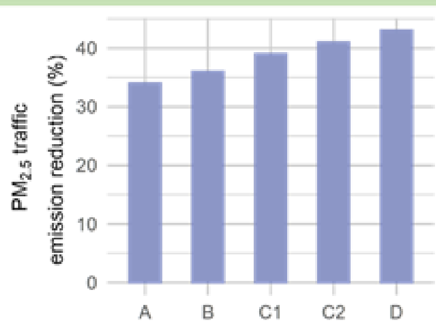


Estimated required switch from internal combustion engine to ZEV (zero exhaust vehicles) in passenger cars (in vehicle-km) if:

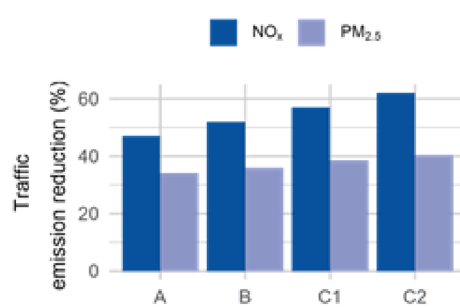
- SCENARIO A: shift to zero-emission cars
- SCENARIO B: shift cars, vans and trucks to zero-emission vehicles
- SCENARIO C.1: modal shift combined with zero-emission buses and cars
- SCENARIO C.2: modal shift combined with zero-emission cars, buses, vans and trucks
- SCENARIO D: 10% modal shift and equal shift to zero-emission vehicles among cars, vans, buses and trucks



Estimated reduction in traffic $PM_{2.5}$ emissions through Scenarios A-D



What if **all** passenger cars switch to ZEV?



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