ECF
EUROPEAN CYCLISTS´ FEDERATION

CYCLING AND URBAN AIR QUALITY

A study of European Experiences

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ABOUT THE EUROPEAN CYCLISTS' FEDERATION

ECF is the umbrella federation of bicycle users' organizations in Europe and beyond. Our aim is to have more people cycling more often and we target to double cycling by 2020 in Europe. To reach this goal we work with our members and partners on putting cycling on the agenda at global, European, national and regional level.

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FOREWORD

Dear Reader,
Breathing clean air is one of the most important things for all of us. Working on our mission 'More people cycling more often', the European Cyclists' Federation (ECF) supports all those who work on the promotion of cycling and strive to achieve better air quality in our cities. This study shows the potential effect of more cycling for cleaner air in our cities.

ECF's main conclusion from this study is that investments in modal shift and getting more people cycling more often, makes a real contribution to improve air quality. Although small, there is actual and real decrease in air pollution from traffic which can be enhanced by its combination with technical measures. However, cities need to be ambitious and strive for a radical transformation of their urban transport system if they want to improve air quality. Air pollution is still too high with moderate increase of cycling or a limited approach for small car-free areas. Cyclists, pedestrians and other inhabitants do not pollute the air in the cities but they are suffering from bad air quality. At the same time, cycling along with good public transport and walking facilities, is a key solution to maintain a good accessibility to green zones and car free areas in cities.

A transformation of the transport system has to be pushed in all policies that have an impact on the mobility choices of people – and air quality policy is one of them. ECF strongly recommends international institutions, countries and cities to include modal shift and cycling as a reliable measure to provide cleaner air in urban areas. I am sure that this study is useful for all policy-makers, advocates and researchers on the local, national and international level for their work on the transition of cities into healthier and more livable places.

Dr Bernhard Ensink,
ECF Secretary General

EXECUTIVE SUMMARY

Air pollution is a major issue of concern to the public and politicians, with the focus of attention being on poor air quality and the way it affects the quality of life in urban areas. It is well recognised that road transport plays a significant part in air pollution in urban environments, and thus contributes to this public health issue.

However, controlling the emissions from road transport, the main source of air pollution in most urban areas, has not been an easy task. This is because transport emissions are influenced by many factors such as vehicle technology, fuel type, vehicle size and driver behaviour. Technical measures alone, in terms of technologies that directly reduce emission from road vehicles, are insufficient to meet compliance with urban air quality objectives. This has been highlighted by the failure of vehicle Euro emission standards to produce the reductions in emissions expected in urban areas. Therefore a more demand-side-focused approach is needed to reduce the impacts of transport, such as air pollution, and develop a more sustainable transport system.

"There are still major challenges to human health from poor air quality. We are still far from our objective to achieve levels of air quality that do not give rise to significant negative impacts on human health and the environment."

Janez Potočnik, European Commissioner for the Environment (Potočnik, 2013)

In line with this approach cycling measures are now present in the air quality and mobility plans of numerous cities around the world. This report sets out to understand in more detail the role that cycling measures can have as part of a mode shift approach to help improve air quality. In relation to this a set of relevant measures directed at increasing cycling mode share were investigated. These measures are classified as to whether they were aimed directly at increasing cycling or aimed at reducing the demand for private motorized transport. The most representative examples of measures directed at increasing cycling were the development of cycling infrastructure such as bicycle share schemes, separated cycling lanes and tracks, provision of trip-end facilities and integration of cycling with urban public transport networks. As for those measures directed at reducing the demand for car use, the most relevant were congestion-charging schemes, low-emission zones, parking rationing and increasing vehicle costs.

To understand the potential role of cycling measures as part of an approach to air quality management a selection of five European cities were studied as case study examples. The selected cities were Antwerp, London, Nantes, Seville and Thessaloniki, all of which are recognised for positively implementing cycling as a feasible alternative to private motorisation, albeit to different extents. All of these cities, except for Thessaloniki, explicitly mention the promotion and development of cycling in their air quality plans. From the review of the respective mode shares, cities with a known and well-developed cycling infrastructure such as Antwerp or Seville exhibited the highest increases in mode share with respect to previous years and have the largest populations of active cyclists. In this regard Seville expects to achieve a reduction of 4 μg/m³ in the annual mean of NO_2 in 2020 due to the implementation of a complete pack of traffic demand management measures including cycling.

The final part of the study provided an illustrative assessment of the impacts of cycling, in terms of mode shift from car traffic, as a potential measure to improve urban air quality levels (NO_2, PM_{10} and black carbon) in three of the case study cities (Antwerp, London and Thessaloniki). To accomplish this, simulations were carried out with two hypothetical scenarios: (i) a typical, moderate cycling investment scenario involving an assumed 23% increase in cycling mode share (away from private motorized transport) and (ii) a limited car-free scenario involving the closure of one or two major roads in the respective cities. The assessment showed that modal shift from private motorisation to cycling produced significant reductions in the emissions of NO_x, PM_{10} and black carbon. This varied from city to city depending on the local traffic situation. These emission reductions in turn resulted in improvements in the air quality levels of the studied zones in the cities. The improvements again varied from city to city as a result of local conditions with for example much greater benefits being seen in Antwerp than London. Also in two of the three case studies the observed reductions were not enough to achieve compliance with the European limit values.

The assessment of air quality impacts was complemented with an analysis of health improvements brought about by the reduction of ambient concentrations of particulates. This assessment was made by estimating the disability adjusted life years (DALY) metric for cardiopulmonary disease caused by poor air quality levels. In all cases, the global disability levels were reduced as a consequence of the improvements produced by modal shift under the two modelled scenarios.

The main conclusion that can be drawn from this study is that cycling measures can improve urban air quality levels as part of a package of measures directed at reducing overall road traffic. Although the extent of the improvement will vary from city to city and across the city itself with our analysis showing changes in NO_2 concentrations from zero to 12.6 μg/m³ and changes in PM_{10} concentrations from 0.3 μg/m³ to 1.4 μg/m³ at the studied monitoring locations. However, overall the changes in London and Thessaloniki were not enough to meet the European limit values. This suggests that mode shift measures alone are unlikely to be sufficient to meet the European air quality limit values in urban areas. Therefore, a successful approach to combat air pollution is a combination of both non-technical and technical measures: encourage a modal shift, including the shift towards cycling, and reduce emissions from the remaining traffic such as public transport and delivery vehicles.

INTRODUCTION

Air pollution is one of the main environmental factors linked to adverse health effects such as premature mortality and preventable illness across Europe. The greatest impact on human health is in urban areas, where air pollution levels are at their highest. Transport is the most important source of air pollution in European cities and as such, has a significant role in improving air quality and public health (Stanley et al., 2011).

The European Union has an air pollution regulatory framework that seeks to reduce the burden of ambient air pollution on human health, natural and managed ecosystems and the built environment. The Air Quality Directive (2008/50/EC) and the 4th Daughter Directive (2004/107/EC) set limit, target and threshold concentrations for a series of pollutants and require Member States to assess and report compliance with these environmental objectives on a regular basis (EEA, 2013; Hitchcock et al., 2014).

Despite the fact that mitigation strategies and significant reductions in emissions have been in focus for many years, ambient concentrations of air pollutants lag clearly behind this emission decreasing trend (Guerreiro et al., 2010). In particular controlling the emissions from road transport, the main source of air pollution in most urban areas, has not been an easy task. This is because transport emissions are influenced by many factors such as vehicle technology, fuel type, vehicle size and power (Sundvor et al., 2012), and most significantly the impact of the Euro vehicle emission standards has been less than anticipated especially for diesel vehicles (EEA, 2013; Hitchcock et al., 2014). Due to the lack of success of direct technical measures in tackling this problem, action has focused recently on a multidisciplinary approach that covers different policy aspects such as promoting clean fuels and vehicles, collective passenger transport, designing demand and mobility management strategies, increasing traffic safety and security, car-independent lifestyles and public involvement.

This context has favoured the position of cycling as a cost-effective alternative to individual motorised transport among environmental stakeholders due to the fact that bicycles are zero-emission, low-carbon vehicles that are efficient in terms of speed, cost and urban space (Börjesson and Eliasson, 2012; Küster, 2013). Additionally, over the last 10 years cycling has been seen as an effective method for improving a healthy lifestyle in developed countries (Steinbach et al., 2011; Press-Kristensen, 2014). The combination of these two factors has made cycling a constant policy option in urban air quality plans, as witnessed in the Air Implementation Pilot which followed urban policy making in 12 cities in Europe during 15 months in 2012 (EEA, 2013). Other European-funded city planning programmes such as CIVITAS contemplate cycling as an essential part of the multidisciplinary approach that is necessary for improving urban air quality levels.

Despite this, there has been little study on the direct impact of cycling measures on air quality as part of an integrated approach to air quality management. The purpose of this report therefore is to provide a consideration of the key aspects that promote modal shift and that reinforce the position of cycling as a cost-effective policy option for the improvement of urban air quality levels and more importantly, for the compliance with the air quality targets established by European legislation.

MEASURES TO INCREASE CYCLING MODE SHARE

Every city has a particular modal split, which is defined by the number of trips that are made using a particular type of transportation. This modal split is related to different aspects such as city size, population, density, age, car ownership schemes, income, households with children, public transport fares, public transport service frequency, rain, trip distance and land-use mix (Santos et al., 2013). Therefore the ECF promotes the "Cycling as a System" concept to consider these diverse city contexts (Ensink and Marhold, 2014).

Most factors that increase modal shift from private motorised transport to cycling can be classified in two categories:

- Pull measures aimed directly at increasing cycling. This category includes measures especially directed to encourage users to change from their usual transport modes to cycling exclusively. Any modal shifts produced by these factors will result in an increase in the proportion of cyclists in the city.
- Push measures aimed at reducing the demand of other transport modes. These factors correspond to measures aimed to restrict the use of non-sustainable transport modes (e.g. cars) but do not directly encourage a modal shift towards a particular alternative. As a result, these measures may not increase the proportion of cyclists.

Apart from these two categories, a host of broader contexts are likely to have key influences in modal shifts. Examples of these can be the public perception on road safety, national energy policy, excessive reliance on fossil-fuels, cultural aspects, etc.

The above described measures are non-technical measures to improve urban air quality: focusing on structural and behavioural changes, while technical measures are usually end-of-pipe measures. However, both are well related since non-technical measures can be used to support the uptake of technical measures (for example, giving fiscal/economic incentives to renew the car fleet).

1. MEASURES AIMED DIRECTLY AT CYCLING

Bicycle share schemes

Bicycle (bike) share schemes have emerged as an innovative approach in a number of cities in Europe, Asia and North America, with over 700 programmes in operation around the world (Meddin and DeMaio, 2014). The first bicycle share programme was implemented in Amsterdam in 1965, being anonymous and free of charge. This factor made the programme fail soon after its launch, due to vandalism. An improved bike sharing programme was implemented in Copenhagen in 1995 through the use of coin-deposit docking stations. This scheme evolved by incorporating advanced information technologies for bicycle reservations, pick-up, drop-off and tracking. In 1998, the city of Rennes (France) launched the first IT-based programme (Vélo à la Carte) and in 2007, Paris launched Europe's largest IT-based scheme with over 20,000 bicycles and 1,450 docking stations available every 300 meters (Vélib). The emerging fourth generation systems have refined the IT-based concept and seek seamless integration of bike sharing with public transportation and other alternative modes, such as taxis and car sharing (Shaheen and Guzman, 2011).

The main benefits of bike sharing are related to the reduction of pollutants and GHG emissions due to the replacement of trips made by cars. After the launch of Bicing in Barcelona (Spain), the city's bicycle modal split increased by 1% (from 0.75% to 1.76% in 2007) over a period of 2 years (from 2005 to 2007). Velo'v in Lyon (France) reported that bicycle use reduced the automobile mode share by 7% in 2007.

Several studies have examined the motivating factors associated with bike share use in North America, China, the United Kingdom and Australia (Fishman et al., 2014). Convenience consistently emerges as the main motivating factor for bike share use. The distance between home and closest docking station is a factor directly associated with convenience and this has been found to be a reliable predictor of bike share usage. A study in Montréal (Canada) reflected that living within 500 m of a docking station resulted in a threefold increase in the use of bike share (Bachand-Marleau et al., 2012). Similar findings were shown in London, where fun appeared to be an additional key motivation for casual users (TfL, 2011).

TABLE 1. PREVIOUS TRANSPORTATION MODE REPORTED BY CURRENT BICYCLE SHARE USERS

City	Private Car	Public transport	Walking	New displacements	Other
Barcelona	10%	51%	26%	0%	13%
Berlin	4%	26%	21%	3%	46%
Brussels	7%	60%	32%	0%	1%
London	0%	54%	39%	0%	7%
Lyon	7%	51%	37%	2%	4%
Paris	8%	65%	20%	0%	7%
Stuttgart	4%	20%	26%	16%	34%

There is an implicit assumption among stakeholders that the implementation of bike share programmes will have a direct impact on motor vehicle use. A recent study on the bike share programmes in Melbourne, Brisbane, Washington D.C., Greater London and Minneapolis/St. Paul showed that this is very dependent on the city. Reductions in motor vehicle use due to bike share were of approximately 90,000 km per annum in Melbourne and Minneapolis/St. Paul and 243,291 km for Washington D.C. In Greater London however, motor vehicle use increased 166,341 km per annum largely due to a low car mode substitution rate (Fishman et al., 2014). A study carried out in Barcelona showed that the bicycle sharing scheme of the city (Bicing) produced an annual change in mortality of 0.03 from road traffic incidents and 0.13 deaths from air pollution. Additionally, this study found that 12.28 deaths were avoided and carbon dioxide emissions were reduced by approximately 9 Gg when compared with car users (Rojas-Rueda et al., 2011).

A study with information from surveys about bicycle share users carried out in London, Brussels, Berlin, Stuttgart, Paris, Lyon, and Barcelona showed that private motorisation is reduced by the implementation of a bicycle share scheme (being as much as 10% in Barcelona). Additionally, other transportation modes such as mopeds or motorcycles suffered important reductions as a consequence of the bicycle share scheme (46% in Berlin and 34% in Stuttgart). Current bicycle sharers reported their previous usual transport to be those shown in Table 1 (Zwerts, 2014).

Cycling infrastructure

Cycling infrastructure refers to the existence of segregated lanes, bicycle parking slots as well as cycle storage facilities at home, work or public transport stations. This infrastructure is not particularly related to a bicycle share scheme, but rather directed to private cyclists.

There is a general perception among stakeholders that creating cycling infrastructure will increase modal shift (usually referred to as the *"build it and they'll come"* principle) and in most cases, this principle is true. However, other factors might as well determine the success of a cycling infrastructure such as the location of facilities along usable commuting routes, the overall network connectivity or the amount of publicity and promotion (Douma and Cleaveland, 2008).

The importance of creating cycling infrastructure is related to the public perception of cycling as risky. A survey carried out in 2010 among UK adults found that 86% selected cycling as the mode most at risk of traffic accidents, as opposed to 2-7% for other modes (Thornton et al., 2010). A similar study in Portland (USA) revealed that there is significant potential for increasing cycling with a safer infrastructure stating that 60% of the residents would cycle if safety was increased, 7% are enthused and confident, less than 1% are strong and fearless, and a proportion are not interested in cycling at all (33%) (Geller, 2012).

This clearly highlights the need of developing separate cycling infrastructure to increase the perception of safety among the public opinion (Goodman et al., 2014). Research confirms that the type of bicycle infrastructure matters: potential users prefer physically segregated bicycle paths to curb lanes, bicycle lanes and roads without bicycle facilities (Heinen et al., 2010).

The creation of new cycling infrastructure is usually directly correlated to an increase in modal shift. A 2003 cross-sectional study in the commuting behaviour of 43 cities in the United States revealed that every additional mile of bike lanes per square mile led to a 1 % increase in bicycle commuters (Dill and Carr, 2003). A study carried out in Dublin in 2012 revealed that the construction of segregated cycling lanes produced a 74.1% change in the opinion of residents on cycling safety, with 56.4% of the surveyed people actually considering shifting to cycling due to these new infrastructures (Caulfield et al., 2012).

Similar findings were observed in Seville in 2010, where the existence of the cycling infrastructure (120 km) produced a global modal shift of 32% from former car users and 5.4% from motorcycle users with a total spent budget of €35 million (Ayuntamiento de Sevilla, 2010). This ultimately produced a global increase in modal share of cycling in the city from 0.5% in 2006 to 7% in 2013. In the city council of Darlington (UK), the injection of €5.3 million in cycling infrastructure (40 km) since 2004 produced a total increase in cycle trips of 26-30% and changed cycling mode share from 1% to almost 3% (5.1 trips per 100 people) (DCC, 2007; Sloman et al., 2010). In Malmö, the construction of 410 km of bicycle lanes in 2009 resulted in a total 20% increase in the number of cycling trips and raising the cycling modal share from 20% in 2003 to 22% in 2013, having spent a total budget of €40 million (ADVANCE, 2014; CIVITAS, 2014).

Provision of trip-end facilities

Apart from the development of the cycling infrastructure itself, ancillary facilities are necessary for encouraging modal shifts. The existence of proper and safe cycle parking and storage facilities is likely to increase the degree of modal shift in a city with cycling infrastructure. A study carried out in the United States revealed that the existence of bicycle parking facilities was the second priority after segregated lanes among surveyed users, lockers being the most preferred (against exterior lockable or covered lockable facilities) (Taylor and Mahmassani, 1996). A study in the Netherlands showed that the existence of cycle storage facilities nearby usual workplaces increase the number of cyclists, and particularly, women cyclists (van der Kloof et al., 2014).

Integration of cycling in public transport networks

The current practises in the promotion of cycling as an alternative mode of transport focus on its seamless integration with existing public transport networks (i.e. *"bike-and-ride"*). The number of policy initiatives to promote the use of bike-and-ride, the combined use of the bicycle and public transport for one trip, has seen a considerable increase over the last 10 years worldwide. Examples of these practises are the design of bicycle routes to stations, the provision of bicycle racks on buses, allowing bicycles on trains, bicycle lockers and parking facilities at stations (IST, 2010).

The integration of cycling in public transport commutes is particularly interesting for reducing door-to-door travel times, particularly in the trips between the transport station and home or the work place. As a feeder mode, cycling is substantially faster than walking and more flexible than public transport, eliminating waiting and scheduling costs (Martens, 2007). A comparison of travel times on 25 home-to-work links in the Netherlands indicated that the travel time ratio between public transport and private car can drop from an average 1.43 to 1.25 hours if the bicycle is integrated in the public transport commute (Martens, 2004).

A study carried out in 2006 in the Netherlands showed that a substantial degree of integration of cycling in the public transport networks is achieved by simply providing sufficient and attractive bicycle parking facilities at public transport stations (Gatersleben and Appleton, 2007). This same experience demonstrated that bicycle lockers located at bus stations were hardly used by passengers due to their cost and the perceived low risks of theft and vandalism.

Cycling integration efforts are currently part of the transport planning strategies of different cities in Europe. In the Flemish region of Belgium, 22% of all trips to the station are made by bicycle. In the Netherlands, 39% of all trips to the station are made by bicycle and 10% of train passengers continue their trips on this mode. In Denmark, 25% of train clients use the bike to get the station and 9% in Sweden, yet in the city of Malmö this number increases to 35%. In Copenhagen (Denmark) and Berlin (Germany), bicycles are allowed in trains and underground transport while in Dresden (Germany), Strasbourg and Lille (France) bicycles are generally allowed on trams (ECF, 2012).

Information and awareness campaigns

Information and public awareness campaigns are important determinants in the success of policies directed towards cycling. There is a need to develop a cycling culture and a critical mass of cyclists which makes further adoption more likely (i.e. commuters are more likely to cycle if those around them are already cycling). Information campaigns are destined to increase the awareness of the general public on the existence of cycling infrastructure and on other factors such as health benefits, cost-effectiveness, etc.

According to Douma and Cleaveland (2009), the effectiveness of cycling campaigns in US cities like Chicago or Orlando was increased by awareness campaigns and bicycling advocacy. These major campaigns advertised the presence of bike lanes and created excitement about the new transportation option. A similar case was observed in Mexico City's, which despite low cycling levels, quickly reached the capacity of its bike sharing scheme of 30,000 members and now has a waiting list to join (Shaheen and Guzman, 2011). Information campaigns have fostered cycling in several German cities such as Berlin, Frankfurt, Hamburg and Munich. In Berlin, communication efforts are less visible than infrastructure improvements while in Frankfurt some communication efforts like the "bike & business" campaign were noticeable despite the less important infrastructure improvements (Lanzendorf and Busch-Geertsma, 2014). The information and promotion campaign undertaken by Munich cost €4 million and between 2009 and 2014 is expected to raise cycling modal share to 17% in 2014 (von Sassen and Kofler, 2013). The UK cities of Peterborough and Worcester invested in the period between 2004-2008 a substantial part of the €8.1 and €5.3 million budgets in funding cycling awareness campaigns that resulted in cycling modal shares of 17% and 16% (38% and 23% increase with respect to 2004) respectively (Sloman et al., 2010).

Particularly important elements of cycling awareness campaigns are cycling demonstration days (i.e. car-free days, traffic-free paths, etc.). One of the principal aims of these days is to encourage people to take up cycling for the first time or to start cycling again, providing the opportunity for less experienced cyclists to gain the confidence, experience and fun necessary to enable them to cycle more. Creating at least one high quality traffic-free cycle route in every urban area drives people to cycling again, enjoying the experience and convincing themselves that the bicycle is a valuable and appropriate means of transport for everyday use (Jones, 2012).

One of the most relevant annual events that raise cycling awareness in Europe is the European Mobility Week, which is an annual campaign on sustainable urban mobility organised by the European Commission. The aim of this campaign is to encourage European local authorities to introduce and promote sustainable transport options and to impulse modal shift from private motorised transport among citizens. One of the most important events that take place during this week is the "In Town Without My Car" day, in which cities set aside one or several areas solely for pedestrians, cyclists and public transport (EC, 2014). An experiment conducted in Brussels during Car Free Sunday (20th September 2009) revealed a reduction in the local concentration of Black Carbon of 6 μg/m³. This reduction lasted only during the hours in which car circulation was restricted. Once normal circulation was re-established, black carbon concentrations returned to their usual levels (38 μg/m³) (Fierens, 2013).

Personalised travel information

In general, aggregate-level studies have found a positive correlation between the investment in cycling infrastructure (particularly lanes) and overall levels of bicycling. However, there are still important knowledge gaps on individual-level preferences, which in some cases have found a correlation between cycling and proximity to separate paths, or that cyclists go out of their way to use paths. A study carried out in the Portland (United States) incorporating GPS data collection revealed that cyclists prefer routes that reduce exposure to motor vehicle traffic (Broach et al., 2012). It highlights the need of designing personalised travel information that reflects individual route choices and assures conditions for efficient transportation, security and comfort. A fully integrated personalised travel information system that accounts for cycling in the urban public transport network is still pending, even in those cities with a fully-evolved cycling policy framework.

2. MEASURES AIMED AT REDUCING THE DEMAND OF OTHER TRANSPORT MODES

Low emission zones (LEZ)

Low emission zones (LEZ) are areas where vehicles that do not meet a minimum standard for vehicle emissions are restricted from entering and are subject to large fines if they do enter. LEZs are deemed restrictive measures since they affect driving habits and involve fleet renewal. More than 200 LEZ have already been implemented in Europe, with the

LEZ of London (UK) and Stockholm (Sweden) the most known examples (Panteliadis et al., 2014). Other LEZs can be found in Antwerp, Athens, Prague, Copenhagen, Berlin, Bremen, Karlsruhe, Budapest, Amsterdam, Utrecht, Rome, Palermo, Verona, Lisbon, Trondheim, Brighton and Oxford.
Promoting cycling is usually included in the implementation of LEZs. Changes to ownership and use of local vehicle fleets are expected effects of the LEZ as well as transport modes. Changes in transport modes take some time to settle down, starting to become apparent in the months preceding the start of enforcement and appear to continue to change for at least one year afterwards (Ellison et al., 2013).

Despite the fact that LEZ do not specifically enhance cycling, their implementation can become an important decision factor for modal shifting. No data is available on the effects of LEZs on modal shift. Some cities like Berlin have increased their modal share of cycling by 10% between 1998 and 2014 (from 3% to 13%) due to traffic management strategies that have discouraged the use of private motorised transportation (SFCC, 2014). In London for example, the bicycle share scheme of the city is deemed an essential part of the general LEZ plan.

Congestion charging

Congestion charging aims to reduce congestion within a specified area of the city through the application of daily tariff that enables motorists to drive in this area, leave and re-enter the charging zone as many times as required in one day. Congestion charging zones are different from LEZ because these charges are for circulation in a specified zone of a city regardless of the vehicle type, whereas LEZ restrict the entrance of a specific type of vehicles (Hamilton, 2011).

The most notable example of a functional congestion charging zone is found in London. The London congestion charging scheme has achieved a 27% decrease in traffic levels of the affected zone since its implementation in 2002 (80,000 fewer cars every day). As a result, the daily journeys by bicycle in Inner London[1] have increased 81% (from 0.32 to 0.58) between 2002 and 2013 (TfL, 2014). Other cities such as Stockholm and Singapore have implemented congestion charging as well. As with LEZ, information on the potential modal shift to cycling originated by the implementation of congestion charging schemes is not available but some modal shift may be expected due to the fact that the scheme does not apply to bicycles.

In Stockholm, the congestion charging zone was introduced in 2007, covering a distance of approximately 5 km from the city centre. However the majority of work commuters to the central areas of the city make trips longer than 5 km. (Jansson, 2008). The application of the congestion charging zone decreased incoming traffic to the inner city zone by 18% (SFCC, 2014).

Other congestion charging schemes can be found in cities like Bergen (Norway), Durham (UK), Gothenburg (Sweden), Oslo (Norway), Trondheim (Norway) and Valletta (Malta).

Cities such as Helsinki (Finland) and Edinburgh (UK) are in the verge of applying a congestion charging scheme and are awaiting a final decision by policy makers.

Speed management: 30 km/h (20 mph) zones

The implementation of speed management measures across urban roads and particularly 30 km/h zones follows the need of maintaining circulation speed at a safe level for pedestrian and cycling activity. Additionally, the measure is directed towards reducing traffic and noise pollution at densely populated urban centres. Several cities in Europe have implemented 30 km/h zones since these were first implemented in 1992 in Graz (Austria). A study carried out in Mol (Belgium) and Barcelona (Spain) suggested that the implementation of 30 km/h zones may have a limited effect in urban air pollution and that the most important advantage of such zones is road safety (Int Panis et al., 2006). Barcelona introduced in 2007 a 30 km/h zone (Zona 30) in its city centre and since then, similar zones are being implemented in the rest of the city and accident rates have dropped by 27% (CDC, 2009). Since the introduction of Zona 30, the 30 km/h speed limit has been extended to 215 km^2 (26% of the city) and has seen cycling trips increase by 30% overall, from around 1% in 2006 to nearly 2% in 2009. The Zona 30 areas included additional mobility measures such as street signs, rubber studs, raised pedestrian crossings and humps. In Bristol (UK), two streets were given 20 mph limits in 2011 and within 6 months, cycling and pedestrian activities increased by up to 12% in these roads (Cedeño-Tovar and Kilbane-Dawe, 2013).

Car-free zones

Car-free zones are usually urban planning strategies that seek to regenerate spaces that are heavily affected by road-traffic. The objective of creating car-free spaces is to increase quality of life in the surrounding areas and to encourage citizens to shift from private motorisation to cycling and walking exclusively. In the European Union, reclaiming city streets for people has become a priority in environmental planning with noticeable policy examples in Copenhagen, Strasbourg, Ghent, London (Vauxhall Cross), Cambridge, Wolverhampton and Oxford (EC, 2014). According to a study carried out in Northampton (UK), reclaiming heavily congested zones through the introduction of car-free zones can reduce 15% of peak hour traffic in the immediate surroundings and helps guarantee critical mass patronage for public transport and cycling (NCC, 2007).

Parking rationing and charging

The use of individual motorised transportation can be discouraged through parking rationing and charging practises. Parking rationing consists in reducing the number of available parking areas in the city while parking charging consists in applying high tariffs to vehicles that use those areas, either generally or during a specific period of time. The usual parking management actions are directed to regenerate city centres and aimed to increase the viability of business by improving trade, and their outcomes are directly related to a modal shift (although not exclusively towards cycling).

[1] Defined as the London boroughs of Camden, City of London, Greenwich, Hackney, Hammersmith and Fulham, Islington, Kensington and Chelsea, Lambeth, Lewisham, Southwark, Tower Hamlets, Wandsworth and Westminster. classification.

Applying high parking charges translates in a reduction of traffic congestion. A study carried out by the Association of Town & City Management in 18 cities in the UK suggested that parking costs should be adjusted to the type of location being referred to in order to be effective (ATCM, 2013). A study conducted in Valletta (Malta), suggested that reducing the amount of parking slots in the central area of the city as well as introducing a charging system for non-residents (6.25 €/day) made the amount of vehicles entering the city centre decline by 7.4%, along with a 10% shift from private motorisation to public transport, cycling and walking (Attard and Ison, 2014).

Higher vehicle costs

Higher vehicle costs should be generally associated with the vehicle ownership costs and the vehicle use costs. Vehicle use costs are usually considered as the costs related to fuel consumption, maintenance and use taxes. When considering economic factors related to ownership and use, cycling is a more cost-effective alternative. In the UK, the following factors apply when counting the costs of choosing a bicycle over a car. The initial outlay of a bicycle is in general, much lower than that of a car (in its cost, the interest lost and the depreciation). The minimum third party liability and the vehicle excise duty (VED) are not mandatory for cyclists. Fuel costs are a major factor where cycling benefits over motoring, as well as maintenance and parts. In general, travelling 10 miles/day by bicycle could save of up to €2,150 each year. This is especially related to the fact that in the UK, about one fifth of the energy consumed in transport comes from journeys of less than 8 km which could be made by foot or bicycle (Brand et al., 2014).

3. PACKAGES OF MEASURES AND LINKS WITH AIR QUALITY POLICIES

On a regional or city level, transport and city planners as well as environmental authorities are working on individual strategies to improve air quality and health according to their regional and local conditions. Regional or urban policies are e.g. bypasses, traffic flow measures, environmental zones, cycling lane networks, improved public transport etc. Some city authorities will go beyond that and use measures for specific hot spots[2] (i.e. 30 km/h zones, car-free zones). In addition, there are measures, that do not change emissions, but exposures, by technical measures (controlled ventilation with filter) or non-technical measures (change in behaviour, e.g. encouraging pedestrians or cyclists to use the least polluted routes). Some city planning measures, e.g. moving households or schools to less polluted areas fall in this category (Transphorm, 2014).
Determining the link of cycling with air quality is not straightforward, due to the fact that its implementation in the city level is usually part of a package of measures that control road traffic pollution as a whole. In the Air Implementation Pilot published by the European Environment Agency, the promotion of cycling is one of the common measures that are implemented by cities to reduce the concentrations of NO_2 and PM_{10}. The Air Implementation Pilot also analysed the Time Extension Notifications (TENS) of the cities of Antwerp (Belgium), Berlin (Germany), Dublin (Ireland), Madrid (Spain), Malmö (Sweden), Milan (Italy), Paris (France), Ploiesti (Romania), Prague (Czech Republic), Plovdiv (Bulgaria), Vienna (Austria) and Vilnius (Lithuania). Most of the TENS for these cities state that cycling is being promoted actively to comply with the European limit values for NO_2, PM_{10} and benzene but cycling is always part of a combination of measures (EEA, 2013).

The impact of a package of measures at the city level

There is little evidence/information in the literature that quantifies the effect on a measure-by-measure basis of air quality policies used by a city to improve air quality levels. The Transphorm Project has developed an integrated assessment tool (IATV) that allows analysing different transport scenarios on a city level for Athens, Helsinki, London, Oslo and Rotterdam. Despite the fact that no explicit scenarios were developed for cycling, a 10% less-traffic scenario in 2020 was elaborated. This 10% traffic reduction could be produced by a modal shift to other transportation modes (such as cycling). The following table (Table 2) includes the PM_{10} concentration (in µg/m³) that this tool quantifies for this 10% traffic reduction scenario as well as the reductions (in µg/m³) in concentrations with respect to the reference year (2008) and the reductions in case of a Business as Usual scenario in 2020. The values calculated are background values, rather than roadside.

In order to identify the current state of cycling promotion as a specific measure for improving urban air quality levels, the analysis of specific air quality plans adopted by European cities is made in the following chapters. Additionally, a series of hypothetic mode share scenarios are evaluated through an air quality modelling approach in order to estimate the potential reductions in pollutants' concentration caused exclusively by such cycling measures.

TABLE 2. PM_{10} CONCENTRATIONS FOR SCENARIOS QUANTIFIED WITH THE IATV TOOL FOR THE 10% TRAFFIC REDUCTION SCENARIO

City	PM_{10} concentration (Baseline: 2008)	PM_{10} concentration (BAU: 2020)	PM_{10} concentration (10% traffic reduction: 2020)
Athens	15.0 µg/m³	8.0 µg/m³	8.0 µg/m³
Helsinki	8.5 µg/m³	7.5 µg/m³	7.0 µg/m³
London	9.0 µg/m³	8.0 µg/m³	7.0 µg/m³
Oslo	15.0 µg/m³	14.0 µg/m³	14.0 µg/m³
Rotterdam	14.0 µg/m³	13.0 µg/m³	13.0 µg/m³

REVIEW OF CASE STUDIES

In this section, the use of cycling as a relevant measure for improving air quality is reviewed in five European cities: Antwerp (Belgium), London (United Kingdom), Nantes (France), Seville (Spain) and Thessaloniki (Greece). These cities were selected by taking into consideration their participation in the European Mobility Week, their recognition as cities in which cycling has been continuously supported and their geographic location throughout Europe. The assessment of the air quality status for each of these cities is made attending to the compliance of the air quality management zones encompassed in the metropolitan areas with the NO_2 and PM_{10} limit values (LV) established in Directive 2008/50/EC and for the latest reported year (2012).[3]

TABLE 3. AVERAGE MODE SHARE OF THE STUDIED CITIES

City	Year	Car	Bike	Walk	Bus	Metro/Tram	Train
Antwerp	2010	41%	23%	20%	6%	8%	2%
London	2006	39%	2%	20%	19%	10%	8%
Nantes	2012	52%	5%	27%		16%	
Seville	2011	53%	7%	7%	28%	5%	0%
Thessaloniki	2010	55%	10%	10%		25%	

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1. ANTWERP

General features

Antwerp is a city located in the north of Belgium (Flemish Region), whose metropolitan zone covers an area of 204 km² (SB, 2014). In terms of its population it is the second most populous city in Belgium after Brussels, with a total of 510,610 inhabitants (2008) (SB, 2008). The city is located on the river Scheldt and is linked to the North Sea, sheltering one of the largest seaports in Europe (Figure 1). The weather in Antwerp is distinctly maritime and usually mild, with significant precipitation in all seasons[4]. The average temperature and precipitation are 3.0°C and 65 mm in January and 18.0°C and 78 mm in July (Peel et al., 2007).

Urban transport and mode share

The city has a well-developed transport infrastructure. It consists in a network of roads (1,206 km) and tunnels, as well as tram (12 lines) and bus lines which provide access to the city centre and suburbs (Flemish Government, 2011). The total number of registered cars in Antwerp is 238,556[5], with 56.2% of the commute journeys made by car and 13.0% made by bicycle (Eurostat, 2014). According to the European Platform on Mobility Management (EPOMM), the general mode share of Antwerp is balanced between car (41%), bicycle (23%) and walking (20%) as shown in Table 3 (EPOMM, 2014). The mode share of cycling in Antwerp is the highest amongst the studied European cities.

Current state of cycling

Policymaking in Antwerp has been traditionally favourable towards promoting cycling as a measure for improving urban mobility as well as air quality. The efforts of the city towards re-establishing cycling as a feasible form of transport as well as the existing bicycle culture are positively perceived in Europe and abroad. In 2013 the city was rated with a 72 Copenhagenize Index[6] (5th place amongst 20 cities worldwide). This index measures the friendliness of a city towards cycling in terms of its infrastructure, facilities, modal split and modal increase projections. As of now, Antwerp has more than 100 km of cycle tracks, separated infrastructure and implemented best practice as a result of intense political engagement. Antwerp has experienced a modal shift of 7% towards cycling in the period between 2008 and 2010 (from an initial 16% to 23%). The majority of people who changed towards cycling were previously using private motorisation and public transport (EPOMM, 2014). Despite this high modal share, in 2011 the city introduced a bike share system in its central part (Velo Antwerpen) that has become popular due to its intelligent placement and saturation rates (CDC, 2014).

Air quality status

The city of Antwerp encompasses two air quality management zones: BEF01S[7] (Port of Antwerp) and BEF02A (Antwerp). In 2012, only zone BEF01S did not comply with the PM_{10} daily LV, exceeding it 36 times in station BELAL05[8] (Beveren) while the city of Antwerp is itself in compliance. To improve the air quality levels, since 2004 the municipality of Antwerp has established a general mobility strategy (Mas-

[2] Measures on hot-spot level are those allocated exclusively on high-concentration zones within a city and not elsewhere. These measures usually differ from city-wide measures in that they intend to abate high pollution levels that occur locally.
[3] NO_2 – annual limit value (40 µg/m³), hourly limit value (200 µg/m³). PM_{10} – annual limit value (40 µg/m³), daily limit value (50 µg/m³).
[4] Köppen climate classification - Oceanic climate.
[5] Number of passenger cars registered as of 2011.
[6] The maximum Copenhagenize Index is 100.
[7] Standard European code for the air quality management zones.
[8] Standard European code for the air quality monitoring stations according to AirBase.

terplan Antwerpen), which contemplates investment in road and public transport infrastructure in order to alleviate the heavily-trafficked zone of the port of Antwerp (CELINE, 2013). The effectiveness of this general mobility strategy has not been quantified due to its long-term nature. In Figure 1 it can be seen that ambient NO_2 levels[9] in Antwerp have decreased 2 µg/m³ in the period between 2000 and 2012 (from 47 µg/m³ to 45 µg/m³). The average mean annual concentration of PM_{10} in zone BEF02A is 27 µg/m³ in 2012 (Figure 2).

Cycling as an air quality improvement measure

The air quality plan of the Flemish Region submitted to the European Commission[10] for a time extension in the compliance of the PM_{10} LVs contemplates the implementation of an integral cycling programme (Totaalplan fiets), which is circumscribed in the general mobility strategy of Antwerp (Masterplan Antwerpen) and the mobility plan of the Flemish Region (Mobiliteitsplan Vlaanderen). These mobility plans aim to increase the modal shift from private motorisation to other transport modes. Concretely, the local cycling programme includes a series of direct investment and promotion actions to increase mode share as well as road safety (Vlaamse Overheid, 2008). Additionally, the city launched a bicycle share program (Velo Antwerp) in June 2011 which has grown up to 150 stations and 1800 bikes, with a total investment of €60 million in 2013. The effectiveness of the local cycling programme and the general mobility strategies in terms of emission reductions and impact on NO_2/PM_{10} concentrations was not quantified and is not reported.

TABLE 4. SUMMARY OF CYCLING AND AIR QUALITY IN ANTWERP

ANTWERP				
Air Quality Metric[a]	**2008***	**2010**	**2012**	**Limit Value**
NO_2 annual mean – [µg/m³]	38	36	35	40 µg/m³
NO_2 hourly exceedances – [hours]	2	0	6	18h >200 µg/m³
PM_{10} annual mean – [µg/m³]	23	27	27	40 µg/m³
PM_{10} daily exceedances – [days]	27	25	27	35d > 50 µg/m³
Mode Share[b]	**2008**	**2010**	**2012**	
Cycling	16%	23%	Unavailable	
Private car	61%	41%	Unavailable	
Measures for air quality improvement				
Summary of measures on road-traffic (2008-2014)[c]	• Mobility plans aimed to improve public transport and slow modes infrastructure – Masterplan Antwerpen. • Cycling program for the region: Totaalplan fiets. • Public transport plan: Pegasusplan. • Parking management measures. • Increasing the uptake of cleaner vehicle fleets (electric, hybrid, etc.). • Adjustment of registration and annual circulation taxes for cars and trucks based on environmental performance. • Road pricing strategies. • Dynamic traffic management.			
Cycling as a measure in the local air quality plan	Yes			
Extension of cycling infrastructure [km]	100 km			
Total budget for cycling (multi-annual, 2013)	€60,000,000			
Bicycle sharing scheme	Velo Antwerp			
Participation in the European Mobility Week	Yes. Latest participation: 2013			
Participation in "In town without my car" event	Yes. Latest participation: 2013			

[a] Average air quality values reported for BEF02A (Antwerp).
[b] Mode share data from EPOMM.
[c] Information from the PM_{10} Time Extension Notification for the Flemish Region (2008).
* Reference years for mode share data according to EPOMM.

[9] Measured as the annual mean concentration.
[10] Reference year: 2005.

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2. LONDON

General features

London is located in the Southeast of Great Britain, covering an area of 1,572 km² and is the capital city of the United Kingdom (Figure 1). Standing on the banks of the river Thames, it is the most populous city in the European Union (8,416,535 inhabitants in 2013), accounting for 12.5% of the UK population (GLA, 2012). London has a temperate oceanic climate (*Cfb*)[1], with average temperatures and precipitations of 8.3°C and 51 mm in January and 23.2°C and 41 mm in July (Peel et al., 2007).

Urban transport and mode share

London has one of the largest transport infrastructures in Europe, consisting in an extensive network of roads (14,830 km), the Underground (metro), many bus lines, a tram, a light railway, and several urban and suburban railways (TfL, 2013). The total number of passenger cars registered in London is the largest amongst the studied cities, namely 3,035,845 vehicles[2] (Eurostat, 2014). While 31.9% of the commute journeys in London are carried out by car, only 4.3% of them are made by bicycle. The poor mode share of cycling in London is confirmed by the average mode share in 2010 (2%), in contrast with the preponderance of private motorisation (39%) and public transport (37%) (EPOMM, 2014).

Current state of cycling

In London, policymaking has been progressively supporting cycling as a feasible transport mode that could help alleviate congestion and increase mobility in the city. The continuous development of cycling infrastructure and promotion has produced an estimated 103.2% increase in cycle journey stages in Greater London since 2000. The most notable cycling-oriented action has been the adoption of the London bicycle share scheme (Barclays Cycle Hire) in 2010 and its continuous integration in the urban public transport network (TfL, 2010). Additionally, the city has been taking part in campaigns promoting public participation in "active travel", and highlighting the existing cycling infrastructure. As of 2012, approximately 150,000 bicycle journeys per day were registered in the Central London cordon (TfL, 2014). Despite the efforts, cycling mode share showed an almost negligible increase (0.9%) between 2001 and 2008, in contrast with public transport which increased its mode share by 4% (EPOMM, 2014). As a consequence, local authorities have outlined plans for spending €1100 million on cycling over the next years in order to deliver a step change in cycling provision and to support the growing number of cyclists in London (TfL, 2014).

Air quality status

The area of Greater London corresponds with the air quality management zone that reports compliance with the European LVs for NO_2 and PM_{10} (UK0001 – Greater London Urban Area). In 2012, this zone did not comply with the two NO_2 LVs (hourly and annual). The NO_2 hourly LV was exceeded 132 hours and the annual mean was 94 µg/m³ in station GB0682A (London Marylebone Road). Source apportionment studies for the city suggest that road traffic is responsible for approximately 70% of the measured air quality levels (Defra, 2011). In order to comply with the NO_2 LVs, the Greater London Authority has established a low emission zone (LEZ) in 2008, affecting the circulation of diesel-engine lorries (>3.5 t), buses, coaches, large vans and minibuses, and will adapt it to different Euro standards. The London LEZ produced a reduction in the NO_2 quality levels of the city of 0.2 µg/m³. In addition to this, the congestion charging zone has been discouraging vehicles from accessing Central London since 2003 and with an average reduction of 8% in NO_x emissions (Defra, 2012). In general, the mean air quality levels of NO_2 in London have not changed significantly between 2000 and 2012 (Figure 1). The average mean annual concentration of PM_{10} in zone UK0001 is 22 µg/m³ in 2012.

Cycling as an air quality improvement measure.

Despite the fact that the London LEZ and the congestion charging zone are the flagship policy instruments for improving air quality in the city, cycling has been considered a relevant abatement measure as well. The 2011 air quality plan elaborated by the Greater London Authority for obtaining a time extension in the compliance with NO_2 LVs outlines the implementation of cycling-promotion measures in 17 boroughs. Examples of these measures are the implementation of cycling best practice, promoting cycling amongst public employees, outlining cycling routes, building and improving cycling tracks, increasing and securing cycle parking slots and tackling cycling burglary (Defra, 2011).The effectiveness of the cycling-oriented measures in terms of emission reductions and impact on NO_2 concentrations was not quantified and is not reported.

TABLE 5. SUMMARY OF CYCLING AND AIR QUALITY IN LONDON

LONDON				
Air Quality Metric[a]	**2001**	**2006**	**2012**	**Limit Value**
NO_2 annual mean – [µg/m³]	51	51	48	40 µg/m³
NO_2 hourly exceedances – [hours]	60	458	132	18h > 200 µg/m³
PM_{10} annual mean – [µg/m³]	27	29	22	40 µg/m³
PM_{10} daily exceedances – [days]	29	152	27	35d > 50 µg/m³
Mode Share[b]	**2001**	**2006**	**2012**	
Cycling	2%	3%	Unavailable	
Private car	41%	39%	Unavailable	
Measures for air quality improvement				
Summary of measures on road-traffic (2001-2014)[c]	• London Low Emission Zone (LEZ). • Low-emission public sector fleets. • Operation of the congestion charging zone. • Promoting smarter travel (enhancing cycling). • Bus emission programme (improvement of bus fleets). • Taxi emissions programme (improvement of taxi fleets). • Increase the uptake of electric vehicles. • Smoothing traffic flow and reducing idling. • Car clubs and car sharing.			
Cycling as a measure in the local air quality plan	Yes			
Extension of cycling infrastructure [km]	Unclassified			
Total budget for cycling (multi-annual, 2013)	€1,100,000,000			
Bicycle sharing scheme	Barclays Cycle Hire			
Participation in the European Mobility Week	Yes. Latest participation: 2013			
Participation in "In town without my car" event	Yes. Latest participation: 2013			

[a] Average air quality values reported for UK0001 (Greater London Urban Area).
[b] Mode share data from EPOMM.
[c] Information from the Air Quality Plan for the Greater London Urban Area (2011).

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3. NANTES

General features

Nantes is a city located in western France and is the capital of the Pays de la Loire region (Figure 1). Its metropolitan area covers 524.6 km² and hosts 873,133 inhabitants (2010) making it the 6th most populous city in France (INSEE, 2014). The city has a Western European oceanic climate, with frequent rainfalls throughout the year and cool temperatures *(Cfb)*[1]. The average temperatures and precipitation are 4.5°C and 91 mm in January and 17.0°C and 39 mm in July (Météo-France, 2013).

Urban transport and mode share

The transport network of Nantes reflects its character as a mid-size European city. The current network has three tramway lines, suburban railways and an extensive bus network with 56 lines. The municipality of Nantes has 481,882 passenger cars registered[2], with 63% of the commute journeys carried out by car and 4% made by bicycle (Eurostat, 2014). The average mode share of the city in 2010 suggests a prevalent private motorisation (52%), followed by walking (27%) while cycling accounts for only 5% of the trips (EPOMM, 2014).

Current state of cycling

Nantes has a 373 km network of separated cycling tracks with a clear trend towards expansion, participating in the inter-regional (la Loire à vélo) and the pan-European EuroVelo 6 routes. There is sufficient political will to maintain cycling investment to impulse modal shifts in the city and the metropolitan areas, having spent €40 million between 2009 and 2014. Additionally, Nantes has a bicycle sharing system in place since 2008 (Bicloo) with more than 5 thousand subscribers (TAN, 2014). Cycling investment has produced a shift in the modal share in the metropolitan area of Nantes of 2.5% (from 2% to 4.5% between 2008 and 2012). As a result of its involvement in promoting and investing in cycling, Nantes has been awarded with a 72 Copenhagenize Index in 2013 (CDC, 2013).

Air quality status

The city of Nantes is covered by the air quality management zone FR23A01 (Pays de la Loire-Nantes), which in 2012 complied with all the LVs established by European Legislation for NO_2 and PM_{10}. Despite compliance with the European LVs, air quality levels in Nantes in 2012 were between 14 and 22 µg/m³ and between 17 and 26 µg/m³ for the NO_2 and PM_{10} annual means respectively. NO_2 levels in Nantes decreased 8 µg/m³ in the period between 2000 and 2012 according to Figure 1. The average mean annual concentration of PM_{10} in zone FR23A01 is 22 µg/m³ in 2012 (Figure 2).

Cycling as an air quality improvement measure

Air quality policymaking in Nantes has been outlined in the Regional Air Quality Plan (Pays de la Loire) and the Urban Travel Plan ("A mobile city is a sustainable city – 2000/2010"). The general objective of the plan is to reduce private motorisation mode share to 50% (currently 52%) and by promoting cycling in the city centre. All of the measures outlined in section 3.3.3 are included in the air quality plan and are expected to be completed in a temporal scale of 5 to 10 years (Nantes Métropole, 2013). The effectiveness of the cycling-oriented measures in terms of emission reductions and impact on NO_2 concentrations was not quantified and is not reported.

TABLE 6. SUMMARY OF CYCLING AND AIR QUALITY IN NANTES

NANTES			
Air Quality Metric[a]	**2008**	**2012**	**Limit Value**
NO_2 annual mean – [µg/m³]	19	14	40 µg/m³
NO_2 hourly exceedances – [hours]	0	0	18h >200 µg/m³
PM_{10} annual mean – [µg/m³]	17	22	40 µg/m³
PM_{10} daily exceedances – [days]	20	20	35d > 50 µg/m³
Mode Share[b]	**2008**	**2010**	
Cycling	2.0%	4.5%	
Private car	Unavailable	52%	
Measures for air quality improvement			
Summary of measures on road-traffic (2008-2014)[c]	• Promotion of sustainable transport strategies (car pools, walking). • Enhancement of cycling infrastructures. • Speed limitations. • Integration of inter-modal solutions for transport. • Encouraging cleaner vehicle technologies among users.		
Cycling as a measure in the local air quality plan	Yes		
Extension of cycling infrastructure [km]	373 km		
Total budget for cycling (multi-annual, 2013)	€40,000,000		
Bicycle sharing scheme	Bicloo		
Participation in the European Mobility Week	Yes. Latest participation: 2010		
Participation in "In town without my car" event	No		

[a] Average air quality values reported for FR23A01 (Pays de la Loire-Nantes).
[b] Mode share data from EPOMM. The cycling mode share in 2008 was taken from (CDC, 2013).
[c] Information from the Revision of the Plan for Atmospheric Protection in Nantes-St. Nazaire (2014).


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4. SEVILLE

General features

Seville is the capital and largest city of the region of Andalusia, in Southern Spain (Figure 1). The city is located in the banks of the Guadalquivir river, covering an area of 140 km² and hosting a population of 703,021 in 2011 making it the fourth most populous in Spain (INE, 2011). Seville has a subtropical Mediterranean climate *(Csa)*[1], with dry summers and wet winters. The average temperatures and precipitation are 10.9°C and 66 mm in January and 28.1°C and 5 mm in July. On average, Seville has 66 days of rain a year (AEMET, 2014).

Urban transport and mode share

The city has an extended transport network that serves the neighbouring urban agglomerations and that connects it with the rest of the region. The public transport network of Seville is composed by urban and interurban bus lines (38 lines), a tram and a metro system with 4 lines. The city is also served by suburban and regional train lines. The total number of vehicles registered in Seville is 281,208 in 2004, with 55.0% of the commute journeys made by car and 1.1% by bicycle (Eurostat, 2014; CTM, 2014). The mode share of Seville is characterised by the importance of private motorisation (53%) and public transport (33%), as well as a moderate penetration of cycling (7%) (Ayuntamiento de Sevilla, 2010).

Current state of cycling

Seville has implemented one of the most ambitious programmes for the promotion of cycling, which has changed the patterns of mobility in the cities. In the period between 2007 and 2010, 80 km of differentiated cycling tracks have been built in the city, organised in 8 itineraries. In the following years, an additional network of 30 km was built in order to complement the existing one. Apart from the infrastructure, Seville has its own bicycle share programme (BiciSevilla), which has gained acceptance among the residents of the city due to its convenience and smart location (especially for commuters to the old town) (Ayuntamiento de Sevilla, 2010). The transformation of the city's mobility has been rapid and positive, partly due to a sustained compromise on behalf of urban planners. This ultimately led to a change in modal share from 0.5% in 2006 to 7% in 2013, which awarded the city with a Copenhagenize Index of 76 (CDC, 2013). As of now, the local and regional governments plan to spend €421 million in maintaining the existing infrastructure and expanding it to the nearby urban areas.

Air quality status

The city of Seville and its metropolitan area are covered by the air quality management zone ES0125 (Nueva Zona Sevilla y Area Metropolitana). Zone ES0125 complies in 2012 with all the LVs established by European legislation, except for the PM_{10} daily LV which is exceeded 40 days in station ES1638A (Bermejales). According to a source apportionment study, most of these exceedances are caused by the intrusion of Saharan dust into the Iberian Peninsula, whose extraction would result in compliance with the PM_{10} daily LV for this zone (Pey et al., 2013). Nevertheless, local authorities have applied for a time extension to the European Commission with a comprehensive air quality plan that contains cycling-oriented measures (Junta de Andalucía, 2014). As for NO_2 mean concentrations, the overall levels in Seville decreased 27 µg/m³ in the period between 2000 and 2012 (from 52 µg/m³ to 25 µg/m³) (Figure 1). The average mean annual concentration of PM_{10} in zone ES0125 is 33 µg/m³ in 2012.

Cycling as an air quality improvement measure

The air quality plan of the city of Seville considers cycling within a pack of measures destined to reduce traffic volumes through the promotion of non-motorised transport. The measure itself is linked with a series of other measures that intend to reduce pollution levels integrally. The document of the air quality plan specifies the measures concerning cycling as (i) the design of cycling itineraries and routes, (ii) reinforcing and expanding bicycle share schemes and (iii) extending and securing bicycle parking slots. To increase modal share (and pollution abatement), the city council will consider implementing eco-bonus instruments for the acquisition of bicycles, as well as trip-end facilities. The seamless integration of cycling into the public transport network is also established in the air quality plan, by specifying that discounts and preferential rates are to be applied for commute journeys that combine cycling and trains or buses. The complete pack of measures acting on road-traffic (including those cycling-oriented) is expected to achieve a reduction objective of 4 µg/m³ of NO_2 or PM_{10} after 2020 (Junta de Andalucía, 2014).

TABLE 7. SUMMARY OF CYCLING AND AIR QUALITY IN SEVILLE

SEVILLE			
Air Quality Metric[a]	**2006**	**2012**	**Limit Value**
NO_2 annual mean – [µg/m³]	34	24	40 µg/m³
NO_2 hourly exceedances – [hours]	3	3	18h >200 µg/m³
PM_{10} annual mean – [µg/m³]	41	33	40 µg/m³
PM_{10} daily exceedances – [days]	152	40	35d > 50 µg/m³
Mode Share[b]	**2006**	**2012**[c]	
Cycling	0.5%	7.0%	
Private car	Unavailable	35%	
Measures for air quality improvement			
Summary of measures on road-traffic (2006-2014)[d]	• Promoting non-motorised transportation modes. • Developing and enhancing cycling in the city. • Creating separate infrastructure for cyclists. • Imposing restrictions to use of private cars (bans). • Incentivising the use of high-occupancy vehicles. • Increasing and improving existing public transport infrastructure. • Introducing new car-free zones in the city centre. • Revising the existing mobility plan to integrate intermodal transportation options.		
Cycling as a measure in the local air quality plan	Yes		
Extension of cycling infrastructure [km]	110 km		
Total budget for cycling (multi-annual, 2013)	€421,000,000		
Bicycle sharing scheme	Bici Sevilla		
Participation in the European Mobility Week	Yes. Latest participation: 2012		
Participation in "In town without my car" event	No		

[a] Average air quality values reported for ES0125 (Nueva Zona Sevilla y Area Metropolitana).
[b] Mode share data for cycling from Copenhagenize Design Company.
[c] Mode share data for cycling in Seville are referred to 2013. Mode share data for private cars is referred to 2011.
[d] Information from the Air Quality Plan for the Metropolitan Area of Seville (2010).

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5. THESSALONIKI

General features

Thessaloniki is the second largest city in Greece and is the capital of the region of Macedonia, covering an area of 111.7 km² with a total population of 322,240 inhabitants in 2011 (NSSG, 2011). The city is located in the northern fringe of the Thermaic Gulf and bounded by Mount Hortiatis on the southeast (Figure 1). The climate of Thessaloniki is determined by the sea, having a humid subtropical climate *(Cda)* with mean temperatures and precipitation of 9.3°C and 37 mm in January and 31.5°C and 20 mm in July (Peel et al., 2007).

Urban transport and mode share

As a mid-size European city, urban transport in Thessaloniki relies basically on private motorisation and public transport. Regarding private motorisation, passenger cars in the city are driven approximately 600,000 veh•km every year. As for public transport, the city is served by 92 bus lines that connect it with its regional zone of influence and a metro system that will be inaugurated shortly. The total number of cars registered in the municipality of Thessaloniki is 145,000 (2006), with 72.4% of the commute journeys carried out by car (OSET, 2014). The mode share of the city in 2010 indicates the preponderance of cars (55%) and public transport (25%). Cycling has a 10% of the mode share, the second highest amongst the studied cities (EPOMM, 2014).

Current state of cycling

Despite the fact that Thessaloniki does not have an extensive cycling infrastructure, important efforts are being done by the local authorities to create a cycling culture that encourages a modal shift among users. Since 2010, the city has been hosting cycling schools and events (the cycling carnival) as well as publishing promotional pamphlets and documents in order to create a critical mass of usual cyclists (DT, 2010). The city currently has a differentiated cycling track in the newly-refurbished seaside zone (Paraliaki), providing an alternative to the congested eastbound streets of the city (Megas Alexandrou and Vasilissis Olgas boulevards). In 2013 the city inaugurated its first bicycle sharing scheme (ThessBike), with 450 public bicycles, 26 collection points and 6 subscription stations (DT, 2014).

Air quality status

The city of Thessaloniki is encompassed within the EL0004 air quality management zone (Oikismos Thessaloniki). In 2012 this zone did not comply with both PM_{10} LVs: the annual LV was surpassed by 1 µg/m³ (41 µg/m³) in station GR0018A (Agia Sofia) and the daily LV was exceeded 79 days in station for that station. Local authorities have applied for a time extension to the European Commission, including an air quality plan which calls for the implementation of low-emission zones, parking penalisation schemes and the eco-bonuses for the renewal of the passenger-car vehicle fleet (Vlachos and Lavdaki, 2004). In general, the average NO_2 annual mean concentrations in Thessaloniki decreased 17 µg/m³ in the period between 2000 and 2012 (from approximately 39 µg/m³ to 22 µg/m³) (Figure 1). The average mean annual concentration of PM_{10} in zone EL0004 is 36 µg/m³ in 2012 (Figure 2).

Cycling as an air quality improvement measure

At present, local authorities of Thessaloniki are not considering actions directed towards increasing investment in cycling to improve air quality. According to the air quality plan of the city, most actions are related to the construction of new public transport networks as well as the drafting of a new mobility strategy for the city and a low-emission zone.

TABLE 8. SUMMARY OF CYCLING AND AIR QUALITY IN THESSALONIKI

THESSALONIKI				
Air Quality Metric[a]	**2006**	**2010**	**2012**	**Limit Value**
NO_2 annual mean – [µg/m³]	39	27	22	40 µg/m³
NO_2 hourly exceedances – [hours]	0	0	0	18h > 200 µg/m³
PM_{10} annual mean – [µg/m³]	30	46	36	40 µg/m³
PM_{10} daily exceedances – [days]	0	0	79	35d > 50 µg/m³
Mode Share[b]	**2006**	**2010**	**2012**	
Cycling	Unavailable	10%	Unavailable	
Private car	Unavailable	55%	Unavailable	
Measures for air quality improvement				
Summary of measures on road-traffic (2004-2014)[c]	• Implementation of a low emission zone. • Construction and development of an underground transportation system (Metro Thessalonikis). • Implementation of economic/taxation instruments for the uptake of cleaner vehicles. • Parking penalisation schemes.			
Cycling as a measure in the local air quality plan	No			
Extension of cycling infrastructure [km]	Unclassified			
Total budget for cycling (multi-annual, 2013)	Unknown			
Bicycle sharing scheme	ThessBike			
Participation in the European Mobility Week	Yes. Latest participation: 2013			
Participation in “In town without my car” event	No			

[a] Average air quality values reported for EL0004 (Oikismos Thessalonikis).
[b] Mode share data from EPOMM.
[c] Information from the PM_{10} Time Extension Notification for the Agglomeration of Thessaloniki (2004).

6. CONCLUSIONS

In general, it can be said that four of the five studied cities are implementing cycling-related measures to comply with the NO_2 and PM_{10} limit values, obligated by European Legislation (the only exemption being Thessaloniki). The degree of development of these cycling measures differs from city to city, from advanced infrastructures and political commitment in the case of Seville or Antwerp, to limited degrees in the case of Thessaloniki. However there is general agreement in the fact that cycling is a useful alternative to reduce motorised traffic, which in turn is the most relevant pollutant source in urban agglomerations. Despite recognising cycling as a potential alternative to private motorisation, its effectiveness as an individual measure or within the broader scope of the air quality and mobility plans has not been assessed by local authorities individually. Only Seville evaluated its effectiveness included in a wider package of road-traffic measures.

FIGURE 1. TEMPORAL EVOLUTION OF THE ANNUAL MEAN CONCENTRATION OF NO_2 IN THE STUDIED CITIES

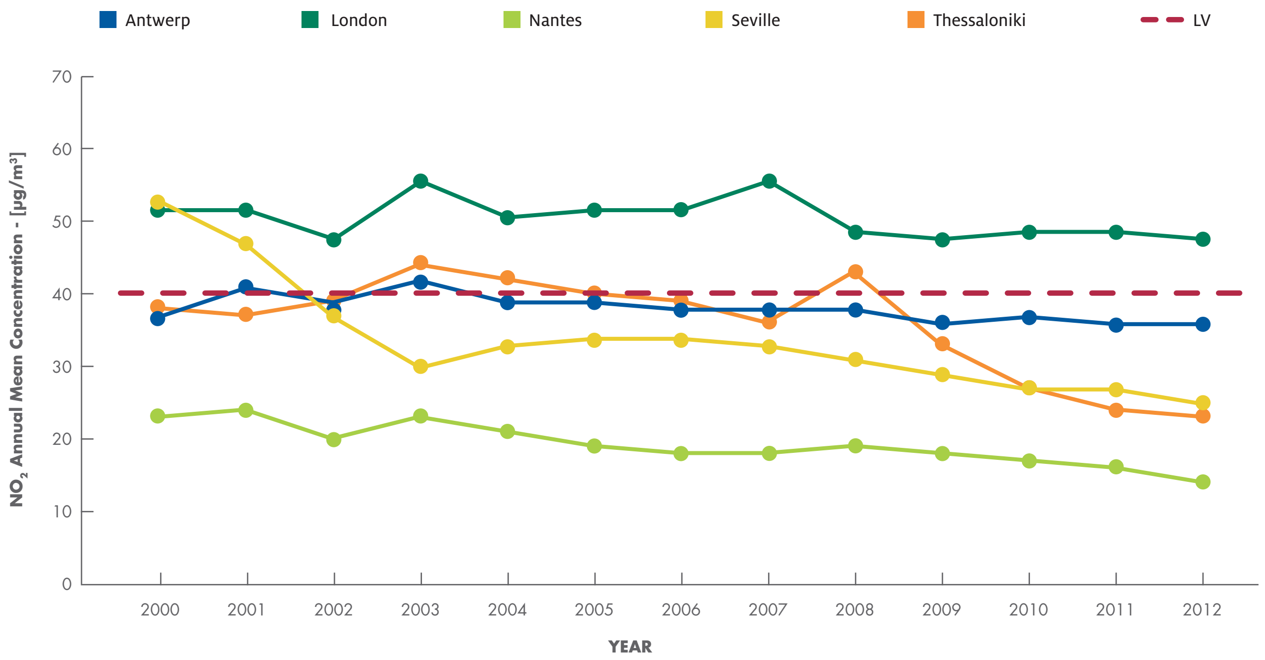
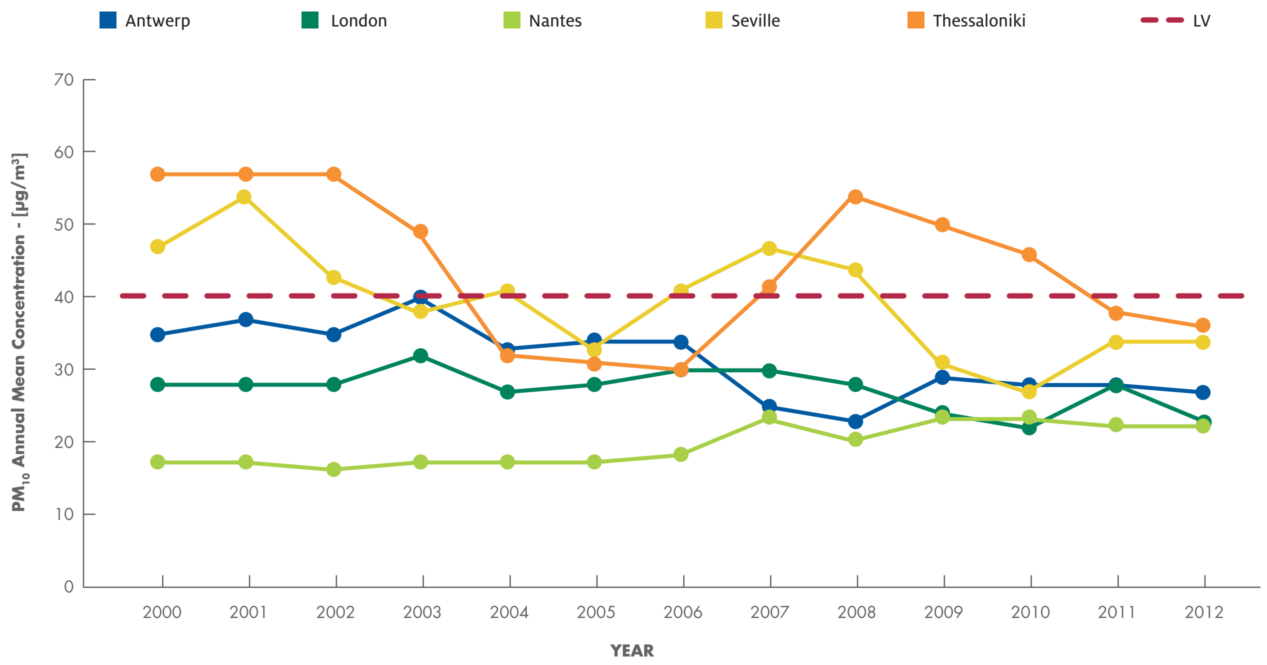


FIGURE 2. TEMPORAL EVOLUTION OF THE ANNUAL MEAN CONCENTRATION OF PM_{10} IN THE STUDIED CITIES.



IMPACT ASSESSMENT

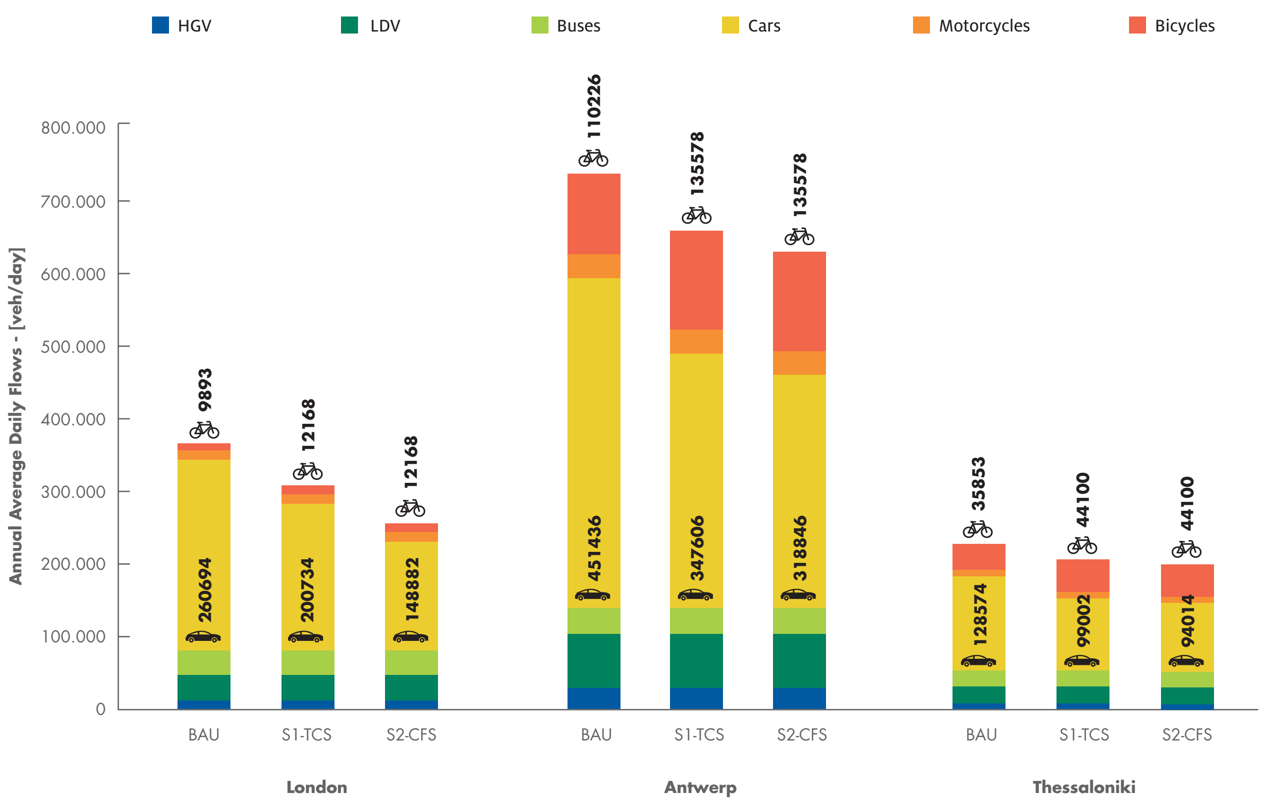
The objective of this section is to estimate the potential reductions in pollutants emissions and concentrations as well as health benefits that cycling measures bring about as part of a package of measures to improve air quality. The study has focused on specific example zones in Antwerp, London and Thessaloniki three of the case study cities. These cities were chosen as these are the cities that, according to section 3, are in infringement of the European limit values for NO_2 and/or PM_{10} and have drafted air quality plans to assure future compliance. The assessment is based on three scenarios that are representative of different degrees of increased cycling mode share representing different levels of cycling investment.

1. SCENARIO DEFINITION

Three scenarios were defined in terms of different degrees of cycling mode share, ranging from a modest penetration of cycling (business-as-usual) to an ideal situation where cycling completely substitutes private motorisation. These scenarios are the following:

- **Business as usual scenario (BAU).** The business as usual scenario contemplates normal vehicle circulation patterns in the studied cities and a mode share in which private motorisation predominates. This scenario tries to reflect as much as possible the current situation of cycling in the urban centre. The respective local[11] mode shares considered for each of the cities under this scenario are shown in Figure 3.
- **Typical cycling investment scenario (S1-TCS).** This scenario reflects the consequences of a constant, moderate investment in cycling on the mode share of a city. For the three studied cases, an increase in the cycling mode share of 23% was assumed as representative of a city in which cycling is encouraged by the existence of infrastructure, bicycle share schemes, etc. (Figure 4). The selection of this modal shift corresponds to the expected growth of cycling in a city with some infrastructure already implemented (derived from our literature review and from previous expert knowledge). For this scenario, it was assumed that new cyclists were former passenger car drivers in every case.
- **Limited Car-free scenario (S2-CFS).** The car-free scenario is a limited and not a radical approach that reproduces a traffic situation in which a limited part of the city, maximum two roads, is closed to motor vehicles. The scenario aims to reflect the "In Town without my Car!" event. One or two important roads in the studied cities were modelled as closed to traffic. Additionally, this limited car-free scenario includes the increase in the cycling mode share of 23% considered for S1-TCS (Figure 4). The car-free scenario is based on closing Plantin en Moretuslei (Antwerp), Marylebone Road and Baker Street (London), Ioanni Tsimiski and Leoforos Nikis (Thessaloniki).

FIGURE 3. ANNUAL AVERAGE DAILY FLOWS PER VEHICLE TYPE IN THE STUDIED ZONES (2012)



In all cases it is assumed that the modal shift to cycling occurs only from private motorisation and not from public transport or other transportation modes. This is simplification just to reflect the potential for cycling as part of a mode shift package.

2. STUDY ZONES

The impact assessment focused on a representative zone of each of the cities, rather than the entire city, for simplicity. In every case, the selected zones were close to monitoring locations in which exceedances of the European limit values were registered in order to assess whether cycling-oriented policies could drive future compliance (section 3). The studied zones are described as follows and presented as maps in technical appendices (available on www.ecf.com/airquality).

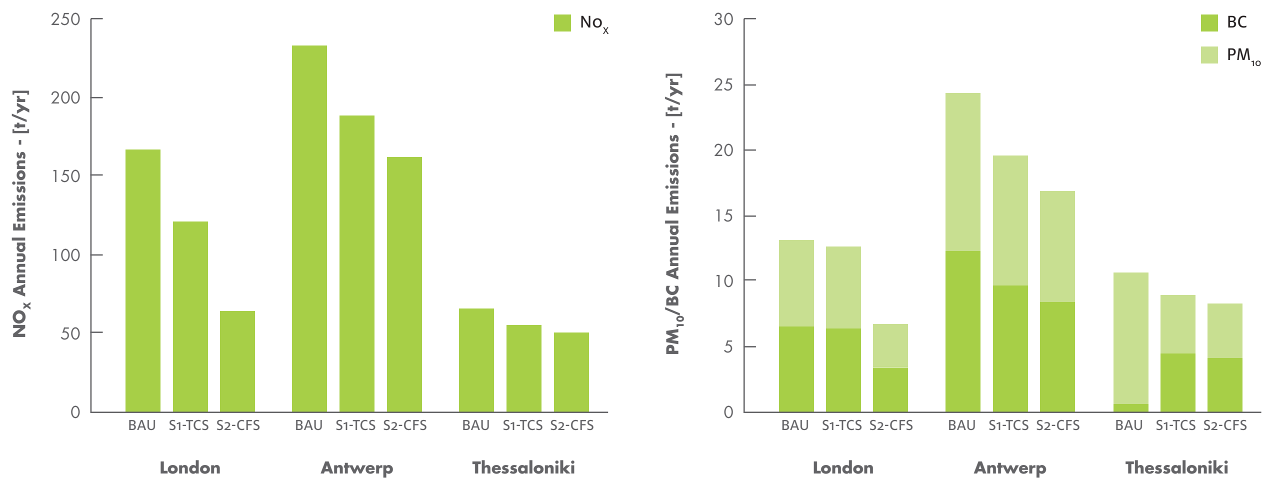
- **Antwerp.** The selected zone consists in an area of approximately 1.6 km² located in the surroundings of Borgerhout air quality station. The area has several major roads (Plantin en Moretuslei, Lieutenant Lippenslaan, Binnensingel, Noordersingel, etc.) and is primarily of a residential character. According to what was presented in section 3, exceedances in Antwerp (zone BEF01S) are driven by station BELAL05 (Beveren) which is located in the industrial zone of the port. As a result, the analysis was made on the Borgerhout station where cycling is more likely to be part of the local mode share.
- **London.** The studied zone of London is an area of 1.1 km² located near the London Marylebone Road air quality station (GB0682A), which drove non-compliance for the entire air quality management zones for the NO_2 limit values in 2012. The zone's most important roads are Marylebone Road (A501), Baker Street and Gloucester Place and the area is of a mixed residential and commercial use.
- **Thessaloniki.** The historic centre of Thessaloniki was chosen as the analysis zone (1.2 km²) because it is the location of the Agia Sofia air quality station (GR0018A), which is responsible for the non-compliance of the zone with the PM_{10} daily limit value. The zone is primarily commercial and residential, with important roads that connect the city east and westbound such as Egnatia Odos, Ioanni Tsimiski, Leoforos Nikis and Mitropoleos.

3. IMPACTS OF CYCLING ON EMISSION REDUCTIONS

Impacts were assessed in terms of the differences in the annual emission of nitrogen oxides (NO_x)[12], particulate matter (PM_{10}) and black carbon (BC)[13] between the three scenarios. Annual emissions for each of the scenarios were quantified from changes in activity (i.e. vehicles kilometre driven) and emission factors for every vehicle type present in the studied zone (Figure 3). The detailed methodology on the quantification of emissions is found in technical appendices (available on www.ecf.com/airquality).

The results suggest that increasing the cycling uptake in the city reduces the emissions of NO_x, PM_{10} and BC[14] in the studied areas. The highest NO_x emission reductions are observed for London[15] followed by Antwerp, with the smallest reductions being in Thessaloniki. In the case of PM_{10} emissions (including BC), the highest reductions are observed for Antwerp. Adopting cycling investment strategies that produce a 23%

FIGURE 4. ANNUAL EMISSIONS OF *a)* NO_x AND *b)* PM_{10}, BC FOR THE STUDIED SCENARIOS IN LONDON, ANTWERP AND THESSALONIKI



[11] The observed mode shares were obtained as a function of annual average daily flows in the studied zones of Antwerp, London and Thessaloniki, considering the cycling mode shares reported in EPOMM, (2011).

[12] Nitrogen oxides (NO_x) corresponds to the total mass of nitric oxide (NO) and nitrogen dioxide (NO_2) emitted at tailpipe. Emissions are reported as NO_x because both, NO and NO_2 suffer chemical changes in the atmosphere (NO is further oxidised to NO_2 and both contribute to the formation of ground-level ozone). Concentrations are reported only as NO_2 because it is the nitrogen oxide which produces health impacts.

[13] The IIASA definition of black carbon is the carbonaceous primary particle species that is emitted mainly from combustion processes, with a 'black', light-absorbing aerosol that composes mainly from elemental carbon and is commonly known as soot (Kupiainen and Klimont, 2007).

[14] The emissions of PM_{10} include the emissions of BC.

(S1-TCS) increase in cyclists led to reductions of 18% in NO_x and 19% in PM_{10} in Antwerp; 27% in NO_x and 4% in PM_{10} in London; and 16% in NO_x and 17% in PM_{10} in Thessaloniki. As might be expected with the additional closure of a major road in the car free scenario (S2-CFS) in each of the study zones the reductions increase to 36% in NO_x and 48% in PM_{10} in Antwerp; 61% in NO_x and 36% in PM_{10} in London; and 15% in NO_x and 17% in PM_{10} in Thessaloniki.

The differences between the cities reflect the differences in the vehicles operating in these cities and the particular zones chosen. This in turn will generate difference in emissions savings from the displaced vehicles as a results of mode shift to cycling. In addition the highest reductions in emissions are associated to those cities in which the closed road has a higher vehicle flow.

4. IMPACTS OF EMISSION REDUCTIONS ON LOCAL AIR QUALITY

Impacts have been assessed as to the differences in the concentration of nitrogen dioxide (NO_2), particulate matter (PM_{10}) and black carbon (BC) between the three scenarios under a representative set of meteorological conditions. The dispersion of pollutants was simulated with the California Line Source Dispersion Model (CALINE4) using the meteorological conditions of the particular days in which exceedances of the NO_2 and/or PM_{10} limit values were registered in the respective air quality monitoring stations (Table 9). The NO_2 hourly means and the PM_{10} daily means obtained from the simulation for all the pollutants were converted into annual means through a statistical parameterisation based on historical air quality observations from AirBase (Vedrenne et al., 2014). Further details on the configuration of the model and the processing of outputs can be found in the technical appendices (available on www.ecf.com/airquality).

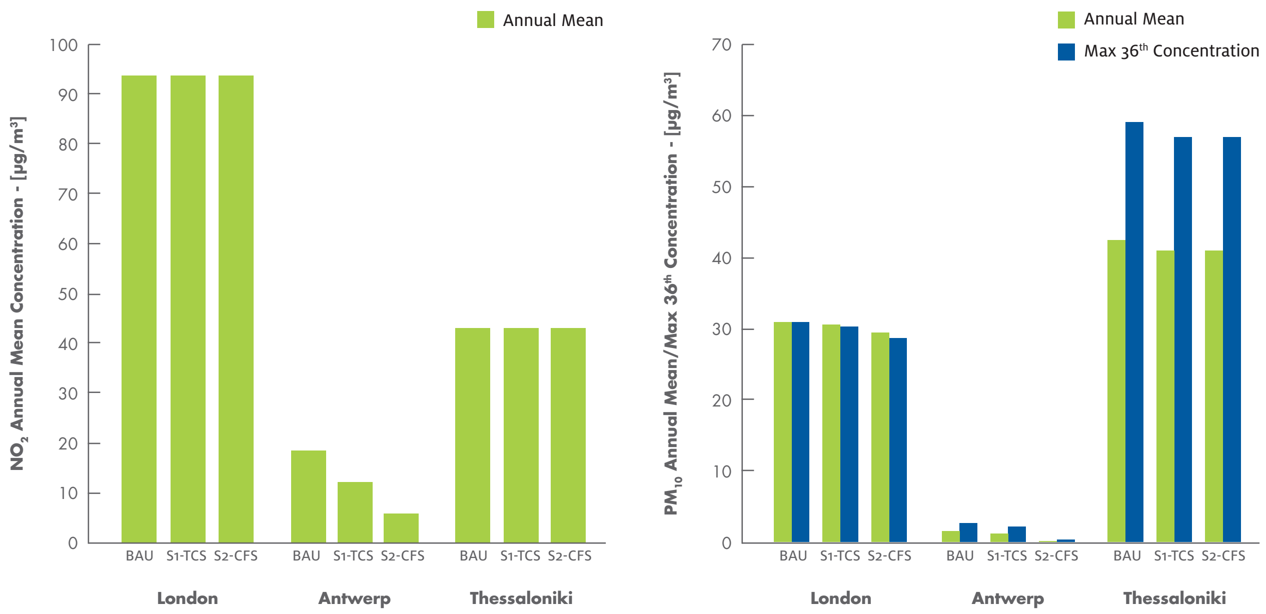
The general modelling process focused only on the contributions of road-traffic in the studied area to the local air quality levels (measured by the respective monitoring location). As a result, the simulated concentrations do not account for all the sources that exist in the area (i.e. residential, off-road, etc.) nor do they consider the contribution of adjacent roads outside the studied domains.

Results are presented as simulated concentrations at the above monitoring locations, as shown in Figure 5, and as general concentration map for each zone. Generally, high

TABLE 9. EXCEEDANCE DATES FOR WHICH IMPACTS IN CONCENTRATIONS WERE EVALUATED

City	Air quality station	Exceeded LV	Date	Value
Antwerp	Borgerhout	None	18/02/2012	-
London	Marylebone Road	NO_2 hourly LV	24/07/2012 (9a.m.)	277 µg/m³
		NO_2 annual LV	2012	94 µg/m³
Thessaloniki	Agia Sofia	PM_{10} daily LV	12/12/2012	57 µg/m³
		PM_{10} annual LV	2012	41 µg/m³

FIGURE 5. *a)* NO_2 AND *b)* PM_{10} AIR QUALITY LEVELS AT THE RESPECTIVE MONITORING LOCATIONS UNDER THE THREE ANALYSED SCENARIOS



concentrations of pollutants in the studied zones are located near high-trafficked roads (Plantin en Moretuslei, Marylebone Road, Ioanni Tsimiski). Concentrations tend to decrease with distance from these roads, unless these roads are adversely affected by specific local conditions and urban structure (for example in Dorset Square in London or Plateia Aristotelous in Thessaloniki).

The results in Figure 5 above show the simulated air pollutions levels for the Business as Usual (BAU) and the reductions achieved with the cycling investment scenario (S1-TCS) and the car free scenario (S2-CFS).

Analysing the achievable reduction of air quality levels at the monitoring locations under the three scenarios allows quantifying the effectiveness of cycling with regards to complying with the NO_2 and PM_{10} limit values.

In the case of Antwerp, S1-TCS reduced the NO_2 annual mean by 6.3 µg/m³ and the annual mean for PM_{10} by 0.3 µg/m³ at the monitoring station location. The highest reductions for this scenario are located at the junction between Noordersingel and Koolstraat (14.0 µg/m³ for the NO_2 annual mean and 2.0 µg/m³ for the PM_{10} annual mean). Reductions are higher with S2-CFS, which decreased the NO_2 the annual mean 12.6 µg/m³ and the PM_{10} annual mean 1.4 µg/m³. The maximum reductions are located at the same junction, with reductions as high as 18.0 µg/m³ for the NO_2 annual mean and 3.0 µg/m³ for the PM_{10} annual mean. These are significant reductions, which although Antwerp is in compliance with European limit values at Borgerhout station, shows further improvements can be achieved.

For London, the NO_2 annual mean was not improved at the air quality monitoring station (Marylebone Road) by any of the scenarios, partially because of the unfavourable dispersion patterns that affect concentrations at this location as well as its exposure to nearby highly-trafficked roads. However, reductions are observed at other locations in the studied zone and range between 8.0 µg/m³ for the annual mean with S1-TCS to 16.0 µg/m³ with S2-CFS respectively in the junction between Melcombe Street and Gloucester Place. In the case of PM_{10} the annual mean is reduced by 0.3 µg/m³ for S1-TCS. The maximum reductions for PM_{10} annual means are achieved in the vicinity of Regent's Park and Baker Street Station (3.0 µg/m³ for the annual mean under S1-TCS and 4.0 µg/m³ under S2-CFS). These improvements are much smaller than seen in Antwerp and so would continue be in infraction of the European limit values even with the cycling measures.

In Thessaloniki, the NO_2 air quality levels were not improved in Agia Sofia under the simulated scenarios. Despite this fact, improvements are seen elsewhere in the streets of Thessaloniki, with the greatest being at the heavily congested junctions of Mitropoleos and Pavlou Mela with Palaion Patron Germanou. These improvements can be as high as 3.0 µg/m³ and 14.0 µg/m³ for the annual mean under both scenarios. In the case of PM_{10}, the annual mean was improved by 0.3 µg/m³ in both cases. Undertaking cycling investment to achieve a modal shift as specified in S1-TCS, does not bring about a sufficient reduction for compliance with the PM_{10} annual limit value (40.9 µg/m³).

The reductions in air pollutions concentration are quite different from the changes in emissions in each of the zones and this is a result of the considerable influence of factors such as meteorology, urban configuration and regional influences (Keuken et al., 2012). This highlights the difficulty of drawing simple conclusion on the impact of cycling measure on air pollution as it depend on a significant range of local conditions including both the existing traffic mix and local meteorology.

5. IMPACTS OF IMPROVEMENTS OF LOCAL AIR QUALITY ON HEALTH

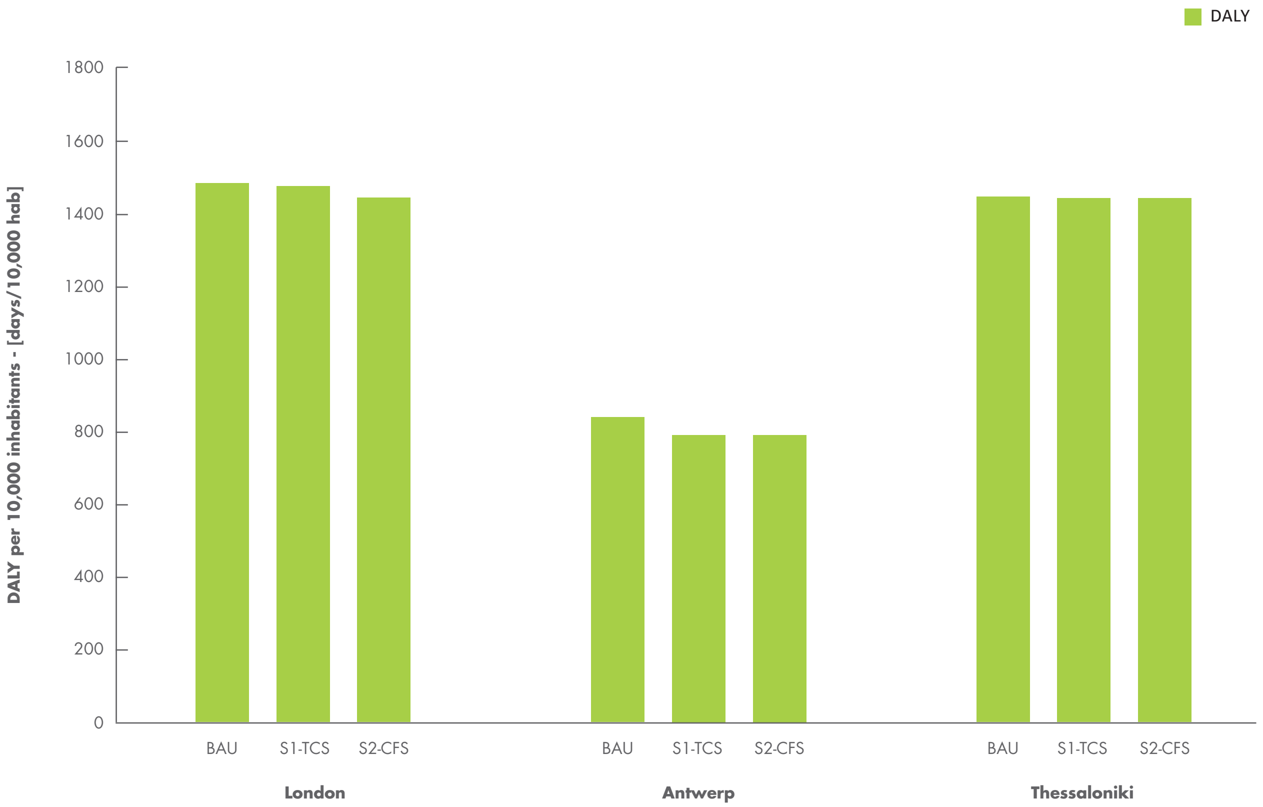
Ultimately the driver to improve air quality is the desire to reduce the health impact of poor air quality on the city residents. This section provides illustrative assessment of the potential health benefits of the scenarios assessed here. For the purposes of this project, the quantification of the impacts of air quality on human health was made in terms of the disability adjusted life years (DALY) metric for black carbon (BC)[16] as recommended in Rao et al., (2013). DALY is a relevant health-impact metric that extends the concept of potential years of life lost due to premature death to include years of healthy life lost by virtue of being in states of poor health or disability (Murray et al., 2002).

In order to allocate the share of damage that air pollution has on poor health, BC concentrations were converted into population-attributable fractions (PAF) which were in turn multiplied by raw DALY rates for cardiopulmonary health outcomes in the countries of the selected cities. These values originally came from the Mortality and Burden Disease Estimates of the World Health Organisation (Mathers et al., 2006). To this respect, health impacts were quantified only for the contributions of road traffic to the air quality levels at the studied monitoring locations (Table 9). Further details on the methodology for quantifying the impacts of local air quality on human health can be found in technical appendices to this study (available on www.ecf.com/airquality).

The DALY rates (in days of disability per 10,000 inhabitants) for the three scenarios and the studied cities are shown in Figure 6. In the case of Antwerp, the BAU scenario produces 836 DALY per 10,000 inhabitants due to cardiopulmonary diseases. The inclusion of cycling measures reduces the disability by 50 years (to 786 DALY) under both scenarios. In the case of London, the BAU scenario produces a disability rate of 1478 DALY per 10,000 inhabitants, which is reduced to 1471 DALY by S1-TCS and to 1438 by S2-CFS (respective reductions of disability in 7 and 39 years). Finally for Thessaloniki, the BAU scenario contemplates a disability rate of 1442 DALY per 10,000 inhabitants which after the adoption of cycling measures reduces this value slightly to 1438 for both scenarios.

[15] Provided data refer to the studied zones and not to the entire urban agglomeration.
[16] The used BC annual means account for the background levels as well.

FIGURE 6. DALY (BC) RATES FOR THE STUDIED SCENARIOS IN LONDON, ANTWERP AND THESSALONIKI



6. CONCLUSIONS

The objective of this chapter was to assess the effectiveness of cycling, as a measure intended to encourage modal shift away private motorisation, in order to improve the air quality levels of Antwerp, London and Thessaloniki under two hypothetic scenarios. In every case, modal shift from private motorisation to cycling produced reductions in the emissions of NO_x, PM_{10} and BC but this varied from city to city depending on the local traffic situation. These emission reductions in turn resulted in improvements in the air quality levels of the studied zones in the cities, although the improvements again varied from city to city as a results of local conditions for example with much greater benefits being seen in Antwerp than London. Other formulation: they contribute partly to compliance with Limit Values.

Even without the improvements being enough to achieve compliance with the air quality limit values they did provide health benefits showing decreases in life year lost (measured as cardiopulmonary DALY rates) in the three cities. In the case of Antwerp and London, the car-free scenario (S2-CFS) produced further reduction when compared to the enhanced cycling investment scenario (S1-TCS) due to the fact that the closed roads had the highest traffic flows in their respective study zones. In the case of Thessaloniki, the reductions achieved by the car-free scenario were marginal due to the fact that the closed roads had significantly lower traffic flows and were not the ones with most circulation in the domain.

These results show that there is no simple relationship between cycling measures and improvements in air quality as the exact relation is very dependent on local conditions. However, the introduction of cycle measures most likely as part of a wider package of measures to reduce road traffic will show improvements in air quality and although these improvements may not be enough to meet air quality compliance levels they will still generate health benefits.

RECOMMENDATIONS

Technical measures alone, in terms of technologies that directly reduce emission from road vehicles, are insufficient to meet compliance with urban air quality objectives. This has been highlighted by the failure of vehicle Euro emission standards to produce the reductions in emissions expected in urban areas as has been noted in various studies (Carslaw et al., 2013: EEA, 2013; Hitchcock et al., 2014). Therefore a more demand-side-focused approach is needed to reduce the impacts of transport, such as air pollution, and develop a more sustainable transport system. A commonly used framework is the three-pillar system known as Avoid-Shift-Improve (Dalkmann & Brannigan, 2007; UNEP, 2013):

- **Avoid** the need to travel to access goods and services, through efficient urban planning, communication technology, consolidation activities and demand management.
- **Shift** people and goods that need to be moved towards more inherently sustainable modes such as walking, cycling, public transport, rail and (where appropriate) water transport.
- **Improve** the environmental performance of vehicles by the adoption of low-emission vehicle technologies and more efficient operation of vehicles.

In line with this approach cycling measures are now present in the air quality and mobility plans of numerous cities around the world. In terms of air quality this needs to be related to a mode shift away from motorised road transport, and the emissions benefits that this brings, rather than an increase in cycling per se. Therefore cycling measures need to be part of an overall approach to reduce road traffic in order to generate air quality improvements.

The examination of the measures aimed at increasing cycling mode share suggests that in order to encourage cycling and attract people out of cars, municipalities have to engage in developing the appropriate infrastructure (bike share schemes, differentiated tracks, end-of-trip facilities, parking slots, etc.), carrying out positive information campaigns and more widely discouraging the use of private motorised transport through the adoption of policy instruments such as congestion charging or low-emission zones.

Analysis of the European case study cities revealed that the most successful drivers for modal change are the development of appropriate cycling infrastructure and its correct integration with the public transport network. In these cases a direct relationship between these variables and an increase in cycling modal share has been observed. For example, cities such as Antwerp or Seville have the highest cycling modal share and the largest cycling infrastructure among the studied cities. In the case of Thessaloniki and London, moderate increases in modal share have been observed as well, yet cycling infrastructure still needs to be improved.

Four of the five studied cities, (Antwerp, London, Nantes and Seville) explicitly present cycling as part of their respective air quality plans. To be most effective at improving air quality local authorities should focus on encouraging modal shift from private motorised transport to cycling in order to reduce road-traffic pollution, rather than promoting cycling per se.

Overall the reduction in traffic levels brought about by cycling measures, and other mode shift initiatives, will generate reductions in emissions and ambient concentrations of pollutants, and ultimately provides a benefit to human health.

The degree to which these air quality benefits will become evident is a function of the level of modal shift as well as the specific characteristics of the city including existing traffic flows, fleet composition, meteorology and urban topology. Therefore the benefit of any package of cycling measures will vary from city to city, dependent on its local situation. However, in all five of the case study cities mode shift to cycling on its own was unlikely to be sufficient to achieve to air quality objectives, although it did generate air quality related and wider health benefits.

The key actors in developing cycling as part of the solution to urban air quality are the city authorities and they need to:

- Promote measures that shift residents from private motorised transport to cycling, rather than promoting cycling per se, to ensure that air quality benefits are generated;
- Integrate cycling measures as part of a wider mode shift package with a combination of 'pull' measures to directly attract car users and 'push' measure to more generally discourage car use;
- Complement cycling and other mode shift measures with technical measures to reduce the emissions from the remaining traffic such as public transport and delivery vehicles.

In addition there are further co-benefits of cycling regarding health (through physical activity), climate change, noise, human rights (access to mobility for all parts of society/population) and economy (congestion-easing, improving travel-time reliability) and all these co-benefits should be taken into account when authorities discuss investments in cycling from the point of view of air pollution.

Thus in summary, from an air quality management point of view, cycling should continue to be part of air quality plans that aim to tackle air pollution at the urban scale. However they must be part of a package of measures directed at reducing overall road traffic, to ensure that the associated emissions benefits and air quality improvements are generated. These air quality improvements will in turn give rise to numerous societal co-benefits. However the extent of the air quality improvements will vary from city to city and across the city itself with our analysis showing changes at the selected monitoring locations in NO_2 concentrations from zero to 12.6 µg/m³ and changes in PM_{10} concentrations from 0.3 µg/m³ to 1.4 µg/m³. Although overall the changes in London and Thessaloniki were not enough to meet the European limit values. This suggests that mode shift measures alone are unlikely to be sufficient to meet the European air quality limit values in urban areas. Therefore, a successful approach to combat air pollution is a combination of both non-technical and technical measures: encourage a modal shift, including the shift towards cycling, and reduce emissions from the remaining traffic such as public transport and delivery vehicles.

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