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, results in 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 systems 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 suffer 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.

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 is 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 NO₂ 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 (NO₂, PM₁₀ 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 25% 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 NO₂, PM₁₀ 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 cities in the zones. 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 NO₂ concentrations from zero to 12.6 µg/m³ and changes in PM₁₀ concentrations from 0.5 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.

Janez Potočnik, European Commissioner for the Environment

‘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.’

(Potočnik, 2013)
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 6th 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 (Guerrero et al., 2012). 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 (Sundqvist et al., 2013), 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; Körber, 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 13 months in 2012 (EEA, 2013). Other European-funded city planning programmes such as CVITAS 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.

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).

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 designed 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 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 1.07% to 1.76% in 2007) over a period of 2 years (from 2005 to 2007). Vélo’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 (TI, 2011).
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 the 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 right. 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 (Bouman 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 over 2% for other modes (Thorton et al., 2010). A similar study in Portland (USA) revealed that 96.6% of the residents would cycle if safety was increased as much as 21% from destinations to major bicycle parking facilities was the second priority after segregated lanes among surveyed users, lockers being the most preferred (against exterior lockers and facilities) (Taylor and Mahmassani, 1996). A study in the Netherlands showed that the existence of cycle storage facilities nearby usual workplaces, supermarkets in Chicago or Orlando was increased by awareness campaigns and bicycling advocacy. Integration of cycling in public transport networks

The current practices in the promotion of cycling as an alternative mode of transport focus on its seamless integration with public transport. 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, 2016). The integration of cycling in public transport commutes is particularly interesting for reducing door-to-door travel times, particularly when the connection between home and work is 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 trips in the Netherlands showed that cycling was 24% faster (in terms of average journey time) than travel by car (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 Aepli, 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 infrastructure to increase the perception of safety with 0.03% from road traffic incidents and 0.13% from air pollution. Additionally, this study found that 12.28% of deaths were avoided and carbon dioxide emissions were reduced by approximately 9 Gt when compared with car users (Bojoi-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 16% in Barcelona). Additionally, other transportations modes such as mopeds or motorcycles suffered important reductions as a consequence of the bicycle share scheme (44% in Berlin and 34% in Stuttgart). Current bicycle shares reported their previous usual transport to be those shown in Table 2 (Zaerdt, 2014).

The creation of new cycling infrastructure is usually directed to the Netherlands. A 2003 cross-sectional study in the commuting behaviour of 145 cities in the United States revealed that every additional mile of bike lanes per square mile led to a 2% increase in bicycle commuting (less than 1% of the surveyed people actually considering shifting to cycling due to these new infrastructures (Caufield et al., 2012).

Similar findings were observed in Seville in 2010, where the existence of the cycling infrastructure (320 km) produced a global modal shift of 32% from car users and 5.4% from motocycles users with a total spent budget of €35 million (Ayuntamiento de Seville, 2010). This ultimately produced a global increase in modal share in cycling in the city of 30% in 2003 to 33% in 2013. In the city of Darlington (UK), the injection of £3.5 million in cycling infrastructures (46 km) since 2004 produced a total increase in cycle trips of 26.30% and changed cycling mode share from 1% to almost 3% (6.5 trips per 100 people) (DCD, 2007; Slamon et al., 2010). In Malmo, the construction of 410 km of bicycle lanes in 2009 resulted in a total 29% 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 €4.0 million (ADVANCE, 2014, CIVITAS, 2012).

There is an implicit assumption among stakeholders that the “build it and they’ll come” principle and the creation of cycling infrastructure is related to the 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, awareness campaigns found a positive correlation between the investment in cycling infrastructure (particularly lanes) and overall levels of bicycling. However, there are some radical differences in the travel preferences, which in some cases have found a correlation between cycling and proximity to separate paths, or that cycling is an unimportant means of transport to use at work. A study carried out in the United States incorporating GPS data collection revealed that cyclists prefer routes that reduce exposure to high traffic volumes, especially to busy streets (Shaheen and Guzman, 2011). The existence of bike lanes results in a modal share of 1% (in Munich) and 2% (in Berlin). Information campaigns are destined to inform 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).

Particularly important elements of cycling awareness campaigns are cycling demonstration days (i.e. three days, traf-fic-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 again cycling, 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 area and involve people to cycling again, the enjoyment 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 mobiisation by the European Commission. The aim of this campaign is to encourage European local authorities to introduce and promote sustainable transport options and to improve 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).

Low emission zones (LEZ)

Low emission zones (LEZ) are areas where vehicles that do not meet a minimum emission threshold are restricted from entering and are subject to large fines if they do enter. LEZs are deemed restrictive measures since they affect drivers who do not live in the area, and can increase the pollution in the surrounding area. More than 200 LEZ have already been implemented in Europe, with the...
LEZ of London (UK) and Stockholm (Sweden) are the most known examples (Panteliadis et al., 2014). Other LEZs can be found in Antwerp, Athens, Prague, Berlin, Bremen, Karlsruhe, Budapest, Amsterdam, Utrecht, Rome, Palermo, Verona, Lisbon, Trieste, 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 LEZ. However, the need for maintaining circulation speed at a safe level for pedestrian and cycling activity. Additionally, the measure is directed at reducing peak hour traffic in heavily polluted 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 Mál (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 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, 2006). Since the introduction of the Zona 30, the 30 km/h speed limit has been extended to 213 km/h (88% of the city) and has seen cycling trips increase by 10% overall, from around 1% in 1999 to nearly 2% in 2009. The Zona 30 areas included additional mobility measures such as street signals, 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 corridors (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 the quality of life in the surrounding areas and to encourage citizens to shift from private motorisation to cycling and walking exclusively. In the UK, car-free zones for people has become a priority in environmental planning with noticeable policy examples in Copenhagen, Strasbourg, Ghent, London (Southwark, Wandsworth), Cambridge, Wolverhampton and Oxford (EC, 2014). According to a study carried out in Northernhay (UK), reclaiming heavily congested zones through the introduction of car-free transport leads to an average reduction of 76% 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 policies. 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).

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, 2011). 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 (6.50 €/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 and use costs (such as parking, fuel and insurance). 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 owning a bicycle or a car (Theocharides, 2011). 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 motorising, as well as maintenance and parts. In general, travelling 100 km/day may save of up to £4,350 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 infrastructure, public transport etc. Some city authorities will go beyond that and use measures for increasing walking, as well as maintenance and parts. In general, travelling 100 km/day may save of up to £4,350 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).

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, 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 1) includes the PM$_{10}$ concentration (in μg/m$^3$) that this tool quantifies for this 10% traffic reduction scenario as well as the reductions (in μg/m$^3$) 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. On the contrary, a series of hypothesis 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>
<thead>
<tr>
<th>City</th>
<th>PM$_{10}$ concentration (BAU: 2008)</th>
<th>PM$_{10}$ concentration (BAU: 2020)</th>
<th>PM$_{10}$ concentration (10% traffic reduction: 2020)</th>
<th>PM$_{10}$ concentration (10% traffic reduction: 2020)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Athens</td>
<td>8.0 μg/m$^3$</td>
<td>8.0 μg/m$^3$</td>
<td>7.2 μg/m$^3$</td>
<td>7.2 μg/m$^3$</td>
</tr>
<tr>
<td>Helsinki</td>
<td>7.5 μg/m$^3$</td>
<td>7.0 μg/m$^3$</td>
<td>6.3 μg/m$^3$</td>
<td>6.3 μg/m$^3$</td>
</tr>
<tr>
<td>London</td>
<td>8.0 μg/m$^3$</td>
<td>7.0 μg/m$^3$</td>
<td>6.0 μg/m$^3$</td>
<td>6.0 μg/m$^3$</td>
</tr>
<tr>
<td>Oslo</td>
<td>13.0 μg/m$^3$</td>
<td>12.0 μg/m$^3$</td>
<td>11.0 μg/m$^3$</td>
<td>11.0 μg/m$^3$</td>
</tr>
</tbody>
</table>

1Defined as the London boroughs of Camden, City of London, Crouchend, Hackney, Haringey, Hertsmere and Redbridge; Westminster, Islington, Camden and Haringey.
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\textsubscript{2} and PM\textsubscript{10} limit values (LV) established in Directive 2008/50/EC and for the latest reported year (2012).\textsuperscript{7}

### TABLE 3. AVERAGE MODE SHARE OF THE STUDIED CITIES

<table>
<thead>
<tr>
<th>City</th>
<th>Year</th>
<th>Car</th>
<th>Bike</th>
<th>Walk</th>
<th>Bus</th>
<th>Metro/Tram</th>
<th>Train</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antwerp</td>
<td>2010</td>
<td>41%</td>
<td>23%</td>
<td>20%</td>
<td>6%</td>
<td>8%</td>
<td>2%</td>
</tr>
<tr>
<td>London</td>
<td>2006</td>
<td>39%</td>
<td>2%</td>
<td>20%</td>
<td>19%</td>
<td>10%</td>
<td>8%</td>
</tr>
<tr>
<td>Nantes</td>
<td>2012</td>
<td>52%</td>
<td>5%</td>
<td>27%</td>
<td>10%</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>Seville</td>
<td>2011</td>
<td>53%</td>
<td>7%</td>
<td>7%</td>
<td>28%</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>Thessaloniki</td>
<td>2010</td>
<td>53%</td>
<td>10%</td>
<td>10%</td>
<td>25%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 1. ANTWERP

**General features**

Antwerp is a city located in the north of Belgium (Flemish Region), whose metropolitan zone covers an area of 204 km\textsuperscript{2} (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\textsuperscript{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 238,356; with 96.2% 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). 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).

**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\textsuperscript{5} (5\textsuperscript{th} 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 modality 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 (Port of Antwerp) and BEF02A (Antwerp). In 2012, only zone BEF01S did not comply with the PM\textsubscript{10} daily LV exceeding it 36 times in station BELAL05 (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...
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 NO2 levels 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 PM10 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 Commission3 for a time extension in the compliance of the PM10 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 Waan). 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 NOx/PM emissions was not quantified and is not reported.

### TABLE 4. SUMMARY OF CYCLING AND AIR QUALITY IN ANTWERP

<table>
<thead>
<tr>
<th>Air Quality Metric</th>
<th>Antwerp</th>
<th>Limit Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx annual mean – [μg/m3]</td>
<td>2008 38</td>
<td>2010 36</td>
</tr>
<tr>
<td>NOx hourly exceedances – [hours]</td>
<td>2008 2</td>
<td>2010 0</td>
</tr>
<tr>
<td>PM10 annual mean – [μg/m3]</td>
<td>2008 23</td>
<td>2010 27</td>
</tr>
<tr>
<td>PM10 daily exceedances – [days]</td>
<td>2008 27</td>
<td>2010 25</td>
</tr>
</tbody>
</table>

#### Mode Share

- **Cycling**: 16% (2008), 23% (2010), Unavailable (2012)
- **Private car**: 61% (2008), 41% (2010), Unavailable (2012)

#### Measures for air quality improvement

- 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.

#### Summary of measures on road traffic (2008-2014)

- **Cycling as a measure in the local air quality plan**: Yes
- **Extension of cycling infrastructure (km)**: 100 km
- **Total budget for cycling (multi-annual, 2010)**: €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

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3. Reference years for mode share data according to EPOMM.
4. Mode share data from EPOMM.
proving 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\textsubscript{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 (Dfra, 2011). The effectiveness of the cycling-oriented measures in terms of emission reductions and impact on NO\textsubscript{2} concentrations was not quantified and is not reported.

### TABLE 5. SUMMARY OF CYCLING AND AIR QUALITY IN LONDON

<table>
<thead>
<tr>
<th>Air Quality Metric(\text{c})</th>
<th>2001</th>
<th>2006</th>
<th>2012</th>
<th>Limit Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{NO}_2) annual mean (\text{[μg/m}^3\text{]})</td>
<td>51(\text{a})</td>
<td>51</td>
<td>48</td>
<td>40 (\text{μg/m}^3)</td>
</tr>
<tr>
<td>(\text{NO}_2) hourly exceedances (\text{[hours]})</td>
<td>60</td>
<td>45</td>
<td>132</td>
<td>18h &gt; 200 (\text{μg/m}^3)</td>
</tr>
<tr>
<td>(\text{PM}_10) annual mean (\text{[μg/m}^3\text{]})</td>
<td>27</td>
<td>29</td>
<td>22</td>
<td>40 (\text{μg/m}^3)</td>
</tr>
<tr>
<td>(\text{PM}_{2.5}) daily exceedances (\text{[days]})</td>
<td>28</td>
<td>152</td>
<td>27</td>
<td>350 &gt; 50 (\text{μg/m}^3)</td>
</tr>
</tbody>
</table>

#### Mode Share\(\text{d}\)

<table>
<thead>
<tr>
<th></th>
<th>2001</th>
<th>2006</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycling</td>
<td>2%</td>
<td>3%</td>
<td>-</td>
</tr>
<tr>
<td>Private car</td>
<td>41%</td>
<td>39%</td>
<td>-</td>
</tr>
</tbody>
</table>
| Measures for air quality improvement

<table>
<thead>
<tr>
<th>Summary of measures on road-traffic (2001-2014)</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>• London Low Emission Zone (LEZ)</td>
<td></td>
</tr>
<tr>
<td>• Low-emission public sector fleets.</td>
<td></td>
</tr>
<tr>
<td>• Operation of the congestion charging zone.</td>
<td></td>
</tr>
<tr>
<td>• Promoting smarter travel (enhancing cycling).</td>
<td></td>
</tr>
<tr>
<td>• Bus emission programme (improvement of bus fleets).</td>
<td></td>
</tr>
<tr>
<td>• Taxi emissions programme (improvement of taxi fleets).</td>
<td></td>
</tr>
<tr>
<td>• Increase the uptake of electric vehicles.</td>
<td></td>
</tr>
<tr>
<td>• Smoothing traffic flow and reducing idling.</td>
<td></td>
</tr>
<tr>
<td>• Car clubs and car sharing.</td>
<td></td>
</tr>
</tbody>
</table>

---

\(\text{a}\) Average air quality values reported for UMR01 (Greater London Urban Area).

\(\text{b}\) Mode share data from EPOMM.

\(\text{c}\) Information from the Air Quality Plan for the Greater London Urban Area (2011).

\(\text{d}\) Mode Share data from EPOMM.

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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 534.6 km\(^2\) and hosts 873,133 inhabitants (2010) making it the 6\(^{\text{th}}\) most populous city in France (INSEE, 2012). The city has a Western European oceanic climate, with frequent rainfalls throughout the year and cool temperatures (18°C). A local cycling-oriented public transport network has been implemented since 2008 (Bicloo). 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 public transport subscribers (TAN, 2014). Cycling investment has produced a modal shift 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 (CICD, 2013).

#### Current state of cycling

Nantes has a 333 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 (CICD, 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 \(\text{NO}_2\) and \(\text{PM}_{10}\). Despite compliance with the European LVs, air quality levels in Nantes in 2012 were between 14 and 22 \(\text{μg/m}^3\) and between 12 and 26 \(\text{μg/m}^3\) for the \(\text{NO}_2\) and \(\text{PM}_{10}\) annual means respectively. \(\text{NO}_2\) levels in Nantes decreased 8 \(\text{μg/m}^3\) in the period between 2000 and 2010 according to Figure 1. The average mean annual concentration of \(\text{PM}_{10}\) in zone FR23A01 is 22 \(\text{μg/m}^3\) 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 56% (currently 53%) and by promoting cycling in the city centre. All of the measures outlined in section 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 Météropole, 2013). The effectiveness of the cycling-oriented measures in terms of emission reductions and impact on \(\text{NO}_2\) concentrations was not quantified and is not reported.
### Table 6. Summary of Cycling and Air Quality in Nantes

<table>
<thead>
<tr>
<th>Air Quality Metric</th>
<th>Nantes 2008</th>
<th>Nantes 2012</th>
<th>Limit Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO _ annual mean (μg/m³)</td>
<td>19</td>
<td>14</td>
<td>40 μg/m³</td>
</tr>
<tr>
<td>NO _ hourly exceedances (hours)</td>
<td>0</td>
<td>0</td>
<td>181-1200 μg/m³</td>
</tr>
<tr>
<td>PM__annual mean (μg/m³)</td>
<td>17</td>
<td>22</td>
<td>40 μg/m³</td>
</tr>
<tr>
<td>PM__daily exceedances (days)</td>
<td>20</td>
<td>20</td>
<td>356 &gt; 50 μg/m³</td>
</tr>
<tr>
<td>Mode Share</td>
<td>2008</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>Cycling</td>
<td>2.0%</td>
<td>4.5%</td>
<td></td>
</tr>
<tr>
<td>Private car</td>
<td>Unavailable</td>
<td>52%</td>
<td></td>
</tr>
</tbody>
</table>

#### Measures for air quality improvement

- **Summary of measures on road-traffic (2008-2014)**
  - 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, 2015)**
  - €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

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**4. SEVILLE**

**General features**

Seville is the capital and largest city of the region of Andalusiıa, 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 sub-tropical Mediterranean climate (Csa), 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 35.0% of the commute journeys made by car and 1.1% by bicycle (Eurostat, 2013). 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 infrastructures, 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 (COC, 2012). 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\_\_daily LV which is exceeded 40 days in station ES168A (Benimátez). 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\_\_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\_\_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\_\_ 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 NO₂ and PM₁₀ after 2020 (Junta de Andalucía, 2014).

**TABLE 7. SUMMARY OF CYCLING AND AIR QUALITY IN SEVILLE**

<table>
<thead>
<tr>
<th>Air Quality Metric</th>
<th>2006</th>
<th>2012</th>
<th>Limit Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO₂ annual mean – [μg/m³]</td>
<td>34</td>
<td>24</td>
<td>40 μg/m³</td>
</tr>
<tr>
<td>NO₂ hourly exceedances – (hours)</td>
<td>3</td>
<td>3</td>
<td>181.2 μg/m³</td>
</tr>
<tr>
<td>PM₁₀ annual mean – [μg/m³]</td>
<td>41</td>
<td>33</td>
<td>40 μg/m³</td>
</tr>
<tr>
<td>PM₁₀ daily exceedances – [days]</td>
<td>152</td>
<td>40</td>
<td>355 &gt; 50 μg/m³</td>
</tr>
</tbody>
</table>

**Mode Share**

<table>
<thead>
<tr>
<th>2006</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycling</td>
<td>0.5%</td>
</tr>
<tr>
<td>Private car</td>
<td>unavailable</td>
</tr>
</tbody>
</table>

**Measures for air quality improvement**

- Promoting non-motorised transportation modes.
- Developing and enhancing cycling in the city.
- Creating separate infrastructure for cyclists.
- Improving 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.

**Summary of measures on road-traffic (2006-2014)**

- Extension of cycling infrastructure [km]: 110 km
- Total budget for cycling (multi-annual, 2012): €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

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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 117 km² with a total population of 332,420 inhabitants in 2011 (NISG, 2011). The city is located in the northern fringe of the Thermaic Gulf and bounded by Mount Hortiatis on the south-east (Figure 1). The climate of Thessaloniki is determined by the sea, having a humid subtropical climate (Cfa) with mean temperatures and precipitation of 9°C and 71 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 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 (EPOCWM, 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 bicycle stands, 26 collection points and 6 subscription stations (DT, 2014).

**Air quality status**

The city of Thessaloniki is encompassed within the EL0044 air quality management zone (Oikismos Thessaloniki). In 2013 this zone did not comply with both PM₁₀ LVs: the annual LV was surpassed by 1 μg/m³ in station GR0018A (Agia Sofia) and the daily LV was exceeded 79 days in station GR0018B for the renewal of the passenger-car vehicle fleet (Vlachos and Lavdaki, 2004). In general, the average NO₂ 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 PM₁₀ in zone EL0044 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.
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 exception 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.

<table>
<thead>
<tr>
<th>TABLE 8. SUMMARY OF CYCLING AND AIR QUALITY IN THESSALONIKI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Quality Metric</td>
</tr>
<tr>
<td>NO$_2$ annual mean – [μg/m$^3$]</td>
</tr>
<tr>
<td>NO$_2$ hourly exceedances – [hours]</td>
</tr>
<tr>
<td>PM$_{10}$ annual mean – [μg/m$^3$]</td>
</tr>
<tr>
<td>PM$_{10}$ daily exceedances – [days]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mode Share</th>
<th>2006</th>
<th>2010</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycling</td>
<td>Unavailable</td>
<td>10%</td>
<td>Unavailable</td>
</tr>
<tr>
<td>Private car</td>
<td>Unavailable</td>
<td>55%</td>
<td>Unavailable</td>
</tr>
</tbody>
</table>

Measures for air quality improvement

Summary of measures on road-traffic (2004-2014)$^d$
- Implementation of a low emission zone.
- Construction and development of an underground transportation system (Metro Thessaloniki).
- 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).

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.

25
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\text{\textsubscript{2}} and PM\text{\textsubscript{x}}, 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 mode share, ranging from a modest penetration of

• **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 prevails. This scenario tries to reflect as much as possible the current situation of cycling in the urban centre. The respective local 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 removes 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 Moretusstule (Antwerp), Marylebone Road and Baker Street (London), Ioanii Tsimiski and Leoforos Nikis (Thessaloniki).

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 Moretusstule, 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 BELA05 (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 (GB0868AA), which drove non-compliance for the entire air quality management zones for the NO\text{\textsubscript{2}} limit values in 2012. The zone’s most important roads are Marylebone Road (A40), 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 (GR0088A), which is responsible for the non-compliance of the zone with the PM\text{\textsubscript{x}}, daily limit value. The zone is primarily commercial and residential, with important roads that connect the city east and westbound such as Egnatia Odo, Ioanii 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\textsubscript{x}), particulate matter (PM\textsubscript{x}) and black carbon (BC) 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\textsubscript{x}, PM\textsubscript{x} and BC in the studied areas. The highest NO\textsubscript{x} emission reductions are observed for London® followed by Antwerp, with the smallest reductions being in Thessaloniki. In the case of PM\textsubscript{x} emissions including BC, the highest reductions are observed for Antwerp. Adopting cycling investment strategies that produce a 23% increase in cycling mode share would reduce annual emissions of NO\textsubscript{x} and BC by 30% and 40%, respectively, in London. In Thessaloniki, annual emissions will increase by 30% for NO\textsubscript{x} and 20% for BC.

The observed modal shifts were obtained as a function of annual average daily flows in the studied zones of Antwerp, London and Thessaloniki, considering the cycling mode share reported by the city authorities (years 2010).

N\textsubscript{\textsubscript{10}} and N\textsubscript{\textsubscript{14}} correspond to the total mass of nitric oxide (NO) and nitrogen dioxide (NO\textsubscript{2}) emitted at tailpipe. Emissions are reported as NO\textsubscript{x}, because both NO and NO\textsubscript{2} suffer chemical changes in the atmosphere (i.e. it is sulfur oxidized to NO\textsubscript{2}), and both contribute to the formation of ground-level ozone. Concentrations are reported only as NO\textsubscript{x}, because it is the nitric oxide which produces health impacts.

The total emissions of black carbon in the laboratories/primary particle aerosol that is emitted mainly from combustion processes, with a ‘black’ light-absorbing aerosol that compose mainly from elemental carbon and is commonly known as soot (Klimont and Kupiainen, 2007).

The emissions of PM\textsubscript{x} include the emissions of BC.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3}
\caption{Annual average daily flows per vehicle type in the studied zones (2012)}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure4}
\caption{Annual emissions of (a) NO\textsubscript{x}, and (b) PM\textsubscript{x}, BC for the studied scenarios in London, Antwerp and Thessaloniki}
\end{figure}
On Local Air Quality

are associated to those cities in which the closed road has a savings from the displaced vehicles as a result of mode shift in each of the study scenarios.

As might be expected with the additional closure of a major road in the car free scenario (S2-CFS) in each of the study locations, high air quality improvements 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 PM₁₀ the annual mean is reduced by 0.3 μg/m³ for S1-TCS. The maximum reductions for PM₁₀ 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 those seen in Antwerp and so would continue be in infraction of the European limit values even with the cycling measures.

In Thessaloniki, the NO₂ 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. 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, BAU scenarios produces 866 DALY per 10,000 inhabitants due to cardiopulmonary diseases. The inclusion of cycling measures reduces the disability by 50% (383 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 747 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.

5. IMPACTS OF IMPROVEMENTS ON 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) 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 5. In the case of Antwerp, BAU scenario produces 866 DALY per 10,000 inhabitants due to cardiopulmonary diseases. The inclusion of cycling measures reduces the disability by 50% (383 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 747 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.

4. IMPACTS OF EMISSION REDUCTIONS ON LOCAL AIR QUALITY

Impacts have been assessed as to the differences in the concentration of nitrogen dioxide (NO₂), particulate matter (PM₁₀) 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 NO₂ target or PM₁₀ daily limits were registered in the respective air quality monitoring stations (Table 9). The NO₂ hourly limits and the PM₁₀ daily limits 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 concentrations of pollutants in the studied zones are located near high-trafficked roads (Plantin Moretusstraat, Marybelle Road, Ioannis 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 pollution 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 NO₂ and PM₁₀ limit values.

In the case of Antwerp, S1-TCS reduced the NO₂ annual mean by 6.5 μg/m³ and the annual mean for PM₁₀ 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 (16.0 μg/m³ for the NO₂ annual mean and 2.0 μg/m³ for the PM₁₀ annual mean). Reductions are higher with S2-CFS, which decreased the NO₂ the annual mean 12.6 μg/m³ and the PM₁₀ 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 NO₂ annual mean and 3.0 μg/m³ for the PM₁₀ annual mean. These are significant reductions, with a modal shift as specified in S1-TCS, does not bring about a sufficient reduction for compliance with the PM₁₀ annual limit value (40.0 μg/m³).

The reductions in air pollution concentrations 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 (Kneken et al., 2010). 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.
The objective of this chapter was to assess the effectiveness of cycling, as a measure intended to encourage modal shift away from 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\textsubscript{x}, PM\textsubscript{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 result 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-CFS) 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.

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; Kittschook 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 reduction or low-emission zones.

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 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;
- Complete 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 including the elderly, disabled, children, etc.), and reduce emissions from the remaining traffic such as public transport and delivery vehicles.

**RECOMMENDATIONS**

**6. CONCLUSIONS**

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;
- Complete 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) and economy and congestion-reducing, 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 improvement will vary from city to city and across the city itself with our analysis showing changes at the selected monitoring locations in NO\textsubscript{x} concentrations from 0.6 µg/m\textsuperscript{3} and changes in PM\textsubscript{10} concentrations from 0.3 µg/m\textsuperscript{3} to 1.4 µg/m\textsuperscript{3}. Although overall the changes in London and Thessaloniki were not large 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.
Cycling and Urban Air Quality: A study of European Experiences


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Rue Franklin, 28 1000 Brussels, Belgium Phone: +32 2 880 92 74 Fax: +32 2 880 92 75 office@ecf.com