LIFE11 /ENV/ES/584

AIRUSE

Testing and development of air quality mitigation measures in Southern Europe

TECHNICAL GUIDE FOR MITIGATION MEASURES FROM THE EXPERIENCE OF THE NORTHERN AND CENTRAL EUROPEAN COUNTRIES

REPORT 29

12/2016

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1. INTRODUCTION

This report describes the mitigation measures that may contribute to reducing nitrogen oxides (NOx) and particulate matter (PM) emissions from traffic, biomass burning and shipping. These are important sources in some or all the southern European cities studied in the AIRUSE project: Athens, Barcelona, Florence, Milan and Porto (AIRUSE, 2015). In addition, the interactions between urban air quality and climate change is summarised, highlighting where policies to reduce CO_2 emissions can led to an adverse impact on air quality. It draws mainly on the experience of northern and central European countries, but also includes assessments of the technologies available for reducing NOx emissions from road vehicles, and NOx and PM from shipping. Further detail of these mitigation measures is available on the AIRUSE website (http://airuse.eu/en/outreach-dissemination/reports).

The EU limit values for PM_{10} and NO_2 remain difficult to achieve in many cities due to several factors, most notably the increase in the number of diesel cars. Since these limit values were adopted the evidence of the health effects of these pollutants, and fine PM ($PM_{2.5}$), has grown. The World Health Organization guidelines (WHO, 2005) for PM are lower than the EU limits and that the European Environment Agency has estimated that over 90% of the EU population is exposed to concentrations exceeding the WHO guideline value for $PM_{2.5.}$ In addition, WHO, following a review of the health effects of NO_2, concluded that adverse effects have been found at concentrations at or below the current EU limit values (WHO, 2013).

The failure of the EU emissions standards to reduce real-world NOx emissions from diesel vehicles, the higher proportion of primary NO_2 in the diesel exhaust and for PM the relatively large emissions from increased urban vehicle fleets and the unregulated non-exhaust vehicle emissions all made achieving the limit values difficult. Road traffic is an important local source of PM, but comprises exhaust and non-exhaust emissions and resuspension of road dust. In some cities non-exhaust emissions of PM may be more important than exhaust emissions, and as more vehicles are fitted with diesel particle filters the non–exhaust contribution will increase in importance. Research is required to understand how these emissions may be controlled.

For NOx emissions it was anticipated that vehicles meeting the most recent emission standards (Euro 6 / VI) would have significantly lower emissions than vehicles meeting earlier standards, but the evidence suggests that average real world emissions from early Euro 6 diesel cars are, on average, seven times the type approval limit (ICCT, 2014), and that some Euro VI buses still have high emissions (Carslaw, 2014). Conventional gasoline car emissions seem to be generally well controlled, but less is known of the real world performance of direct injection gasoline cars and hybrid vehicles. The introduction of in-service portable emissions measurement systems, proposed from 2017, should ensure that real-world emissions are better controlled. The introduction of this important measure is vital, should have a low conformity factor (i.e. the ratio of the emissions on the road to the emissions measured under the laboratory tests) and should not be delayed.

The more detailed reports on which this technical guide is based are available on the AIRUSE website (www.airuse.eu).

2. MEASURES TO REDUCE TRAFFIC EMISSIONS

2.1. Low emission zones

There are over 200 low emission zones (LEZs) in European cities, excluding the very large number of LEZs in small towns in Italy. These vary from small scale LEZs covering a few streets to the London LEZ which covers over 1,500 km^2. Most operate all the time but some are restricted to specific seasons, times of the day or days of the week. Most LEZs in Northern Europe only restrict heavy duty vehicles. Some only apply to buses. In Italy many of the LEZs also restrict two–wheeled vehicles. In German LEZs light duty vehicles are also restricted, and LEZs in other countries are beginning to follow their lead.

Enforcement of LEZs ranges from automatic number plate recognition (London) to a windscreen sticker with manual enforcement (German LEZs). For large LEZs affecting many vehicles automatic enforcement may be appropriate, however for small LEZs only affecting buses, manual enforcement would be appropriate. An added incentive to comply would be for the vehicle driver to be given penalty points on their driving license, as happens in Germany.

Evidence of the efficacy of LEZs is unclear due to the confounding effects of meteorology, natural changes in the vehicle fleet and policy changes at the national, regional and EU levels (e.g. the introduction of zero sulphur automotive fuels). The clearest evidence is from German LEZs which apply to both light and heavy duty vehicles. These may have resulted in a small, possibly a few percent, reduction in long term average PM_{10} and NO_2 concentrations.

Elsewhere the picture is more mixed with no effects of LEZs generally being observed. There is some evidence that LEZs may result in larger reductions in the concentration of carbonaceous PM, which may be beneficial for public health. A higher proportion of this component of PM comes from vehicle exhaust and therefore the effect of changing the fleet composition is easier to detect. In many cities there is a large contribution from regional scale pollution, including secondary PM. Local measures can only influence local emissions, although these do affect air quality elsewhere. Therefore it is important that city authorities undertake source apportionment studies at several roadside locations to identify the potential contribution that the LEZ can influence.

There is some evidence that the most recent Euro 6 cars have lower emissions than previous generations In the future, when real-world testing of NOx emissions is mandated, emissions are likely to fall further and stringent LEZs may have a role in improving air quality for a number of years until the majority of the vehicle fleet meet these standards. Alternatively, a more radical solution would be ultra-low emission zones in which only battery or plug-in hybrid electric vehicles are permitted. Sales of electric cars are starting to grow across Europe, albeit still a small fraction of new cars sold, and electric buses and urban delivery vehicles are becoming viable. As discussed later the widespread adoption of electric vehicles would require long term support from national or regional Governments. The advantage of these vehicles is that they have no exhaust emissions and are more efficient in urban driving conditions than internal combustion engines. Provided the power stations are outside cities there could be a significant reduction in emissions within the LEZ. For the greatest environmental benefit the electricity should be generated from non-combustion renewable energy sources such as solar or wind power.

A national, or possibly an EU wide, LEZ framework is recommended as this would reduce the cost, time and effort in setting up LEZs, make communicating the entry criteria easier and increase industry and public acceptance. This should be sufficiently flexible to allow city authorities to address the local issues. There is also a need for certification of retrofitted abatement equipment such as DPF and selective catalytic reduction (SRC). While EU certification schemes are under development the timescale for their publication is unclear.

Long term (several years) air quality monitoring should be undertaken before and after introduction of a LEZ. The monitoring locations are very important in determining the effectiveness of the LEZ, and should be carefully selected. The pollutants to be measured also need careful consideration depending on the aim of the LEZ. In cities where the exhaust emissions of PM from local traffic contribute relatively little to ambient concentrations it may be preferable to measure carbonaceous particles as well as the more conventional mass based particulate matter metrics (PM_{10} and $PM_{2.5}$). This may make quantifying the air quality benefits of a LEZ easier.

The financial, socio-economic and political impacts of the LEZ also need to be considered at the planning stage. When estimating the cost of the scheme the impacts on the local authority of implementation, operation, enforcement and monitoring, the vehicle operator/owner of upgrading vehicle(s), and the societal benefits should be considered.

2.2. Promoting electric vehicles, hybrids and gas vehicles

Currently there are few electric vehicles, hybrids or gas vehicles in use in the EU. Experience suggests that this is unlikely to change until the cost of these vehicles is at least equivalent to conventionally fuelled vehicles, and even then it will take some time for consumer acceptance of these technologies to grow. It is only in those countries with a long and consistent incentive programme i.e. Italy (gas), Norway (EVs) and Japan (HEVs) that have achieved a significant (i.e. greater than around 5%) market share of non-conventional vehicles. Experience from California suggests that mandating a fixed market share can be problematic.

Norway has the highest proportion of battery electric cars in the world's (12.6% of new car sales in 2014, ICCT, 2015a). In the 1990s the Norwegian Government introduced the first incentives for these vehicles. The policy has been to make electric vehicles as attractive as possible, and incentives have been added one at a time until the market finally responded with increased sales. The wide range of incentives include exemption from vehicle registration tax, VAT (25% on the new car price), parking fees and road tolls, reduced company car tax and annual car tax, and access to bus lanes. The price difference between a new battery electric vehicle and a comparable gasoline car can be as low as €1,000. The access to bus lanes is thought to have been particularly important near majority cities with high congestion, due to the time savings.

Electric and gas vehicles require an appropriate charging/fuelling infrastructure. This already exists for gas vehicles in Italy and Germany, is growing for electric vehicles across France, but both outside these countries the infrastructure needs further development. In 2014 the EU agreed the Directive on the deployment of alternative fuels infrastructure(2014/94/EU), which provides common technological specifications for recharging and refuelling points and requires Member States to set binding targets for the development of recharging/refuelling stations.

Plug-in electric cars primarily run on electricity but have a small international combustion engines to extend the vehicle's range. Experience suggests that the range of electric vehicles is sufficient for the vast majority of journeys which are typically re-charged at home or work. Plug-in electric vehicles are useful to overcome the problems associated with the inconsistent density of re-charging points, particularly for longer journeys until the network expands. Fast charging stations are necessary to provide a quick solution at motorway service stations, in public car parks, and at selected major road junctions. The private sector is beginning to develop this infrastructure albeit generally with the support of public funds.

New systems for charging for the electricity used are being developed, so that drivers can effectively monitor their motoring fuel costs. However, roaming systems, similar to those used for mobile phones, for charging for the electricity used at public charging points, need to be developed. In addition, motorists should be able to pay directly for the electricity at the charging point without pre-registering.

Local governments can provide incentives such as the use of bus lanes and access to restricted areas, preferential parking spaces and/or free or reduced parking rates. Local government also has an important role to play in promoting these vehicles, and educating the public on the benefits and performance characteristics of these vehicles, such as by providing electric vehicle test drive events to increase pubic acceptability, and supporting car clubs that use electric vehicles.

However, in most cases these measures are unlikely to be sufficient to result in a significant increase in battery, plug-in electric vehicles or gas vehicle use until the initial vehicle cost is reduced thorough tax incentives or direct subsidies. As noted above, restricting access to LEZs to these vehicles, may provide an additional incentive for car sales to increase.

2.3. Discouraging diesel cars

Most European Governments have promoted policies that support the purchase or use of diesel cars, by providing fiscal incentives for cars with lower CO_2 emissions. These have replaced previous tax systems based on weight or power. There is evidence that these incentives have reduced real world CO_2 emissions but probably only marginally, while at the same time exacerbating poor urban air quality, making achievement of the EU ambient air quality limit values more difficult to in many cities.

The average gap between the official data and real world driving CO_2 emissions data has increased from 8% in 2001 to 40% in 2014, with the gap larger for diesel cars (42%) than gasoline cars (37%). Hybrid cars have performed worst with approximately 50% higher CO_2 emissions on the road than the official figures. This is to some extent because the test cycle is not as demanding as real driving conditions but is mainly due to the automotive industry using flexibilities and tolerances in the type approval test procedure to minimise the official CO_2 emissions. These are thought to be responsible for about 75% of the gap (ICCT, 2015). The official figures show a significant reduction in CO_2 emissions; from 170 g/km in 2001 to 123 g/km in 2014 (27 percent reduction). However, using real-world data, the actual reduction has been from 184 g/km in 2001 to 168 g/km in 2014 (8 percent reduction).

There have been few studies explicitly investigating the reasons for the increased number of diesel cars sold in different European countries. Those that exist generally pre-date the introduction of the mandatory new car CO_2 targets which are likely to have influenced consumer choice since 2008. Some economic models suggest that fuel price and annual car tax may be the most important determinants of diesel car purchase, while other studies show that steeply graduated purchase / registration tax, possibly part of a feebate system, is more important.

Each country uses a different combination of taxes for both private and company cars,, and these tax regimes are often changed, making identifying the influence of a single tax difficult. Many of the studies have relied on economic models to identify the effect of changes in taxes, but these do not take account of the wide range of non-economic influences on car purchases.

Diesel is cheaper than gasoline in virtually all EU countries and together with better fuel economy provides an incentive for consumers to purchase diesel cars. However, there is a significant difference in the new diesel car market in individual European countries, and no simple relationship with either pump price or fuel taxation. It appears that there are other economic and political influences that affect consumer choice. For example, The Netherlands has the lowest proportion of new diesel cars in Western Europe (27%), despite having one of the largest gasoline / diesel price differentials (diesel is approximately 20% cheaper). This is thought to be due to the Dutch refineries configured to produce more light than middle distillates, favouring the production of gasoline over diesel. As a result Dutch tax policy has, over many years, penalised diesel cars. As far back as 1998 the National Environmental Policy included a target to reduce the share of diesel vehicles from 11% in 1998 to 5% in 2010 (in reality it was 20% in 2010). The car taxation system changed in 2008 to become primarily CO_2 based, but with a penalty for diesel cars. The Dutch market share of new diesel cars has remained in the range 20% to 28% from 2001 to 2014 (ICCT, 2015).

It has been suggested that the volume of diesel car sales is correlated with employment in the automotive industry, except in those countries where there is a large export market. In countries with indigenous car manufacturing the industry have been able to use their influence with governments to get favourable fiscal treatment for these vehicles (Cames & Helmers, 2013). The European motor industry have invested heavily in the development of diesel engines, and it is one of only two markets where there are significant sales of diesel cars , the other is India (ICCT, 2015).

The French automotive industry, for example, was an early investor in diesel engines, and the country has one of the largest new diesel car markets in Europe. Conversely in Greece there is no automotive manufacturing industry, and therefore the industry has little influence over Government policy, and it had for many years the lowest diesel market share. This was due to a ban on diesel cars in the two main cities. Since the Greek ban was lifted in November 2011 there has been a rapid increase in diesel car sales. Diesel car sales increased from 4% in 2010; to 10% in 2011 and 40% in 2012. By 2014 over 60% of new cars were diesel (ICCT, 2015).

However banning diesel cars is politically difficult as illustrated in London recently. The Mayor of London proposed banning all pre-Euro 6 diesel cars, i.e. essentially those manufactured before 2015, from the London ultra-low emission zone in 2020. Following media objections he revised the policy within days. It seems unlikely that a ban would be acceptable in countries with a significant automobile manufacturing presence.

2.4. Eco-labels

Providing easy to understand information on a car's emissions performance using an 'eco-label' could help consumers differentiate the emissions of different models. A successful eco-label could also be used to define the entrance criteria for LEZs, and be linked to vehicle taxes, such as an emissions annual tax.

Eco-labels to promote products with a 'low' environmental impact were first established several decades ago in Germany (Blue Angel) and Sweden (Nordic Swan). In 1992 the EU launched its eco-label system. The aim of these schemes is to independently verify individual products against pre-defined criteria. A secondary aim is to stop inaccurate advertising and marketing claims about products.

So far none of these eco-labels have included cars. This may be because EU legislation requires all car manufacturers to provide labels for new cars that describe the vehicle's CO_2 emissions and fuel consumption (Directive 1999/94/EC as amended). Some Member States have gone beyond the requirements of the Directive and also require labels for vans (Denmark) and used cars (UK). In general these car labels are based on the household appliance energy label which is widely recognised by consumers. The labels provide either relative or absolute information. Relative labels compare a particular model with other cars in the same class and an absolute system compares all vehicles irrespective of size or type. Absolute classification systems are likely to be more effective than the relative system. In a relative system a high emitting car could be rated as low emitting when compared to other high emitting cars and given an 'A' rating, and in the past a car model has been rated A, B or C depending on the national scheme. This adds to consumer confusion. In an absolute system a car with low emissions would be 'A' rated whatever its size or type.

There is no similar EU legislation requiring the labelling of cars based on NOx and PM emissions because of the mandatory limit values for these pollutants.

It is not easy to directly compare the emissions of local and global pollutants in a single rating system. As discussed later (section 5) there is no common metric for comparison and the effects occur over different temporal and special scales. Therefore simply comparing the emissions in g km^{-1} is not appropriate. For CO_2 life-cycle or fuel-cycle emissions are most appropriate; while for local air quality only the exhaust emissions should be considered.

Allgemeiner Deutscher Automobil-Club (ADAC), Germany's largest automobile club, has provided an environmental ranking and labelling scheme for new and used cars for over a decade. It tests more than 150 of the most popular car models each year using a chassis dynamometer. Emissions are measured over the current official test cycle (NECD), the proposed new test cycle (WLTP) and their own motorway cycle. Dual fuel gas vehicles are tested only when running on gas, if technically possible. Plug-in hybrids and electric vehicles have adapted tests which take account of the electric power used and charging losses. The air quality pollutant (AQP) emissions are considered separately to the CO_2 emission, and are published on the car's eco-label. As ADAC undertake tests independently of the manufacturer the test conditions and chassis dynamometer settings are unlikely to be optimised for low emissions, and therefore may more accurately reflect reality.

The Belgium Ecoscore system ranks light-duty, heavy-duty and two-wheeled vehicles using a a well-to-wheel emission ranking system. This scheme uses official type approval data to classify vehicles according to their CO_2 and AQP exhaust emissions and engine noise, over a well-to-wheel cycle. This system is likely to be less able to accurately differentiate between car models, due to the gap discussed previously between real world and type approval emissions data and the emphasis on life cycle emissions.

Developing a robust ranking procedure for motor vehicles is not trivial. There are a very large number of models on the market, and a lack of robust data. An effective new eco-label system needs to provide information on as many models as possible based on real world emissions (and fuel economy) data rather than relying on the official, but misleading type approval data. With portable emissions testing it is possible to independently collect this data, and with international collaboration between interested bodies, such as city administrations, it may be possible to collect a sufficiently large database of the most popular models sold in the EU for a robust eco-label system to be developed.

It is recommended that separate labels for passenger cars, light commercial vehicles (vans), and possibly also two wheeled vehicles are developed. These labels should be for both new and used vehicles and be based on exhaust NOx and PM emissions and well-to-wheel CO_2 emissions, with no weighting in favour of a single pollutant.

Initially an Eco-Label could be based on type approval data with average conformity factors used to convert to an 'equivalent' real world emission for generic fuel types / Euro classes. This simplistic approach would discriminate against those models that perform better than the average. In the longer term it would be preferable for the car eco-label to be based entirely on portable emissions monitoring system data. The 'well to tank' CO_2 emissions should be used to enable ICEs and electric vehicles to be compared on a similar basis.

The label should be based on the domestic appliances label using an A to G rating with additional information on running costs as there is evidence that consumers prefer cost data to fuel consumption information. The criteria need to be updated on an annual basis by allocating a fixed percentage of models to each band. Long-term public education is required to support the eco-label.

2.5. Measures to reduce NOx emissions from road vehicles

There is little robust evidence that real world NOx emissions from diesel vehicles declined from when the Euro emission standards were first introduced in the early 1990s until the Euro 6 (light duty) and VI (heavy duty) standards were introduced from 2014 and 2013 respectively. PM abatement has increased the proportion of NO_2 in the NOx emitted from vehicles. Both these factors, together with the increasing proportion of diesel cars in the vehicle fleet, have contributed to the difficulty in achieving the EU ambient NO_2 limit values in many cities across Europe.

There is some in-service evidence that NOx emissions for Euro 6 cars vehicles are typically lower than from earlier generations, but they remain on average well above the type approval emission limit. Portable emissions measurement system testing shows that there is a very large variation in emissions depending on the test conditions and vehicle. There is concern that Euro 6 cars using exhaust gas recirculation (EGR) on its own will have high NOx emissions during motorway driving, and that cars using selective catalytic reduction have high NOx emissions at low exhaust temperatures, such during cold starts and in congested traffic. The introduction of real driving emissions (RDE) tests for Euro 6c cars is designed to address this issue.

The same picture can be seen with NOx emissions from early generations of HDVs fitted with selective catalytic reduction (SCR). These devices were not very successful at reducing real world NOx emissions especially, but not exclusively, at low vehicle speeds. Although some Euro IV and V HDVs have been shown to have low real world NOx emissions under all driving conditions, good abatement of the emissions from these vehicles is not universal. The introduction of the ‘not to exceed’ emission standards, designed to capture heavy duty vehicle emissions under conditions excluded from the test cycles, and RDE tests, has resulted in Euro VI NOx emissions being low, at least for long distance trucks. There remain problems, however, with emission from urban buses and distribution vehicles. The SCR does not operate when the engine is cold, and it can take many minutes to warm up, and following periods in congestion the engine-out temperature can also fall to below the SCR operating temperature.

Combined NOx abatement systems that exploit the advantages of different abatement systems are likely to be used increasingly in the future. Sophisticated EGR combined with SCR enables lower emissions under low loads. Alternatively, low NOx traps combined with SCR allow the NOx to be trapped under cold conditions and released when the SCR is warm. Systems that combine SCR with diesel particle filters are also commercially available.

For light duty vehicles the new more stringent test procedure (WLTP) and associated real driving emissions tests to be introduced with the Euro 6c standard from 2017/2019 are likely to reduce in-service NOx emissions. It is important that the introduction of these measures is not delayed, and that the agreed conformity factor is as low as reasonable. As these standards will only apply to new vehicles it will be a number of years before the benefits are observed at ambient monitoring stations.

The RDE requirements for heavy duty vehicles need to be modified to ensure that NOx emissions from urban vehicles are low under all driving conditions.

Retrofitting urban buses and distribution vehicles with low NO_2 selective catalytic reduction traps (SCRT®) offers a cost effective method to significantly reduce NOx, NO_2 and PM emissions and could have an important role to play in achieving the ambient EU limit values in locations where these vehicles are a major source.

2.6. Reducing the re-suspension of road dust

The contribution of non-exhaust emissions to ambient PM_{10} concentrations varies significantly depending on a range of factors including the meteorological conditions and the amount of road dust accumulated. In colder climates the use of studded tyres results in a high surface dust loading due to the abrasion of road surfaces, whilst in warmer countries the low precipitation rates also leads to high dust loading. In addition, the Mediterranean countries are more often exposed to African dust events than central or northern Europe.

Various estimates suggest that road dust can contribute a similar amount as exhaust emissions to traffic related emissions of PM, but in some northern European countries where studded tyres are used it can be much higher (Thorpe and Harrison, 2007). Several studies have also identified paved road surfaces around industrial and construction sites as locations with higher than normal dust loadings.

There have been a number of studies of the impact of street sweeping and washing and the application of dust suppressants to reduce PM_{10} concentrations in Europe. Most have only covered a small area for a short period of time. The road sweeping studies have generally shown no effect. The one widespread and long term study, undertaken in the United States, showed benefit of road sweeping in reducing road PM_{10} emissions but it required all roads over a large area to be swept.

Road washing, either alone or in combination with sweeping, generally shows a reduction in PM_{10} concentrations where there are high dusts loads. This is probably due to the water reducing the release of PM_{10} into the air rather than removing dust from the road surface. It has been suggested that to reduce road dust emissions in hotter climates, such as in southern Europe, light but frequent moistening of roads might be more effective than intensive occasional cleanings used in northern Europe.

There is some evidence that vacuum road sweepers can increase local PM_{10} emissions. To overcome this some manufacturers are now using filter bags to reduce the PM_{10} emissions from the air outlet of the sweepers. New technologies are being developed to improve the removal of PM_{10} from road surfaces and reduce ambient PM concentrations, and there is evidence that some sweepers perform better than others. Further real world tests of different sweepers, as well as tests over a large area are required to increase understanding of the effects of street cleaning on PM_{10} emissions and whether it can play a role in reducing exceedences of the daily PM_{10} limit value in Mediterranean countries..

The effectiveness of chemical dust suppressants at reducing road dust emissions has been investigated in European regions with relatively wet climates (Sweden, Norway, Finland, Netherlands, UK, Germany, Austria and North Italy). In these areas the application of dust suppressants has been shown to be effective at reducing the daily average PM_{10} concentrations and the numbers of days when it exceeds 50 µg m^{-3}, but only where there were high dust loads and the road dust contributes a significant proportion of the daily average PM_{10} concentration. For the best results dust suppressants need to be applied over a wide area using a 10 g m^{-2} coverage on paved roads. On unpaved roads, and industrial and construction sites a higher application rate is needed (100-200 g m^{-2}). The effects of dust suppressants may last for several days after application, but are dependent on the traffic flows, weather conditions and road surface characteristics.

In the Mediterranean region, there is no evidence of effectiveness of dust suppressants, while road washing has been shown as best measures to reduce road dust emissions in paved and unpaved roads.

Calcium magnesium acetate (CMA), potassium formate, calcium chloride ($CaCl_2$) and magnesium chloride ($MaCl_2$) appear to be equally effective but CMA and potassium formate are preferred as they are less corrosive and more biodegradable in ground water than the chlorides.

However, no statistically significant reductions in PM_{10} or $PM_{2.5\text{-}10}$ concentrations were found following the application of dust suppressants in a southern European city (AIRUSE, 2015). This is thought to be due to the high solar radiation drying the road surface rapidly and thus reducing the efficiency of the suppressant.

3. MEASURES TO PROMOTE CLEANER BIOMASS COMBUSTION

3.1. Domestic Biomass Combustion

The AIRUSE project has found that biomass burning is often the second most important source of PM in southern European cities after traffic (AIRUSE, 2015). Vehicle exhaust PM emissions are declining with the increasing use of diesel particle filters but emissions from wood burning are growing. There is evidence that the switch to domestic biomass burning is giving rise to air pollution episodes during the winter in a number of European cities.

Wood, including wood waste, is the largest source of renewable energy used in Europe and between 2000 and 2013 the use of biomass for energy doubled in Europe. In some Scandinavian and Baltic countries biomass already contributes almost one third of the energy consumed. Climate change mitigation policies which favour the use of renewable energy is one reason for the growth in domestic wood combustion. Other reasons include the cost of fossil fuels and public perception that wood is a ‘green’ fuel. In addition, there is some evidence of a rise in so called ‘recreational burning’ for aesthetic reasons.

Emissions of PM and benzo(a)pyrene from residential biomass burning have increased over the last decade and ambient concentrations are particularly high where biomass burning is widespread. Modern automatic pellet and wood chip appliances are significantly more energy efficient and have lower emissions than traditional fireplaces and wood log stoves, but most residential biomass burning is likely to take place in inefficient and polluting open fireplaces or simple wood stoves.

Emissions from these appliances are not regulated in most EU countries. Only in the Nordic and Alpine countries, where domestic wood burning is most widespread, have emission limits been adopted into national legislation. EU emission limits have been agreed for small scale space heaters and boilers from 2022 and 2020 respectively. These limits are less stringent that those in adopted in Germany. In addition, the burning of non woody biomass is excluded from the EU requirements despite the burning of this material being particularly polluting.

To reduce emissions from domestic biomass combustion as soon as possible may require national/regional/city authorities to require new appliances to meet the EU limits ahead of the mandatory requirements, or to link fiscal incentives to appliances that meet the standards. Alternatively fiscal incentives could be linked to the best practice benchmarks contained within the EU regulations. This would provide a clear incentive for manufacturers to invest in developing cleaner technology.

The typical lifetime of biomass burning appliances is likely to be several decades. Therefore legislation affecting new appliances will only be effective when a large number of new appliances are sold each year. As there is already air pollution resulting from the use of these devices, emissions from existing appliances need to be reduced. Transitional arrangements, as in the German legislation, could be introduced to require the gradual replacement of the oldest devices over the next decade or so. National and regional governments could support voluntary replacement programmes. Financial incentives may be necessary to assist with the capital cost.

It may be appropriate to ban the combustion of biomass in open fireplaces and simple wood burning stoves in areas where there are high PM concentrations, particularly when pollution episodes are forecast. This, however, may meet with consumer resistance because of the emotional attachment to residential wood burning, and should not apply to households where biomass burning is the only source of heating.

Only certified wood pellets meeting high quality specifications should be permitted to be sold. For wood logs and chips suppliers of these products should be only permitted to sell seasoned wood with a specified limit on the moisture content. The residential burning of wood treated with preservatives and surface coatings such as wooden furniture should be banned as these contaminants increase the metal content of the PM emission.

There is a need for independent and authoritative advice for members of the public to fully understand the impact of different types of biomass combustion systems and fuels on air quality and human health. Whilst this is important for those seeking to invest in a new system, it is possibly of greater importance for those that have an existing appliance. Few people have been taught the factors that affect emissions and how to minimise them. This is especially important for the control of emissions from manual devices. Consumer advice should include using commercial fire lighters or a small amount of newspaper to light the fire; not to use the appliance as a waste incinerator; maintain good control of the air flow (where possible), maintain the appliance according to the manufacturer’s specifications; clean it regularly; and have the chimney professionally swept annually. Fuel should be stored under cover to keep it dry. In addition, the thermal insulation of homes should be improved to reduce wood consumption and the associated emissions.

3.2. Combustion of Agricultural Residues

The other major anthropogenic source of PM emissions from biomass combustion is from the open burning of agricultural wastes, such as the burning of stubble from cereal crops. This practice has declined in many EU countries in recent decades. According to the European Environment Agency the amount burnt fell by 84% between 1990 and 2012. However, the practice is still widely used in parts of southern Europe. Large scale agricultural burning affects air quality over large areas. When poorly managed it can result in the large scale burning of vegetation, including the unintended destruction of forests.

The only mitigation measure to reduce emissions is to ban the practice. The United Nations Environmental Programme and the EU Common Agricultural Policy support this. In reality Member State allow exemptions in many areas. It is important that Member States understand the air quality consequences of wide scale burning of residues in fields and farm advisory services educate farmers on this issue. In addition, Member States should provide fiscal and other support for the development of markets for agricultural wastes.

4. MEASURES TO PROMOTE CLEANER SHIPPING

Ship emissions can make a significant contribution to air pollution in populated coastal areas and to the formation of secondary pollutants such as ozone and sulphate aerosols further inland. These emissions are currently poorly controlled. Emissions from land-based combustion plant greater than 50MW have been controlled at the EU level for almost 15 years, yet many ships have uncontrolled engines with a higher combined rating. Abatement measures exist and have been demonstrated for use on ships.

Emissions of sulphur oxides have started to be controlled and there is some evidence that ambient concentrations of sulphur dioxide have reduced as a consequence of MARPOL, the International Marine Organisation (IMO) agreement on controlling pollution for ships, and EU restrictions on the sulphur content of marine fuels used in ports. There are two sulphur emission control areas in northern Europe covering the Baltic Sea and the North Sea (including the English Channel) where sulphur emissions are more tightly controlled. There is a case for designating the Mediterranean Sea a sulphur emission control area but it is likely to be politically difficult to get agreement among all nations with a Mediterranean coastline. From 2020 the sulphur content of marine fuel will be reduced throughout the EU, and therefore a significant reduction in emissions will occur anyway. However due to the anticipated increase in shipping, emissions may grow in the future in the absence of further control, and therefore a sulphur emission control area within the EU territorial waters may be the best pragmatic solution.

The sulphur content of marine fuels will reduce globally to 0.5% in the next decade; however this is two orders of magnitude or more higher than that permitted for land-based transport. Low sulphur fuels enable catalyst based abatement systems to work most effectively. If IMO continues to allow wet scrubbers to be used as an alternative to reducing the fuel sulphur content controlling NOx emissions is likely to be difficult.

There are no international limits on PM emissions from ships, although measures to reduce sulphur emissions also reduce PM emissions. No specific PM abatement technology is used on ocean going ships.

The IMO has agreed NOx emission limits for new and reconditioned ship engines. Vessels meeting the most stringent limits are, however, only required for nitrogen emission control areas, and there are currently none in Europe and emissions may increase in Europe in the future. If a nitrogen emission control area was designated in Europe it could still take several decades for virtually all ships to comply due to the long life of many marine engines.

There are a number of strategies to reduce air emissions from ships. They can broadly be divided into fuel quality improvements, alternative fuels, engine improvements, after-treatment, operational changes and market incentives. The adoption of many of these techniques is likely to be driven by the need to reduce fuel consumption. If significantly less fuel is used there will also be air quality benefits. There is a huge variation in energy consumption between ships with the best being about twice as efficient as the worst due to new ships' technical improvements, operational practices, and size differences.

The international shipping industry is highly competitive and very cost driven, and the financial incentive to adopt new technologies and practices is dependent on marine fuel prices. These have dropped by approximately one third between December 2014 and December 2015 (Bunker Index, 2015). Currently, there is little, if any, incentive, to invest in fuel economy measures.

There are a wide range of measures available to reduce AQP emissions from ships, but their adoption is likely to be driven by legislation. Due to the international nature of shipping, regulations need to be agreed either within the EU or IMO and the adoption of regulations within these institutions is a long slow process. This includes the designation of emission control areas which have to be agreed by IMO.

There are some local measures which can be introduced to reduce emissions. Ports can invest in shore based power to reduce AQP emissions from berthed ships, emissions differentiated port and fairway dues can used to encourage investment in emission abatement, and local restrictions can be introduced. For example the Swedish Maritime Administration introduced an emissions graduated fairway dues scheme to provide an incentive for the shipping industry to invest in low NOx technology. Currently the reduction in fee starts at 6 g kWh^{-1} reaching a maximum reduction at 0.4 g kWh^{-1}; vessels below 0.4 g kWh^{-1} are exempt. This emission level is well below the most stringent IMO limit and specifically aims to provide an economic incentive for ship owners to install selective catalytic reduction for NOx emission control of auxiliary engines.

The World Ports Climate Initiative (2015) has developed an Environmental Ship Index to classify vessels based on their sulphur oxide and NOx emissions. By June 2015, 27 ports, mainly in northern Europe but also in Asia, North America, and the Middle East, were using this index to set graduated ports fees. A number of ports in northern Europe, Portugal, and elsewhere also reduce port dues for vessels with a Green Award certificate. This is an independent certification scheme subject to annual verification and is valid for three years.

The larger Swedish ports also differentiate their port dues on the basis of their own environmental criteria. In Gothenburg, for example, the dues are based on the Environmental Ship Index and the Clean Shipping Index. There is an additional discount for LNG ships.

In 2007 Norway introduced a tax on NOx emissions from ship engines above 750 kW. The tax is applied to ships within Norwegian territorial waters, but for Norwegian registered vessels it is applied to emissions within 350 nm of the Norwegian coast. Voluntary agreements between the Norwegian Government and companies in the off-shore sector exempt them from the tax for three years provided they make payments to a NOx fund.

Venice Blue Flag is a voluntary agreement between the Municipality of Venice, the Harbour Master, the Port Authority and cruise operators that sets additional controls on the sulphur content of fuels used in the Venice Lagoon to improve air quality in the city.

5. MEASURES WITH CO-BENEFITS FOR AIR QUALITY AND CLIMATE

Policies to reduce climate change and improve urban air quality have typically been considered in isolation, with more prominence given to the mitigation of climate change than improving urban air quality over recent years. This is despite many of the same pollutants affecting both environmental issues. The emission of the traditional AQPs either directly, or indirectly as a result of atmospheric chemistry, affects the concentrations of several climate pollutants; while climate change affects the ambient concentrations of the AQPs. Some pollutants, such as ozone (O_3) are both an AQP and a greenhouse gas (GHG). Black carbon, an important component of PM from diesel vehicles has a positive climate forcing effect; while the organic carbon from biomass burning has a negative effect. The interactions are complex with the AQPs both enhancing and mitigating global warming.

Comparing air quality and climate change impacts is challenging because there is no common metric available for comparison. For climate change, it is important to consider fuel cycle or life cycle emissions, while for air quality the location and altitude of emissions are of prime importance. The impact of a tonne of NOx emitted at ground level is very different to the same amount emitted from a tall stack. For CO_2 the location of the emission is unimportant. In the long term, large reductions in both the AQPs and greenhouse gases (GHGs) are needed to minimise climate change and improve public health. Priority should be given to measures where there are clear co-benefits such as energy conservation measures.

Switching from fossil fuels to renewable, non-combustion, fuels offers a huge potential for co-benefits. However the main renewable fuels used in Europe are solid biomass and liquid biofuels. The use of these fuels is not always beneficial for mitigating climate change or improving urban air quality. Indirect GHG emissions occur from land use changes when energy crops are grown on previously uncultivated land, and there can be a conflict with food production. In addition, there can be higher emissions of PM from the combustion of solid biomass, and NOx and organic compounds from biofuels depending on the blend with conventional transport fuels. Used appropriately, with end-of-pipe abatement, these fuels may be acceptable in the medium term.

Many of the options that are likely to be important in the longer-term to mitigate climate change (e.g. increased use of electricity for transport and heating) result in a shift of emissions from the point of use to that of fuel production. In terms of urban air quality this is likely to be of benefit, provided the majority of the electricity production uses clean renewables such as solar and wind power or takes place outside urban areas. Thus, in the long term, there are likely to be co-benefits for both urban air quality and climate change.

Many EU governments have policies that have inadvertently led to the deterioration of urban air quality. These include car taxation based on CO_2 emissions and fuel taxation that favour diesel over gasoline. These measures have led to the increasing share of diesel cars. The adverse effects have been discussed previously in this report. Similarly, fiscal incentives for biomass burning, without good PM control, have led to increasing AQP emissions. Simple, but misleading, public education campaigns have resulted in many people believing that both diesel and biomass are ‘cleaner’ than their alternatives.

To reduce emissions from road transport requires a large shift to electric vehicles, which are more efficient in urban driving conditions than internal combustion engines, and have no exhaust emissions at the point of use, coupled with an increasing proportion of renewable electricity. These vehicles should be prioritised for fiscal incentives to increase their market share, and there should be a move away from graduated CO_2 taxation of passenger cars based on misleading 'official' CO_2 emissions (which are on average 40% higher than when driven on the road).

Emissions of PM and benzo(a)pyrene from residential biomass burning have increased over the last decade as policies to promote renewable energy have taken effect. Ambient concentrations are particularly high where biomass burning is widespread. Modern automatic pellet and wood chip appliances are significantly more energy efficient and have lower emissions than traditional fireplaces and wood log stoves, but most residential biomass burning is likely to take place in inefficient and polluting appliances.

AQP emissions limits for combustion plant of various sizes are proposed or already agreed for introduction over the next few years. There are, however, no proposed limits for boilers in the 300 kW to 1 MW range; and in countries where there are a significant number of these plants affecting urban air quality; governments may consider the introduction of emission legislation to fill this gap.

In the meanwhile Member States are encouraged to promote the use of appliances that meet Eco-design benchmarks (e.g. the Blue Angel and Nordic Swan schemes) by linking fiscal incentives to appliances which achieve the benchmarks. This should be accompanied by an effective public education campaign. Only high quality certified pellets should be allowed to be sold, wood logs should have maximum moisture content, and the use of contaminated waste wood should be banned for domestic use. Users should be provided with advice on how to store and use biomass effectively.

National and regional governments could support voluntary replacement programmes to encourage households to replace older appliances with safer, more efficient, cleaner burning technologies. Financial incentives may be necessary to assist with the capital costs. In addition, in areas where high concentrations of PM are forecast domestic biomass burning in old inefficient appliances could be banned, except where this is the only source of heating.

6. CONCLUSIONS

The main anthropogenic sources of urban air pollution in southern European cities are traffic, biomass burning and shipping emissions. Measures to mitigate climate change have exacerbated the emissions from traffic and residential heating, whilst shipping emissions remain largely uncontrolled.

With the growing evidence of the adverse health effects of PM and NO_2, and the large proportion of the EU urban population exposed to concentrations above WHO guideline values, further measures are needed to improve air quality.

For road transport the NOx emissions from diesel vehicles need to be better controlled under real driving conditions, and for all cars the official CO_2 data needs to better reflect reality. The best vehicles for low emissions during use are electric and plug-in hybrid vehicles with small internal combustion engines. There are no exhaust emissions when running on an electric motor and they are energy efficient under urban driving conditions. Fiscal and other incentives should focus on promoting these vehicles rather than those with internal combustion engines.

Those countries which have the highest proportion of electric, plug-in electric and gas vehicles, and the lowest diesel proportion are where there has been consistent and decades long policies to encourage/discourage these vehicles. The 20 year ban of diesel cars in the two major cities in Greece was an effective measure. However, it is considered unlikely that a similar blanket ban would be acceptable in most EU member states.

There is evidence that LEZs which restrict cars as well as heavy duty vehicles have reduced long term average NO_2 and PM concentrations, albeit by only a few percent. LEZs, including those that only restrict heavy duty vehicles, have been shown to reduce the carbonaceous component of PM.

Virtually all new diesel vehicles are fitted with particle filters which are effective at reducing exhaust emissions, and in many cities non exhaust emissions. These come from the wear of tyres, breaks, and road surfaces and the re-suspension of deposited dust, and are equally important sources of PM as exhaust emissions. Research is required to understand how these emissions may be controlled.

In the foreseeable future, while most road vehicles have internal combustion engines, there is a role of a car Eco-Label that focuses on the exhaust emissions of PM and NOx and the well-to-tank CO_2. This should be based on real world emissions data not the type approval data, and be for both new and second hand vehicles.

Road washing and the use of dust suppressants have been shown to be effective at reducing ambient PM concentrations where there are high road dust loads in northern and central Europe, however the use of dust suppressants in southern Europe seems to be less effective. Light but frequent moistening of roads might be more effective at reducing the resuspension of road dust.

To reduce the PM emissions from residential biomass combustion new appliances must meet the EU limits as soon as possible. Fiscal incentives should only be given to appliances that meet the limits or, preferably, the best practice benchmarks. The latter would provide a clear incentive for manufacturers to invest in developing cleaner technology.

Biomass burning appliances have a long life and fiscal incentives should be provided for voluntary replacement programmes. It may be appropriate to ban the combustion of biomass in open fireplaces and simple wood burning stoves in areas where there are high PM concentrations, particularly when pollution episodes are forecast. Only certified wood pellets should be permitted to be sold, and for other types of biomass there should be limits on the moisture content. The burning of treated wood should be banned for residential burning. There is a need for independent and authoritative advice for members of the public to fully understand the impact of different types of biomass combustion systems and fuels on emissions and air quality

The open burning of agricultural residues should be banned. This may require fiscal and other support for the development of alternative uses for the waste.

Shipping emissions are largely uncontrolled. The exception is the limit on the sulphur content of marine fuels which reduces both sulphur dioxide and PM emissions. Emissions may increase in the future as international shipping increases unless further regulation is agreed. Individual ports have introduced fiscal incentives for cleaner vessels and Scandinavian governments have introduced fiscal incentives for cleaner vehicles.

Finally, it is important that there is greater integration of air quality and climate change policies to ensure that there is no significant adverse impact of policies that support one issue to the detriment of the other. In particular policies that promote fuels such as biomass and diesel that increase emissions of AQPs, and make the achievement of EU air quality limit values more difficult, should be reversed as soon as possible.

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