Effectiveness of short-term (emergency) actions to control urban air pollution – review of schemes

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1. Summary

This report is part of a wider set of work packages that gather evidence on the health impacts of emergency short-term action plans to control air pollution episodes in London. Short-term actions plans are enacted during air pollution episodes or as a preventative measure to avoid air pollution problems during important public events.

The work packages a to e:

a. Summarised the health effects of short term exposure to very high levels of air pollution.
b. Estimated the magnitude of the health impact of very high air pollution episodes in London.
c. Reviewed the evidence on the effectiveness of emergency measures (e.g. Madrid, Paris, Beijing) (this report).
d. Assessed the accuracy of existing air quality modelling for use in triggering emergency air quality measures.
e. Convened an expert workshop that considered the work packages a to d and the conclusions that could be drawn from them.

This report is work package c and reviews the evidence on the effectiveness of emergency measures or short-term action plans. Within the UK, these actions are limited to public information only and do not contain measures to reduce emissions or concentrations. Outside the UK there are examples of short-term action plans that include controls on emissions. However, emissions and concentrations are not the same thing and reductions in emissions will not always have a direct effect on the air that we breath. Dispersion and chemical processes in the air affect the linkage between emissions and concentrations. Finally, the impacts of the air pollution control on health are determined by how much people are exposed. These indirect linkages make it hard to evaluate the impact of emergency measures.

The first examples of short-term actions to control air pollution come from the US in the 1940s and 1950s. Today there are many examples of plans in European cities; including examples in France, Spain and Norway, across the Americas and in China. Despite their widespread adoption few schemes have been evaluated. Instead, many short-term action plans are justified based on prior knowledge of the relative contribution of pollution sources. For instance, taking action to reduce traffic or wood burning is justified because these are the largest pollution source.

There are many methodological difficulties in assessing these types of scheme that include meteorology and lack of understanding of what would have happened if the plan had not been enacted.

Evidence from traffic restrictions in Madrid and Paris based on odd or even number plates suggest that traffic reductions of between 15 to 20% can be achieved and NO_X and NO_2 can be decreased by a similar amount. However, studies in Madrid, San Paulo and Paris raise important questions about public compliance with traffic restrictions.

Modelling studies have shown that actions at a European scale would be effective and their effectiveness increases when implemented over several days. In Beijing widespread restrictions on

industry and traffic for major public events have been shown to decrease pollution concentrations by between 36 to 62%, depending on the pollutant considered.

There is a lack of peer-reviewed evidence on the effectiveness of wood burning bans, however there is evidence that burn bans being imposed for most of a season can yield measurable health benefits.

Although there are large gaps in the evidence base for short-term actions, where evaluations have been undertaken they indicate that the actions can be effective if they are sufficiently ambitious.

There is evidence that air pollution episodes can lead to long-term media interest in air pollution issues but few studies have looked at short-term action plans as a tool to raise public awareness of air pollution.

There is a clear need for schemes to be better designed rather than simply justified on the basis of doing something to tackle the largest pollution sources. Both modelling and monitoring have an important role to ensure that schemes are optimised and remain effective over time.

2. Introduction

The health impacts of air pollution are well recognised and have been the motivation for air quality legalisation in states around the globe. Within the European Union, Directive 2008/50/EC sets out air quality limits and target values along with dates for compliance forming a pan-European framework for the assessment and management of air pollution

The Directive also includes alert thresholds and a framework for short-term action plans that,

> "[may] provide for effective measures to control and, where necessary, suspend activities which contribute to the risk of the respective limit values or target values or alert threshold being exceeded. Those action plans may include measures in relation to motor-vehicle traffic, construction works, ships at berth, and the use of industrial plants or products and domestic heating. Specific actions aiming at the protection of sensitive population groups, including children, may also be considered in the framework of those plans."

As with other member states the UK transposed the directive into domestic law. This was achieved through the Air Quality Regulations 2010. These *require* the Secretary of State to set up short-term action plans if there is a risk of alert thresholds being exceeded and they *may be drawn up* if there is a risk of exceeding the target values.

Within the UK, short-term actions in the event of an air pollution episode provide public information only and do not contain measures to reduce emissions or concentrations. By contrast the short-term action plans used in some European cities include controls on emissions. Outside Europe short-term actions have been enacted to control pollution episodes or to minimise air pollution when a city is hosting a prominent international event, the Olympic Games for instance.

An early example of using emergency measures to control air pollution episodes comes from the US town of Donora, Pennsylvania. Located in a valley, thirty miles south of Pittsburgh, the town was dominated by a steel blast furnace and zinc works. A smog began on a Tuesday night in October 1948. By Friday night ill people were crowding into medical centres and hospitals, and fire service volunteers using their breathing apparatus to treat people with oxygen. Although some evacuation of vulnerable people was attempted on the Friday night, by Saturday the thick smog made moving around the town almost impossible. There are reports of one doctor leading an ambulance on foot to take people to hospital. Initial reports listed around 600 people who became ill and the smog led to the deaths of eighteen in a community of 14,000 people, with many more reporting breathing difficulties. Part of actions to bring the smog to a halt was an emergency shut down of the town's smelter at 6 am on the Sunday morning with a change in the weather dispersing the pollution that afternoon (MoH, 1954; Synder, 1994).

Perhaps the first example of the types of region or city-wide short-term actions envisaged by the EU Directive comes from Los Angeles in 1955. As part their response to the 1952 London smog, Los Angeles devised a system for city-wide short-term measures during pollution episodes. A network of 14 monitoring sites was intended although only three were operating when the scheme began. Each was continuously staffed during periods of possible smog with results being telephoned to a central operations centre. The declaration of an alert was made via police and other radio dispatch systems, media wire services and teletype systems to then be broadcast on local radio stations. Cascading information during the declaration of an alert was thought to take about 15 minutes. At alert level 1 members of the public were asked to stop rubbish burning (the city had no refuse collection until 1957) and curtail their car use. Level 2 included industry shut downs and at level 3 the governor would declare a state-wide emergency. Over 30 level one alerts were called in the first fourteen months of the scheme, lasting between 35 minutes and three and a half hours. Despite no level 2 alerts during the first 14 months of the scheme it attracted criticism from industry given the time and cost incurred by any shut downs and the time taken to resume their activities. A lack of voluntary shut down plans from industry led to additional regulation to mandate plans. Other critics of the scheme pointed to the hours or days required for smog to form meant that effective action would need to be taken before the alert level was reached not once it had been breached. (Chass et al 1958).

Both of these early examples raise important questions on short-term measures that are still relevant today. Was the Donora smog cleared by shutting down the smelter or would it have dissipated anyway with a change in the weather? Similarly, could the extreme short-term nature of the Los Angeles alerts ever have been effective given the time taken to cascade the message, the time for an emissions response and the slow rate of formation of secondary pollutants in the city's air.

This report will look at assessments of the effectiveness of the short-term actions taken in cities around the globe.

3. Evaluation challenges

Evaluating the effectiveness of measures to control air pollution is not straight forward. Although a change in air pollution is the primary goal of short-term action plans, they do not act on the air pollution directly; instead they act on a polluting activity such as reducing traffic. If successful, this should reduce air pollution emissions. However, emissions and concentrations are not the same thing. Dispersion and chemical processes in the air affect the linkage between emissions and concentrations. Finally, the impacts of the air pollution control on health are determined by how much people are exposed.

A useful way in which to consider the impact of interventions is to think of the 'chain' of steps from a change in activity through to potential health effects. This sequence of steps is often called an 'accountability chain' and has been popularised by the Health Effects Institute (HEI) in the US (HEI, 2003) and also formed the structure of the evaluation of the first phase of London's Low Emission Zone (TfL, 2008).

The schematic shown in Figure 1 provides an overview of some of the steps that could be involved in the assessment of an action plan; in this case for an example based on a road traffic intervention. The shaded boxes in Figure 1 show the main steps involved from the original policy, which results in a change in activity, *Δactivity*, a change in emissions, *Δemissions*, a change in concentrations, *Δconcentration* and finally some health change, *Δhealth*. Progressive layers of confounding influences mean Interventions become more difficult to assess with each step in the effects chain.

Assessing the effectiveness of short-term action plans is especially difficult due to the confounding effects of meteorology. Permanent interventions can be assessed over a period of months or years and changes in meteorology that affect the linkage between emissions and concentrations can be largely accounted for in the assessment process. Short-term actions are taken during air pollution episodes which typically occur at meteorological extremes such as still, cold days or hot summer afternoons and a small change in the weather at these times can produce a major change in concentrations without any intervention.

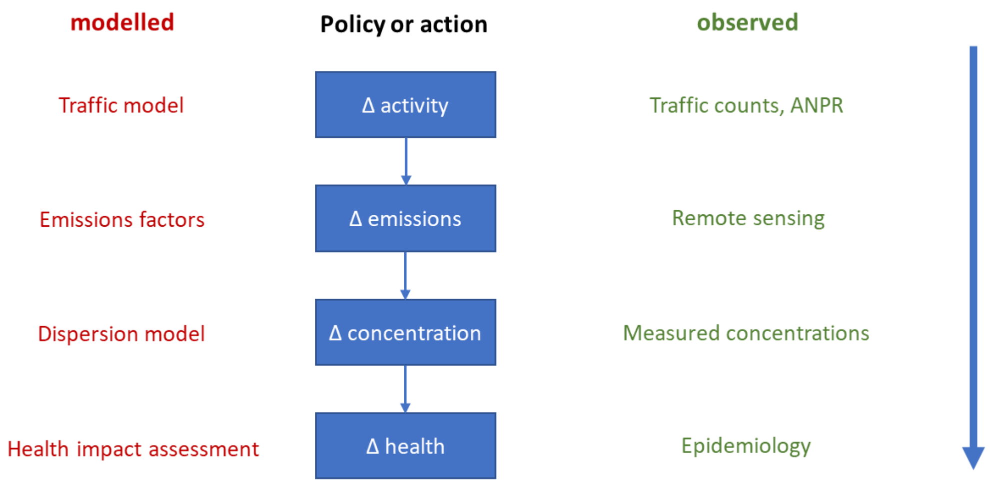

Figure 1 Schematic of the stages involved in assessing interventions. In this example, the intervention is related to a road traffic intervention. (prepared for AQEG, 2020).

4. Case studies

This section describes a series of relevant case studies. These were identified by a combination of expert knowledge of the authors, discussion with experts in other cities, literature searching (but not as a formal systematic review) and following up references in the originally identified papers.

4.1. European Commission review

Following a commitment in Directive 2008/50/EU the European Commission published a review of short-term action plans in 2012 (Conlon et al 2012). Part of the review sought to identify areas of member states at risk of exceeding the alert thresholds that were therefore required to prepare a plan. The project also used a questionnaire approach to compile the first EU inventory of short-term plans. Fourteen member states provided details of a total of 39 actions plans. The *verbatim* responses can be found in appendix 1.

There was a diversity of emergency measures within plans. These included:

- Information to the public.
- Reduced speed limits.
- Free public transport.
- Vehicle restrictions including odd / even number plate bans, restrictions on heavy good vehicles, restrictions on motor bikes or the restriction on pre-EURO or early EURO class vehicles.
- Restriction on industrial point sources.
- Heating restrictions including solid fuel use and imposition of maximum temperatures inside public buildings.
- Road cleaning and the use of dust suppressants (in Sweden where road wear from studded winter-tyres is a major problem. Road washing was also included in plans in the Czech Republic).
- Restrictions on construction.

The plans were based on local derived thresholds for actions and it was noted that there was wide variation in the action levels between cities. Many of the action plans were aimed to help meet limit values, especially the daily mean limit value for PM10 and this pollutant was the most frequent trigger for plans to be activated.

Many plans included a forecast element and member states were using deterministic models and statistical techniques to forecast air pollution typically up to three days in advance.

Some French plans were highly developed and robust and were therefore used as the basis for good practice recommendations. These clearly laid out the responsibilities of different organisations, the actions taken when information and action thresholds are exceeded and their geographical extent. Equally importantly the best plans also included criteria to terminate the actions at the end of the pollution episode.

Few action plans gave details of evaluations to determine their effectiveness. The evidence base from the EU survey is summarised in Table 2 and includes the information as supplied by each individual authority. Approaches to evaluation included those based on emissions inventories and in some cases, these were no more sophisticated than noting that traffic or industry was a large source; justifying the plan rather than evaluating its effectiveness. Other evaluations have used dispersion models, but it was unclear if these were based on assumed responses from the emitters or actual changes in activity; data on reduced traffic for example. These modelling studies suggest that measures might be effective for NO_2 but not for O_3. Few action plans had been evaluated by measurement; the only ones being the Swedish and Finnish plans, where they referenced the evidence on road washing and dust suppression, and a Belgian study on black carbon and speed restrictions.

4.2. Modelling Europe-wide actions

One route to assessing the impact of short-term action plans is through modelling. These allow scenarios to be tested and also their impact on past episodes can be examined.

A recent modelling study by Thunis et al (2017) sought to examine the theoretical impacts of short-term action plans in major European cites. The study modelled the impacts of action over durations of one to three days during winter (January) and springtime (May). The actions did not apply to all emission sectors. Instead the model examined the impacts of short-term impacts of changing emissions in the industrial, agriculture, road transport and residential heating sectors only. Concentrations were modelled on a 50 km x 50 km grid and was therefore not able to consider spatial variations in pollution concentrations within each city or local hotspots, next to roads for example.

Importantly, the action plans were based on taking action not just within each city but across the whole of Europe. Although this is perhaps not representative of cities acting alone it allowed the modellers to determine which source sectors would have most impact on concentrations within each city.

Scenarios that reduced emissions from all four sectors: industrial, agriculture, road transport and residential heating, by 100% for 24 hours led to decreases in PM10 concentrations of between 20-40% in in most cities. Eastern European cities were most responsive to shutting down residential heating emissions, whereas western European cities, including those in the UK were most responsive to reductions in agricultural emissions. This was reflective of inclusion of spring time in the assessment. For NO_2,cities were most responsive to changes in the road transport sector and concentrations could be reduced by 50 to 70% in most cities, including those in the UK. Taking actions together over a three-day period increased the effectiveness of PM10 abatement.

4.3. Madrid

In 2015 Madrid City Council set up a short-term action plan to disseminate public information and reduce road transport emissions and population exposure if NO_2 concentration exceeds a specific threshold. The plan divides the city (605.77 km^2) into five zones based on population distribution, location of air quality monitoring stations and the road network. Of particular note is zone 1 that encloses the city centre and it is defined by the inner ring road (M-30). The short-term action plan is summarized in Table 1. In addition to measured air pollution reaching the corresponding thresholds, the activation of any of the three stages of the plan requires an adverse meteorological prediction for the following day, although the nature of these adverse conditions is not specified.

Action stage	Trigger threshold	Measures
Stage 1	Information threshold	Information to public, speed limit reduction in M-30 and access links to 70 $km \cdot h^{-1}$ and promotion of public transport.
Stage 2	Information threshold (two consecutive days) or warning threshold (one day)	No surface public parking allowed inside M-30 (from 9 AM to 9 PM) in addition to stage 1.
Stage 3	Warning threshold (two consecutive days)	Access restrictions to the city centre (zone 1) for private vehicles, both passenger cars and "duty" vehicles (even/odd plate numbers –except for low emission technologies) from 6:30 AM to 9 PM in addition to stage 2.
Stage 4	Alert threshold	Even/odd plate number limitation extended to M-30 ring road and access links on top of stage 3. Restrictions on the circulation of unoccupied taxies.

Table 1 Summary of short-term actions plans in Madrid from Borge et al (2018a).

Borge et al (2018a) looked in detail at the meteorological conditions and air pollution measurements during an NO_2 episode at the end of December 2016 when the city's short-term action plan was implemented. Stage 1 actions started on 22nd December and remained in force until 1st January 2017, with the exception of the Christmas public holidays (25th & 26th). Stage 2 was enacted between 28th and 30th December and the plan was escalated to stage 3 on 29th December. The effectiveness of the actions was estimated by looking at the ratio of NO_2 concentrations inside and outside the M-30 ring road and compared to the ratio of SO_2 concentrations inside and outside the M-30 on the basis that these should not have been affected by the action plan. It was estimated that the stage 3 measures reduced NO_2 concentrations by around 15% within the M-30 ring road (around 7% when averaged over the whole24-hour period) but the impacts of the action plan outside this area was "practically negligible or it may have even contributed to increased pollution levels in some areas or the city outskirts."

The same episode was also analysed by Querol (personal communication) who looked at the NO_2 : SO_2 ratio. To validate his approach Querol first looked at Christmas day. Although the actions were suspended the different travel patterns on the public holiday led to a 35% reduction in NO_2 in the central area when traffic volumes also reduced by 43%. Looking at the action days Querol then found that the stage 3 actions on 29th December decreased NO_2 by 13% in the central area and traffic decreased by 17% compared with traffic on comparable days in 2017.

Borge et al (2018b) also assessed the measures using a modelling approach. Specific traffic modelling was undertaken to account for the expected traffic during this holiday period when schools were closed, many people were off work and there was far greater traffic in retail areas. Stage 1 and 2 actions had very little impact. The stage 3 restrictions by number plate in the central area reduced traffic volume by 23.0% and less congestion led to an increase in average speed by 19.6%, resulting in an average 23.6% reduction of NO_X emissions inside the M-30. According to the simulations, the stage 3 restrictions led to some traffic increase in the city surroundings, especially on the outer ring road, M-40. NO_2 was estimated to have reduced 9% when averaged across the central area with some areas having reductions of 14% and as much as 25% in highly trafficked street canyons compared with the do-nothing scenario. This prevented a further deterioration in NO_2 during the episode. A major uncertainty in the assessment was however the modelling of traffic during the

Christmas holiday season. Interestingly the authors made no comment on the actual traffic reduction compared with the theoretical reduction from the number plate-based restriction.

4.4. Paris

Paris has a sophisticated and detailed structure for implementing short-term action plans during air pollution episodes. These depend on the type of episode, with different plans in place for ozone and particle episodes. Measures begin with public information and progress to traffic speed restrictions, parking measures, bans on home wood burning and also actions on agriculture in the Paris region to reduce ammonia emissions and secondary particle formation. Other measures have included free public transport and alternate day traffic restrictions based on an odd/even number plate system.

The effectiveness of action plans have been evaluated by a combination of measurement and modelling. The odd/even number plate restrictions were implemented during a prolonged particle pollution episode in March 2014. Traffic decreased by around 18% resulting in a 2% decrease in PM10 in urban background locations. Close to major roads PM10 was estimated to have decreased by 6% and as much as 20% on the Paris ring-road during rush hour. NO_X decreased by up to 30% ((Airparif, 2016, Gersi – personal communication).

However, an odd/even number plate ban had less effect during a wintertime episode in early December 2016. This episode was remarkable not only for the maximum concentrations measured, which were the greatest in ten years, but for the duration of the episode which persisted for 18 days. In addition to speed restrictions and a ban on heavy duty vehicles from the city centre, an alternating odd/ even number plate ban was put in place on 6^{th}- 9^{th} December and then again on 16^{th} and 17^{th}. During these times public transport was free and residential parking restrictions were lifted to encourage people to leave their car at home. Other actions included free cycle hire and fines on aircraft using auxiliary power units. In contrast to the March 2014 episode traffic volumes decreased by just 5% despite increased police controls. This was partially attributed to the break-down of a Metro line but caused a wider re-think of the traffic restrictions. The revised system, based on the French Critair scheme, now bans the oldest and most polluting vehicles during episodes; effectively tightening the city’s low emissions zone as a short-term measure. This is now supported by reduced cost, rather than free, public transport and was implemented for the first time in January 2017 (Airparif, 2016, Gersi – personal communication, Fuller and Moukhtar, 2017). This is yet to be evaluated.

4.5. Oslo

Oslo implemented its first emergency traffic restriction in January 2017. In contrast to the odd/even number plate approach this measure banned all diesel cars from municipal roads (*the Guardian*, 16th January 2016). Road washing was also undertaken. Traffic counts showed a 31% decrease in diesel cars on the day of the ban but analysis of the impact on air quality was confounded by a change in the weather. On the day of the ban the temperature inversion was not being as strong as expected, there was snowfall in the early hours of the morning and rain later in the day which would have improved air pollution. (NILU, 2017, Aas – personal communication)

4.6. Santiago

Santiago, Chile is considered to be particularly susceptible to air pollution. Prior to the implementation of air quality management plans in the 1980s, concentrations of PM10 over 300 µg m^{-3} were not uncommon and occasionally levels of more than 500 µg m^{-3} were measured within the city. Plans brought forward in 1997 included short-term actions during pollution episodes based on banning types of cars according to number plates. At their maximum, these restrictions covered 80% of non-catalyst cars (for example registrations ending in 0 to 7) and up to 40% of catalyst cars although it is thought that some families buy an additional vehicle to get around bans. Other measures include cessation of up to 50% of industrial emissions and banning non-certified wood burners. (Mullins and Bharadwaj 2004).

Mullins and Bharadwaj (2004) adopted a novel approach to assessing the impacts of the measures. To compare action days with non-action days, researchers used a statistical method to match days when no episode was declared (1994-2008) to those days when episodes were declared. The majority of the control days were therefore in the pre-1997 period. Given evidence from South California that action plan compliance can diminish on successive episode days[1], the study only considered isolated action days. Actions were found to decrease PM10 by around 20% on the day of implementation[2] and led to decreased mortality amongst the elderly (3.6 fewer deaths per 100,000 aged over 64) in the following three days, compared with equivalent days when no alert was issued.

4.7. Beijing – Olympic and Paralympic Games, "APEC blue" and "parade blue"

Three recent short-term action plans in Beijing have attracted a lot of international research interest.

Perhaps the most widely known action plan was around the time of the 2008 Olympics and Paralympics (Schleicher et al 2012)[3]. Control measures were put in place over an area with a radius of about 150 km from Beijing. Many factories, especially those burning a lot of coal (including iron and steel production and a refinery) were relocated and many of the remaining industries were ordered to cut emissions by 30 %. Construction was suspended. Vehicles that did not conform to European Euro standards were banned along with half of private cars on using an odd-even number plate scheme. Seventy percent of government vehicles were taken off of the roads. Public transport was promoted leading to an increase in buses and also taxis. Light duty vehicles were reduced by 30 % and heavy-duty vehicles were reduced by 54 %. The action plan was considered a success with decreases in PM concentrations most especially those components from anthropogenic sources. For example, black carbon concentrations decreased by around 50 % compared with the pre-games period and similar decreases were found for anthropogenic derived metals in PM[4]. The assessment was however confounded by rain during the first week of the games which would have led to

[1] Zivin and Neidell (2009) used attendance data at Los Angeles Zoo and the Griffith Park Observatory to assess how the population respond to smog alerts that advised to limit outdoor activities. Attendance fell by 15% at the zoo and 8% at the observatory on the first day of an alert but there was a smaller effect on day 2 and no detectable effect on day 3 suggesting that people are prepared to change their behaviour as a one-off but this readiness diminished over time.

[2] Reanalysis by Mullins (2015) estimated reduction as 16.9%. See accompanying review of short term intervention studies.

[3] See accompanying review of short term intervention studies for other papers looking at health outcomes

[4] See accompanying review of short term intervention studies for estimates, by various authors, of reductions in other pollutants

decreased concentrations in the absence of any short-term actions. Fireworks also led to a short-term increase in concentrations.

During 2014 short-term action plans were put in place to control air pollution during the Beijing Asia-Pacific Economic Cooperation (APEC) Economic Leaders' Meeting and then again in 2015 for the events and parade to mark the 70th anniversary of the ending of World War II. The changed colour of the Beijing sky during these air pollution events have been termed “APEC blue” and then “Parade blue”.

The spatial scale of these measures extended far beyond the city boundaries and actions were taken over a wide area and not just on the day of the event. The APEC meeting took place from 5th to 11th November 2014 but emissions controls began on the 1st and ended on 12th. Pollution reduction took place over six provinces (Beijing, Tianjim, Hebei, Shanxi, Inner Mongolia, and Shandong). This covers an area of 500,000 km^2 and a population of nearly 300 million people[5]. Measures included reducing or stopping production in factories, halting construction sites, imposing the odd-even traffic rule for vehicles, and improved road cleaning. Plans were tightened further in response to a forecast of poor air pollution dispersion on 8th to 10th November. For example, in Hebei province the iron and steel, glass, cement, and coking industries stopped production or soaking. All industries that discharged volatile organic compounds (VOC) stopped or limited production. The change in air pollution was assessed by comparison with similar time period in the previous five years to control for season and weather patterns. Measured SO_2, NO_2, PM10, and PM2.5 decreased by 62%, 41%, 36%, and 47% respectively during the APEC period, whereas average concentration of O_3 increased by 102%. A possible cause of the increase in O_3 was that stricter controls were applied to NO_X emissions than emissions of VOC, shifting the atmospheric chemistry in an adverse manner. (Wang et al., 2015).

Stricter short-term actions were put in place for the 2015 World War II victory parade. Once again these applied to Beijing and the surrounding provinces. Actions began on 20th August, ahead of the parade on 3rd September. Traffic on Beijing’s roads was reduced by half, more than 10,000 enterprises across seven municipalities and provinces were suspended or ordered to limit production, and various construction activities were also forbidden. The assessment by Li et al (2016) focused on the PM1 fraction and found a decrease of 52-57% due to the action plan, a greater reduction than that achieved during the APEC blue event and the 2008 Olympics.

4.8. Wood burning bans

The main focus on many emergency and short-term action plans is on industrial sources and traffic. These sources have been at the fore front of the UK air pollution debate since the 1980s. Prior to this time, during the 1950s and 1960s, it was the pollution from heating our homes with coal that was the main target for air pollution controls. The 1956 Clean Air Act and the availability of natural gas for space heating from the early 1970s made dramatic changes to urban air pollution on the UK. However, an increase in the popularity of home wood since the turn of the century has reversed some of the improvements made in solid fuel emissions.

Around the world most wood smoke control programmes focus on minimum emissions standards, but short-term action plans are also used in the form of “no burn” days in many parts of the USA

[5] Source http://www.stats.gov.cn/english/ by comparison the EU27 have a combined population of 508 million people and an area of 4 million km^2 https://europa.eu/european-union/about-eu/figures/living_en

(and beyond) to reduce home heating emissions when unfavourable meteorological conditions are expected (WHO, 2015).

Examples include: the Bay Area Air Quality Management District in California that issues "Spare the Air Tonight" advisories. Bernalillo County (Albuquerque), New Mexico, that has a winter "no burn" programme restricting non-EPA-certified fireplaces or stoves. Denver, Colorado, that has mandatory bans on "red" days. Perhaps most well-known is the scheme in Puget Sound, Washington, which includes Seattle and the surrounding area. Here air quality burn bans temporarily restrict some or all indoor and outdoor burning and are usually called when weather conditions are cold (WHO, 2015). A two-stage process is used. During stage one uncertified wood burners are banned and all wood burning is banned at stage two. Starting with the 2012-2013 home-heating season and continuing in 2013-2014, burn ban triggers were tightened. During this time there were seven burn bans spanning 27 days. More than 60 staff were trained to assist with enforcement and patrol hours increased substantially to include dusk and night when more people are burning wood for heat. Over 2,000 notices of violation were issued over the two winters. First time violators of burn bans could avoid paying a penalty but repeat violations could result in a fine of up to $1,000. As an alternative to fines homeowners could take a clean burn test, remove their uncertified stoves or sign up for notification alerts through email, text or social media. Other measures to reduce air pollution from wood burning include subsidised upgrades or removal of older non-certified stoves. Looking between 2005/06 and 2015/16 burn bans are thought to have reduced PM2.5 by around 10-20% (Saganić – personal communication; Washington State Department of Ecology, Puget Sound Clean Air Agency 2014).

The only evaluation in the peer-reviewed literature relates to the scheme in San Joaquin Valley in southern California (Yap and Garcia, 2015). Here winter is characterised by cold rainy weather and dense low fogs. The most severe smogs were attributed to home wood burning. A new scheme for wood burning bans was introduced in 2003 and bans were imposed when air pollution was forecast to be poor. Concentrations and health metrics in the first three winter's operation of the scheme were compared with the three winters prior to the scheme. Burn bans were called on around 100 days each winter, around 80% of days. The winter average PM2.5 decreased by around 11 to 15%. Hospital admissions for cardiovascular and ischemic heart disease in over 65-year olds decreased by 7% to 17% depending on the health end point chosen[6]. Improvements were greatest in those areas with the highest prevalence of home wood burning.

A wood burning advice system operates in Flanders, Belgium (Vercauteren – personal communication) and asks people not to use wood heating unless it is their primary source of heating. Alerts are sent by press release when the running daily mean concentration of PM10 is greater than 50 µg m-3 and this is expected to persist for the next 24 hours. Alerts are typically issued three or four times each winter. An air pollution evaluation has not been undertaken but a survey of 600 people showed the effectiveness of the scheme in raising awareness with 70% of people being aware of the alerts (80% of people that burn wood). The scheme was supported by 90% of the population with 50% of wood burners saying that they adjusted their behaviour; 20% stopped burning and 30% reported that they burnt less. It is believed that the wood burning alerts have changed the public and political perspective on wood burning impacts.

[6] See accompanying review of short term intervention studies.

5. Discussion and conclusions

Short-term action plans form part of air pollution control strategies in many cities around the world. Despite their wide-spread use many schemes have not been evaluated. Instead, many short-term action plans are justified on the basis of prior knowledge of the relative contributions of pollution sources. For instance, taking action to reduce traffic or wood burning is justified because these are the largest pollution source. This may be reflective of the challenges and costs to undertaking a robust assessment. Where assessments have been undertaken, they tend to be in the largest cities. This might be reflective of the cost and practicalities of assessing such scheme which, for many towns, might be disproportionately large compared with the cost of the scheme itself.

It is challenging to evaluate any air pollution intervention since the policy control does not affect the outcome directly. Typically, interventions affect either an activity or emissions which in turn affect air pollution and health, although these linkages are confounded by meteorology and exposure. The main difficulty in evaluating the outcome of air pollution interventions is establishing a robust counterfactual; what would have happened with no intervention. For permanent interventions it is possible to look at before and after scenarios, compare the action area with a non-action area or to use statistical approaches that try to remove the confounding effects of meteorology. However short-term action plans are normally implemented for periods of not more than a day or so, in local areas and at extremes of meteorology where there may be few past analogies, making them more challenging to evaluate robustly.

Where evaluations of actions have been undertaken it is clear that ambition and spatial-scale is important. Schemes that focus on traffic pollutants such as NO_2 and to a lesser extent PM_{10} and $PM_{2.5}$ have an impact close to the source. For instance, the stage three traffic restrictions in Madrid reduced NO_2 concentrations by around 15% within the M-30 ring road (around 7% when averaged over the whole 24-hour period) but the impacts of the action plan outside this area were negligible. Similarly, in Paris the implementation of odd/even number plate bans resulted in a 2% decrease in PM10 in urban background locations but close to roads the impact was greater; PM10 was estimated to have decreased by 6% and as much as 20% on the Paris ring-road during rush hour. NO_X decreased by up to 30%.

Effective measures to control PM10 and PM2.5 away from roads require actions to be taken over a very wide area. This is reflective of the long atmospheric lifetime of this pollutant and, also, the way in which much of the particle pollution in our air is formed from other pollutants in processes that can take hours or days as air travels over a region or between countries. Successful measures, such as those for the Beijing APEC summit and World War two victory commemorations therefore included actions often tens or hundreds of kilometres from the city. In the London context, this underlines the importance of cities and towns in the UK working closely with cities in the near continent.

Where they have been evaluated, the efficacy of the short-term, or emergency, actions is normally framed in terms of air pollution concentrations, but the social and behavioural dimension also needs to be considered. There is evidence that short-term actions can be effective in raising awareness of air pollution issues and sources. There is evidence that air pollution episodes themselves can lead to long-term media interest in air pollution issues, examples include the 2014 spring time pollution episodes in London and the debate about NO_2 on Oxford Street (Kenis ,2017) and further evidence of awareness raising is available from surveys following wood burning bans in Flanders.

However, studies in Madrid, Sao Paulo and Paris raise important questions about how effective traffic restrictions are in practice and the Paris experience suggests that public willingness to comply might be limited when restrictions are used frequently or for successive days. This idea of diminishing public willingness is supported by evidence from compliance with pollution advice to vulnerable people in Los Angeles. Although traffic data was collected in the Madrid study, it is unclear if the actual reductions match those expected. For Sao Paulo, it is thought that some families buy an additional vehicle to get around bans based on number plate. It is hoped that restructuring the Paris ban to focus on older and more polluting vehicles will prove more effective.

While some short-term plans are triggered by measurement, others are triggered by air pollution forecast models. It is unlikely that the emergency measures applied for just a few hours in Los Angeles would have helped pollution concentrations given the photochemical nature of the smog that took many hours or even days to form. This is also the case with episodes that are dominated by secondary particle formation suggesting that accurate air pollution forecasts should be an important part of an optimised scheme. The need for air pollution forecasts is lessened for pollutants that are either primary or when problems are found local to the sources; control of high concentrations of nitrogen dioxide close to roads for example.

Modelling studies have shown that actions at a European scale would be effective and their effectiveness increased when implemented over several days. These modelled scenarios are of similar scale to those implemented in China. The Chinese scenarios had a major impact on sulphur dioxide and airborne particle concentrations more than a week before the parade and APEC blue events in Beijing, with widespread restrictions on industry and traffic reducing pollution concentrations by between 36 to 62%, depending on the pollutant considered. While actions on this scale can be implemented in China, they would be challenging in Europe without extensive international cooperation and would have to deal with the difficulty that the country with restrictions might not be the one that benefits.

There is a lack of peer-reviewed evidence on the effectiveness of wood burning bans, however there is evidence that burn bans being imposed for most of a season can yield measurable health benefits and that burn bans can be an effective tool for awareness raising.

Short-term action plans can be effective if the scale of the plan matches the time taken for a pollution episode to form and the spatial extent of the contributing sources. Although there are large gaps in the evidence base for short-term actions, where evaluations have been undertaken, they indicate that the actions can be effective if they are sufficiently ambitious.

6. Recommendations for short-term action plans

From the review of evaluations of short term action plans it is recommended that:

- Short-term action plans need to be designed, rather than simply justified on the basis of doing something to tackle the largest pollution sources.

    - Analysis of past air pollution concentrations should be undertaken to yield information on the frequency and magnitude of air pollution episodes prior to designing a scheme.

    - Potential schemes could be designed and optimised in a modelled environment before implementation. This should include the change in activity / emission, concentration and health impact.

- Schemes need a clearly laid out pathway for triggering the short-term action and equally importantly for determining how the short-term action should be ended.

- Forecast models could provide a warning of the air pollution episode before the short-term action plan is enacted and a combination of measurements and forecast models should be used as part of triggering and ending the action plan. The use of forecast models is especially important for pollutants that take time to form in the atmosphere or pollutants where sources outside the city form a large component of the exposure.

- Short term action plans should be set up with evaluation included as part of the design process.

    - The first step in considering the effectiveness of a plan is to gather data on the change of activity; the change in traffic flow or proportion of people burning wood for example. This is essential to be able to demonstrate a link between the policy action and any change in concentrations and to be able to show compliance and continued compliance with the scheme. This requires data to be gathered routinely on days when the plan is implemented and on non-implementation days.

    - Both modelling and monitoring have an important role to ensure that schemes are optimised and remain effective over time. This has to include analysis of activity data as well as air pollution measurements.

- Awareness raising should be evaluated as an outcome from some short-term action plans.

    - Surveys of public and other stakeholder opinion should be undertaken both before and after the short-term action plans are implemented.

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9. Appendix

Table 2Table 2 shows questionnaire responses collected by Conlon et al (2012). These are largely reproduced *verbatim* with the correction of spelling mistakes only.

Country / region	Evaluation
Austria	For ozone source apportionment by MM5/CAMx modelling as well as emission scenario based modelling of ozone concentrations in the relevant zone; see http://www.wien.gv.at/umweltschutz/pool/luft.html#ozon (in German language)
Belgium	During particulate matter smog episodes a speed limit reduction from 120 to 90 km/h is introduced on some highways in the three Belgian regions. The effect of this measure on the concentrations of Elementary Carbon (EC) and total mass particulate matter (PM10 and PM2.5) was calculated using a chain of different models. The results are published in Atmospheric Environment: Lefebvre et al, "Modelling the effects of a speed limit reduction on traffic-related elemental carbon (EC) concentrations and population exposure to EC", 2010 : http://www.sciencedirect.com/science/article/pii/S1352231010008010
Czech Republic	Based on the maps of PM10 annual average concentrations and PM10 daily limit value exceedance number, probability of smog alert thresholds violation is estimated by the statistical approach in regular 1x1 km network over the whole Czech Republic territory. Regions-in-risk where operation of smog warning system might be meaningful were marked using these maps. In the next step, particle pollution sources located in these regions or their near surroundings were selected from the emission database. Using a simplified Gaussian dispersion model, a contribution of selected sources to the PM10 concentration level in potential smog regions was estimated. Sources with the significant contribution to the human exposure to PM10 in their vicinity were put into group of sources obliged to apply regulation measures during the smog episodes
Finland	In cases of sudden increases of PM10 the Environment Centre may require the city street maintenance personnel to spray the streets with calcium chloride in order to reduce re-suspension of PM10 from the road surfaces. The expected impacts have not been accurately quantified but several studies have shown that dust binding is the most effective means to reduce acute high concentrations of PM10. In extreme situations of elevated NO_2 levels caused by traffic emissions the Mayor of Helsinki may restrict the use of private passenger motor vehicles in the area. The measure has not been put to use as the action threshold has not been exceeded. The expected impacts of such a restriction have not been accurately quantified. As traffic emissions are the main source of NO_2 in Helsinki, a reduction in traffic volume is expected to reduce the concentration of NO_2 in ambient air. This has also been proved by dispersion modelling, which was carried out recently when preparing the time extension application for the NO_2 limit value
France -Centre	In episodes of ozone pollution, it appears that the introduction of speed limits does not present additional efficiency. Given the extent of affected areas measures should be put in place on a large spatial scale.
France - Alsace	Evaluation of measures in the report "Rapport relatif a l'evaluation des mesures d'urgence potentiellement mises en oeuvre en Alsace pour limiter les pics de pollution atmospherique". Measures were moderately effective for NO_2 and PM10 but local measures were not effective for ozone
France Base Normandy	In Base Normandy there have been very few triggers emergency measures to date and therefore not implemented measures to reduce planned not to assess the likely impact of emergency measures.
France Brittany	No impact prediction
France Ile de France	No impact prediction
France Limousin	No impact prediction
France Provence Alpes Cote d'Azur	No analysis, (reducing speed has very little impact on pollution peak). http://www.paca.developpement-durable.gouv.fr/IMG/pdf/rapport_etude_ozone_cle014deb.pdf
France Rhone Alpes	Modelling studies showed that the effectiveness of reducing speed 20 km / h was much greater if carried out on the entire region rather than the big cities only (reduction emission of nitrogen oxides 10 times higher).
Hungary	There is a possible list of measures (from air pollutant to air pollutant to be applied in smog situations) in the annex 3 point B to Governmental Decree No. 306/2010. (XII. 23.) on the protection of ambient air. Choice of measures should be decided on the spot, for individual situations. Source appointments should be prepared locally, details can be found in relevant questionnaires

Italy Bolzano	Regarding the emission inventory the traffic sector is one of the main sources of PM10. See http://www.provinz.bz.it/umweltagentur/luft/luftqualitaetsplan.asp?&somepubl_action=300&somepubl_image_id=197192
Italy Toscana	The information on emission source apportionment are made on the Regional Sources Emission Inventory IRSE. The estimate of the effectiveness of plans is made on emissions saved in the urban area of interest. The choice of measures is made based on the relative importance of various activities that produce emissions.
Poland Slaskie	The main source of pollution emission is the emission from individual housing furnaces. Spot and line emission (industry and transport respectively) influences the poor air quality to much smaller extent
Spain Catalunya	Not quantified
Sweden Gothenburg	The expected impact is based on several investigations concerning the effect of binding the PM10 to the street surface.
Sweden Jonkoping	We do not have a short-term action plan, but our general action plan contains measures that can be considered as short-term actions. Dust-binding is carried out in order to keep road surfaces damp and bind particulate matter to the surface, preventing it from being suspended in the air. Evidence from trials and other municipalities within Sweden shows that dust-binding gives an effect. Temporary speed reductions have also been shown to have a positive effect on particulate matter concentrations. The effect of a reduction from 50 km/h to 40 km/h has been estimated to give 10-15% reduction in concentrations. There is however some degree of uncertainty to this estimation.
Sweden Norrkoping	Peak concentrations of PM10 in spring is caused by suspension of road dust. Dust-binding through the spreading of CMA is therefore carried out to reduce suspension. This measure was chosen following evaluation studies on dust-binding in Norrköping and in other cities
Sweden Stockholm	Based on the continuous monitoring of air pollution in Stockholm it is stated the local traffic is the major source for NO2 and PM10 during periods with high concentrations. http://slb.nu/slb/rapporter/pdf8/slb2011_001.pdf The short-term actions are therefore taken against the emission from the traffic.

Table 2 Summary of methods used to evaluate short-term action plans from Conlon et al (2012) as completed by the individual regions and cities.