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Air quality strategies and technologies:

A rapid review of the international evidence

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Summary

- This report provides a rapid review of measures enacted worldwide to improve air quality. Air pollution tends to be worse in cities, and the main source are vehicles that use fossil fuels. For this reason, the report focuses on initiatives concerning road transport in urban areas.

- Air quality is determined by the levels of pollutants in the air. The main pollutants are particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NO_x), sulphur dioxide (SO_2), carbon monoxide (CO) and volatile organic compounds (VOCs).

- We divide air quality initiatives into strategies, which are the policy levers available to governments, and technologies.

- **Strategies** often involve discouraging private petrol and diesel car use and encouraging less polluting transport use:

  Low or zero emission zones can be effective in bringing about localised air quality improvements, although there is a risk that emissions are simply displaced, rather than reduced overall.

  Good public transport and cycling infrastructure are necessary to create a behavioural shift away from private car use.

  Low speed limits can have a prompt impact on air quality near roads, primarily through reducing the stop-start nature of the traffic flow.

- **Technologies** either retrospectively remove pollutants from the air, or try to prevent emissions in the first place:

  There is a lack of evidence on the effectiveness of initiatives that remove pollutants from the air, such as the air purifying tower in Xi'an, China.

  Electric vehicle numbers are increasing worldwide and have the potential to significantly reduce certain pollution emissions. Financial incentives, such as subsidies, can be effective in encouraging electric vehicle uptake.

  Suitable roadside barriers may be a simple means of improving air quality.

- Three cities which rank highly for air quality are used as case studies: Honolulu, Tallinn and Edinburgh.

  Policy measures consistent across the cities are: good public transport coverage, a good cycle network, and financial incentives for electric vehicle purchase, although these incentives typically apply to the whole country. There was otherwise divergence between the cities' air quality policies.

Introduction

Poor air quality negatively affects human health and the environment. For this reason, governments and private sector organisations across the world are developing and trialling a wide range of ways to improve air quality. This report provides a rapid review of the different types of air quality initiatives that exist internationally and offers a brief indication of the evidence base behind them.

Air quality is understood as the levels of pollutants in the air and how these compare with permissible levels (Kuklinska et al., 2015). The key air pollutants are: particulate matters ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NO_x), sulphur dioxide (SO_2), carbon monoxide (CO) and volatile organic compounds (VOCs). Ozone (O_3) forms when VOCs react with hydrocarbons and NO_x in the sunlight (see Table 1).

Air quality in Wales

Air quality legislation in Wales is currently determined by EU regulations that have been enacted into Welsh law. The Air Quality (Wales) Regulations 2010 brought into law EU Directive 2008/50/EC on ambient air quality and cleaner air for Europe (Welsh Government, 2010). The EU directive sets limits on the average daily and yearly mean for pollutants $PM_{2.5}$, PM_{10} and NO_2, and a maximum daily eight hour mean for O_3. In addition, the World Health Organisation (WHO) sets separate and more stringent guidelines for the same pollutants (European Environment Agency, 2017a).

Air quality in Wales ranks relatively poorly compared to the UK average and international guidelines, which may be unexpected due to its small cities and low population density. For example, the level of particulate matter $PM_{2.5}$ in both Cardiff and Newport is at the WHO's recommended limit (World Health Organisation, 2018). Although there has been a decrease in PM and NO_x levels in Wales over the past two decades, air pollution is still thought to cause approximately 2,000 deaths in Wales per year, and disproportionally affects people living in deprived areas (Abernethy, 2018). Exposure also depends on factors such as proximity to main roads and the times of day one travels (Buechler, 2018). Air quality is largely managed by local authorities, who are required to produce annual progress reports and implement Air Quality Management in areas deemed likely to exceed air pollution limits, of which there are currently 39 (Abernethy, 2018).

Table 1: Air pollutants

Pollutant	Sources	More information
Particulate matter (PM)	Transport (including exhaust fumes and tyre and brake wear), combustion, industrial processes, construction and demolition.	Harmful particulate matter are particles with a diameter of less than 2.5 and 10 micrometers ($PM_{2.5}$ and PM_{10}).
Nitrogen Oxides (NO_x)	Transport and combustion.	NO_x is the umbrella term for nitrogen oxides most relevant to air pollution, including nitrogen dioxide (NO_2) and nitric oxide (NO).
Sulphur Dioxide (SO_2)	Transport and combustion (especially coal).	
Carbon Monoxide (CO)	Transport (especially petrol-based), combustion and industry.	
Volatile Organic Compounds (VOCs)	Various, including transport and combustion.	VOCs are organic compounds which evaporate easily and react with other substances in the sunlight.
Ozone (O_3)		O_3 forms when Volatile Organic Compounds (VOCs), hydrocarbons and NO_x react in sunlight.

(Adapted from: Hesketh et al., 2017 and Liu et al., 2008)

The link between strategies and technologies to improve air quality and human health can be broken down into: strategies and technologies that affect the emission of pollutants, the levels of which determine air quality, which impacts human health and environmental wellbeing.

Figure 1: Link between strategies/ technologies and health

(Adapted from: Bigazzi, 2017)

Our approach

This report presents a rapid literature review of both academic and “grey” literature. It was carried out according to the principles of a systematic literature search but does not aim to be a systematic review. For a more detailed discussion of our search methodology, please see Appendix 1.

The main source of ambient air pollution is emissions from fossil fuel vehicles, and air pollution is generally worse in cities (World Health Organisation, 2018). Traffic related emissions make up approximately 64% of pollution in urban areas (NICE, 2017) and there is substantial research linking air pollution from traffic to negative health outcomes (Slovic and Ribiero, 2018). Although pollution from other sources, including agricultural, industrial and domestic, is an important consideration, the air quality impact of industrial and domestic pollutant sources tends to remain consistent or be improving over time, whilst traffic pollution problems are worsening across the world (DEFRA, 2018). For these reasons, it was deemed most appropriate to focus on strategies and technologies relating to road transport in urban areas, and policies regarding other sectors are beyond the scope of this short report.

We divide air quality initiatives into strategies and technologies. **Strategies** encompass the policy levers available to governments, including legislation, “soft power”, and taxation and funding. **Technologies** are subdivided into those which prevent emissions, and those which seek to retrospectively remove emissions from the air.

To assess the evidence-base for interventions, we use the following framework: evidence of effects (i.e. this has been shown to work), evidence of no effects (this has been shown to not work) and lack of evidence (there is insufficient evidence to determine whether this works or not) (Langer et al., 2016).

Improving air quality: individual strategies and technologies

In this section, we review individual policy measures which aim to improve air quality, and indicate what evidence is available about their effectiveness.

Strategies

The majority of air quality strategies for which evidence exists focus on discouraging private car use. This is predominantly done via regulations and legislation, as well as investing in infrastructure which promotes alternative transport. Here we discuss some key air quality strategies and offer illustrative examples where they have been put into practice.

Low emission zones

Low emission zones (LEZ) are areas in which vehicle use is restricted in order to limit tailpipe emissions. They are a popular localised air quality measure in European cities, with approximately 200 in existence across 12 European countries including, for example, England, Italy, Sweden and Holland (Holman et al., 2015). Restrictions typically apply to heavy duty vehicles, which usually run on diesel, but some LEZs also encompass other types of vehicles. The zones are often created to ensure that cities comply with European emission standards, which have become more stringent over time, and so the types of vehicles which are allowed entry vary according to each location's needs.

London's low emission zone, which applies to most of the area within the M25 ring road and targets heavy duty diesel vehicles, is a prominent example and one of a number of area-specific air quality measures currently in place in the city. From April 2019 an Ultra Low Emission Zone will be introduced in the Congestion Charging area and will include cars, motorcycles and vans, which will need to meet tighter emissions standards. In October 2021 this Ultra Low Emission Zone will be expanded to the inner London area, bounded by the North and South Circular roads (Transport for London, 2018c).

There is some evidence that low emission zones can have a positive effect on air quality (Bigazzi and Rouleau, 2017), although their efficacy varies dependent on the location's characteristics, as well as how stringent the zone's requirements are. For example, a study conducted in five Dutch cities found that low emission zones directed solely at heavy goods vehicles have no significant impact on air quality, suggesting that more wide-ranging restrictions achieve better air quality results (Boogaard et al., 2012).

A variation on low emission zones are zero emission zones, in which only cars that produce no tailpipe emissions, such as electric vehicles, are permitted. Oxford City Council is currently consulting on introducing a zero-emission zone (Oxford City Council, 2018).

Congestion charging zones are an example of an associated initiative which is not primarily focused on air quality, but may have effects thereupon. The cost of driving is increased via a congestion charge within a designated area or on certain roads, which acts as a deterrent for drivers. There is evidence that congestion charging assists a behavioural change shift from private car use to public transport (Santos et al., 2010), which may in turn improve air quality. An issue with low emission zones and congestion charging zones, like all measures focused on a particular area, is that emissions may be displaced rather than reduced overall, and can result in poorer air quality outside of the zone (Hawkes, 2015).

Private vehicle behavioural change

Public transport

Urban air quality policy combinations often ally methods for discouraging private car use with measures to make less polluting forms of transport, such as cycling and public transport, more appealing (UN, 2016). Investments in cycling and public transport infrastructure, such as creating a network of cycle lanes, are costly in the short term but may assist in facilitating long term behavioural change away from polluting transport. To ensure it is a viable option, public transport needs to be frequent, reliable, relatively quick and potentially subsidised. Several countries are also considering ways to help people connect easily between different forms of transport. Singapore plans to create more integrated transport hubs, enabling easier transition between different modes of transport, for example, from bus to tram (UN, 2016). An integrated hub linking bus, train and cycling facilities opened in Port Talbot last year (Neath Port Talbot Council, 2017) and a number of stations in London serve as underground, train and bus stations, and provide cycle racks, often inside the building. Examples include Paddington, Euston and King's Cross, amongst others.

Cycling

Cycling is one of the least polluting transport modes, falling under the active travel category, along with walking (Public Health England, 2016). Despite this, there is a lack of evidence quantifying the air quality impacts of cycling, since traffic related air quality research tends to focus on pollutant emissions produced. Ballinger et al. (2017) have recently attempted to estimate air quality impacts from a number of walking and cycling schemes run by Sustrans, an active travel charity, in towns and cities in the UK. They provide estimates of the air quality benefits for local populations due to reduced emissions from car journeys, and the impacts on an individual due to change in pollution exposure from shifting to active travel. Although there was an improvement in some areas, the schemes did not have uniformly positive impacts and in some cases, such as Leeds, there was a negative effect. This is because the impacts of the schemes depend on the number of participants, the extent to which walkers and cyclists are exposed to air pollution, and the population density of the surrounding area, amongst others (Ballinger et al, 2017). The report suggests that in areas where the majority of cycle routes are not separated from vehicle traffic, such as Cardiff and Plymouth, the schemes had a detrimental effect on people who use active travel (Ballinger et al., 2017).

Other studies like Rojas-Rueda et al. (2012), for example, estimate that a 40% reduction in car trips in Barcelona City would yield a reduction of $PM_{2.5}$ concentrations of only 0.64%, and 10.03 air pollution related deaths avoided per year. They also find that the benefit for the general population due to reduced air pollution is much smaller than the benefit of the physical activity that cycling yields, a result also reported by Rabl and de Nazelle (2012). Cycling initiatives, therefore, are a promising air quality improvement strategy, but must balance the potential negative side effects of cycling, such as the exposure of cyclists to vehicle emissions.

Increasing cycling effectively requires a network of dedicated cycle lanes with full coverage of a town or city, along with outreach campaigns to address issues related to safety perception. It is worth noting that the decision to cycle is influenced by many factors, including convenience (Bopp et al., 2012; Mackett, 2003), distance (Scheiner, 2010), safety perception (Bonham and Koth, 2010; Wang et al, 2014), and weather conditions (Sabir, 2011), amongst others. Simpler and less resource intensive initiatives include minor changes to existing infrastructure, such as ensuring that cyclists are permitted to take their bicycles onto trains and providing safe parking facilities at train stations (Rietveld, 2000). These smaller measures are unlikely to individually have a measurable impact on air quality, but may cumulatively assist in making an environment where cycling is a more appealing option.

Bicycle and car sharing schemes are also promising initiatives for improving air quality, and can be aided by technology, such as apps for car clubs (Bigazzi and Rouleau, 2017; Haq, 2018). They can also be encouraged by regulation or legislation. For example, in San Francisco employers are required to encourage cycling, car-pooling and public transport use by employees through subsidies or pre-tax deductions of transport costs (Hesketh et al., 2017). Equally, the UK Government runs a “Cycle to Work” Scheme, in which employers can loan employees a bicycle tax free, sometimes in the form of a salary sacrifice arrangement (Department for Transport, 2011).

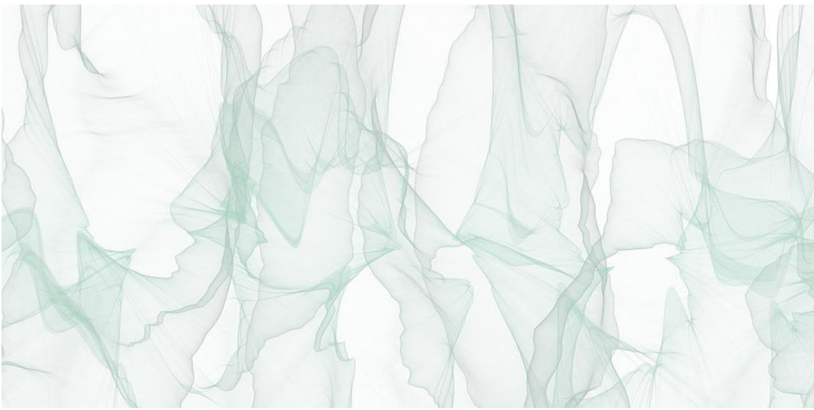
Speed management

Lower speed limits may be a cost-effective way of quickly making an impact on air quality near roads (Porter et al., 2010) and are included in several European countries' air quality plans (D'Elia et al., 2018). For example, the Welsh Government has recently introduced 50mph speed limits on five main roads (Welsh Government, 2018), and 20mph speed limits will be introduced on all Transport for London managed roads (approximately five per cent) in central London by 2020, although the measure is primarily aimed at improving road safety conditions (Transport for London, 2018b). The effect on emissions from lower speed limits is generally due to mitigating the stop-start nature of traffic, thus preventing unnecessary acceleration and deceleration, rather than the actual speed of the vehicles (Santos et al., 2010). This includes pollution produced through brake and tyre wear, given that stopping from 20mph emits approximately half the amount of particulate matter from the brakes as stopping from 30mph (Fuller, 2016). The effects of speed management measures are dependent on local weather conditions and the physical infrastructure surrounding the road. For example, in Amsterdam, a speed limit reduction from approximately 62mph to 50mph resulted in decreased PM concentrations, but had no effect on NO_x (Dijkema et al., 2008). Speed management has in places been complemented by "eco-driving" campaigns, which educate the public on fuel-efficient forms of driving. An eco-driving programme carried out in the Netherlands between 1994 and 2004 is thought to have reduced fuel consumption by between 0.3 and 0.8% (Harmsen et al., 2007).

Outreach strategies

Outreach and marketing activities have been shown to increase public awareness and compliance when used in conjunction with other air quality initiatives (Bigazzi and Rouleau, 2017). For example, Singapore's air quality strategy emphasises creating community ownership of air quality issues and holds annual 'community and youth for the environment' days. The Royal Borough of Kensington and Chelsea enlists 'green champions' to educate members of the community on energy efficiency and ways of reducing pollution (Hesketh et al., 2017). Involving stakeholders from industry, academia and NGOs in designing and implementing interventions also leads to improved compliance, and can be facilitated through awards schemes, such as the City of London Corporation's awards for business which use sustainable technology (Hesketh et al., 2017).

On the other hand, the impetus for environmental ownership may arise from communities themselves, rather than local or national authorities. In 2017, residents of the Kings Heath suburb of Birmingham collaborated with the consultancy firm Earthsense to monitor local pollution levels, as well as organising a "Clean Air Day" where residents were encouraged to commute by active travel rather than private car (Environment Times, 2018). The European Union also funded the CITI-SENSE project, in which approximately 400 volunteers were involved in establishing and monitoring an air quality sensor network of 324 individual units across Europe (CORDIS, 2017).



None of these community-led initiatives are likely to result in long-term impact by themselves. Whilst leaving the car at home may be feasible for everybody supporting the action one day, it may not be practical for all the other days of the year. Similarly, whilst neighbours may volunteer to help with air quality measurements for one day, it is unlikely that they would agree to do so to that extent on a regular basis. However, these community-led initiatives show that people in areas of high air pollution are aware of, and concerned by, the situation and may therefore be more likely to support policies introduced by the government.

Technologies

Removing pollutants from the air

Technologies designed to remove pollution from the air often gain media attention due to their unusual designs. The key problem with such initiatives is that only a small fraction of air ever comes into contact with any given technology, meaning that the overall impact on air quality is often negligible. Lewis (2018) urges caution regarding such initiatives and argues that "*it is far, far easier to come up with technologies and schemes that stop harmful emissions at source, rather than try to capture the resulting pollution once it's free and in the air*."

Examples of these initiatives include a 100-meter-tall air purifying tower in Xi'an, China, which is shaped like a chimney and uses greenhouses to move air through a filtration system. There is little evidence to substantiate the initial success claims made for the tower (Lewis, 2018). Buses which filter out particulate matter as they move through the air have been introduced in Southampton (Taylor, 2018), and water cannons to wash pollution out of the air have been trialled in Delhi, with no measurable effect (Suri, 2017).

Separately, using substances which react with NO_2, absorbing it from the air, have been trialled in several countries, including the Netherlands, Japan and England (Lorch, 2013). These can be applied to surfaces as paint or be integrated within materials themselves such as paving slabs and roofing felt. The results of these initiatives are as yet inconclusive, and everyday wear and tear can limit their effectiveness (Lorch, 2013).

Switching to less polluting cars

Petrol and diesel

A number of technologies exist to make diesel and petrol cars less polluting. Catalytic convertors, devices which make tailpipe emissions less harmful, have been a legal requirement for new vehicles in the UK and most other countries worldwide for several decades. The oil company Shell has developed a synthetic "drop in" alternative to diesel, i.e. one that requires no modification to the engine. This may have positive effects on NO_x and PM emissions, but is yet to be rigorously evaluated (Howard, 2016). Alternatively, San Paulo has focused on "flex" vehicles, which can run on different forms of fuel, usually a combination of petrol and ethanol (Slovic and Ribiero, 2018). There is some evidence that ethanol-based flex vehicles may produce less NO_x than petrol or diesel fuelled cars (Hubbard et al., 2014), but the specific context in Brazil, including their investment in ethanol production infrastructure (Anderson, 2009), may mean that flex vehicles are a less viable initiative elsewhere. Flex vehicles are different to hybrid vehicles, which are usually powered by both electric and fuel-burning engines.

Electric vehicles

Another common strategy is to encourage the population to substitute older, more polluting vehicles for newer, cleaner versions, which is most often achieved through a variety of taxation, subsidies and funding. Electric vehicles are the most high-profile cleaner car, and the proportion of the vehicle fleet made up by electric cars worldwide is increasing (International Energy Agency, 2018b). Electric vehicle uptake spans the strategies and technologies distinction, since this new technology can only make a positive impact on air quality if the population changes their buying behaviour and begins to use them. The majority of EU member states offer tax incentives or grants for buying and running electric vehicles (ACEA, 2018b). On a smaller scale, San Paulo does not tax electric or hydrogen vehicle imports (Slovic and Ribiero, 2018), and Southampton City Council used a DEFRA Air Quality Grant to fund cash-back for taxi drivers to replace polluting vehicles (Centre for Cities, 2018). By contrast, cities around the world, including Mexico City, Athens, Paris and Madrid, plan to employ a legislative approach by banning diesel vehicles from city centres by 2025; and many countries have pledged to stop new petrol and diesel car sales by a set year, for example France and England by 2040 (Oltermann, 2018).

The International Energy Agency (2018b) predicts that under the policies and measures that governments around the world have already put in place, the global stock of electric vehicles will reach 13 million by 2020 (up from 3.7 million in 2017) and nearly 130 million by 2030. Electric vehicles produce no tailpipe emissions whilst being driven, but consideration must be paid to how the electricity that powers them is generated, as well as whether they are charged in the daytime or at night (Li et al., 2016). Electric vehicles also still produce particulate matter resulting from tyre and brake wear and road abrasion. In the UK in 2015, the latest year for which statistics are available, 31% of PM_{10} emissions from road transport were from tailpipes, 45% were from tyre and brake wear, and 24% were from road abrasion (Department for Transport, 2017).

In the longer term, there is a movement towards electric vehicles becoming autonomous, i.e. not requiring a human to drive them. Autonomous vehicles may have a positive impact on air quality by mitigating the human tendency for stop-start driving, as well as breaking, and via vehicle platooning, where a number of vehicles travel closely together to improve aerodynamics (Howard, 2016). A drawback of the increasing proportion of electric vehicles is that if numbers continue to grow as predicted, there may be the knock-on effect of reduced income from fuel duties for governments.

Roadside barriers

Roadside noise reduction barriers, like congestion charging zones, have effects on air quality without this being their original purpose. Artificial barriers tend to lead to decreased pollution behind the barrier and are therefore regarded as a promising air quality measure (Brantley et al., 2014; Tong et al., 2016). Barriers comprised of a mixture of vegetation and artificial material seem to have the most positive impact on air quality, although barriers made solely of vegetation with thick foliage are also regarded as promising (Abhijith et al., 2017).

Trees and vegetation

Perhaps counter intuitively, for the same reason that vegetation barriers can be effective in preventing the movement of pollution, trees can lead to reduced air quality within built-up urban environments. If they are planted along major roads, their canopies can act as a roof, preventing pollution from dissipating (Franklin-Cheung, 2017), However, they can still be an effective way of improving air quality in less built-up environments (Abhijith et al., 2017, Jayasooriya et al., 2017) and their leaves are capable of filtering out certain pollutants, such as NO_2, from the air (Franklin-Cheung, 2017). Guides regarding where to plant trees for optimal air quality benefit have been created, such as Morani et al.'s "planting priority index" map which ranks areas according to localised pollution levels, population density and existing tree cover (2011). There has also been research into the most effective tree species for improving air quality; conifers have been found to capture more pollution than broad leaved trees (Yang et al., 2015). Initiatives focused on planting trees, such as New York's "Million Tree Initiative," therefore, may be beneficial, but should not be seen as the panacea for air quality issues (Vos, 2013).

There is some evidence that "urban greening" initiatives, such as green walls and vertical gardens can have a positive effect on air quality due to their capacity for trapping NO_2 and particulate matter (Pugh et al. 2012). Sydney, Singapore and Mexico City are amongst the many cities worldwide to experiment in urban greening (Richardson, 2017). More research is needed to determine the effects of urban greening (Zupancic et al., 2015), but evidence suggests that urban form plays an important role in their effectiveness, for example, green walls may be most beneficial in "urban canyons", streets with high buildings along each side (Pugh et al., 2012). Consideration must also be given to upkeep costs and quantities of water required.

Air quality monitoring

Choosing the most effective air quality initiatives is predicated on knowing both the overall air pollution levels and the chemical composition of the pollution. Most countries, however, do not have a systematic approach to air quality monitoring. This results in a lack of air quality data, which undermines attempts to evaluate the effectiveness of air quality initiatives (UN, 2016). The need to expand and improve monitoring networks is consistently referenced in the literature as a fundamental prerequisite for improving air quality (for example, Craig et al., 2008; Kuklinska et al., 2015; UN, 2016). As well as the EU funded CITI-sense network, and citizen-led monitoring mentioned above, attempts being made to address this include the Chinese government's creation of a nationwide network monitoring $PM_{2.5}$ levels, the data from which is publicly available and can be checked in real time by anyone with a smartphone, much like the "LondonAir" app in England (Gardiner, 2017). The potential for monitoring to improve air quality links to the broader interest in smart cities, a term used to denote the many and combined ways that technology can be incorporated into daily urban life to improve it (Dutta et al., 2017).

Improving air quality: City case studies

In this section we examine the policy initiatives of three cities which rank highly for air quality: Edinburgh (Scotland), Honolulu (Hawaii) and Tallinn (Estonia). The World Health Organisation (WHO) Global Ambient Air Quality Database (2018) was used to select cities with the lowest combined $PM_{2.5}$ and PM_{10} concentrations and populations above 300,000.[1] Edinburgh, Honolulu and Tallinn also happen to be relatively small coastal cities, which may increase their comparability to Wales' main cities, although this was not a selection criterion. We focus on policies initiatives relating to road transport emissions, grouped into legislation and regulatory measures, "soft power" measures and financial incentives. This is by no means a comprehensive review of all policies targeting air pollution but aims to provide an overview of the types of initiatives generally employed by cities with good air quality. Table 2 provides a comparison of the policies used in each city.

Copenhagen (Denmark), Freiburg (Germany) and the city-state Singapore often feature in air quality discussions, and for this reason a brief indication of their main air quality initiatives is included as Annex 2. They have not been selected for detailed examination as they ranked less highly for air quality than Edinburgh, Honolulu and Tallinn.

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[1] Although the WHO Database does not take into account other air pollutants, $PM_{2.5}$ and PM_{10} levels are regarded as good indicators of overall air quality. The cities with populations over 300,000, identified as having the lowest combined $PM_{2.5}$ and PM_{10} levels are: Honolulu (USA), Halifax (Canada), Albuquerque (USA), Tallinn (Estonia), Colorado Springs (USA), Surrey (Canada), Tucson (USA), Seattle (USA), Helsinki (Finland), Wellington (New Zealand), Edinburgh (United Kingdom), Ottawa (Canada), Vancouver (Canada), Auckland (New Zealand), Sintra (Portugal). Out of these cities, Honolulu, Tallinn and Edinburgh were chosen for the case studies in order to provide an insight from different global regions, and to avoid an overrepresentation of cities from North America.

Honolulu

Honolulu is the capital of the US state of Hawaii, an island chain in the Central Pacific. As a US state, the overarching legislation governing air quality in the city is the US Federal Clean Air Act. Honolulu has an approximate population of 350,395 (United States Census Bureau, 2017). The city has an annual mean PM_{10} concentration of six micrograms per cubic meter of air (ug/m^3) and a $PM_{2.5}$ concentration of three ug/m^3. This is less than half of Cardiff's annual mean of 14 ug/m^3 of PM_{10} and 10 ug/m^3 of $PM_{2.5}$ (World Health Organisation, 2018).

Legislation/regulation measures

Interestingly, Honolulu has relatively few regulations that prohibit polluting activities. There are no low or zero emission zones in the city, and no existing bans on diesel and petrol cars, although the state has pledged to eliminate fossil fuel use by ground transport by 2045 (Drive Electric Hawaii, 2018). Nonetheless, Hawaii has low speed limits compared to other US states and European countries: 25mph in residential areas, 45mph on major roads in central Honolulu and 55mph on most motorways. Leaving a car engine idling whilst stationary is also illegal, with a few exceptions (United States Environment Protection Agency, 2006), although it is not clear whether this restriction is enforced.

Soft power measures

Viable alternatives to private car use, such as good public transport and cycling provision, are key to encouraging less polluting behaviours. Honolulu has an extensive public transport network, with TheBus operating 104 routes across the city. Households defined as extremely low income are eligible for subsidised bus passes, and there is a free on-demand transport service for people with disabilities (City and County of Honolulu, 2018a). Oahu island, on which Honolulu is located, has 147 miles of cycle paths, and the Department of Transportation Services is currently updating the 2012 "O'ahu Bicycle Master Plan" with a focus on extending the network of cycle lanes, including protected bicycle lanes, where there is a physical barrier between the traffic and the cycle path (City and County of Honolulu, 2018b). A bicycle sharing scheme of 1000 bicycles at 100 stations was also introduced in 2017 (Wallace, 2017).

Financial measures

Hawaii has one of the highest fuel tax rates of US states with a petrol tax of 44.39 cents per gallon, and a diesel tax of 41.83 cents per gallon over and above the baseline federal tax.

In the US the federal tax is 18.4 US cents per gallon for petrol and 24.4 US cents per gallon for diesel (American Petroleum Institute, 2018). In addition, the different states can add a further tax, which in the case of Hawaii is 18.5 US cents per gallon for both petrol and diesel.

Honolulu has another tax on top of the federal and state taxes of 16.5 US cents per gallon (US Energy Information Administration, 2018). The total fuel tax paid by motorists in Honolulu is therefore 53.4 US cents per gallon for petrol and 59.4 US cents per gallon for diesel, or 12.1 and 13.5 euro cents per litre for petrol and diesel, respectively. This is higher than the average for the US, which is 46.7 and 53.7 US cents per gallon, or 10.6 and 12.2 euro cents per litre, respectively. Although the total tax paid by motorists in Honolulu is amongst the highest in the US, it is still low in relative terms given that the US has the lowest fuel duties of all OECD countries (International Energy Agency, 2018a).

Hawaii has also encouraged electric vehicle purchase by offering federal tax credits of up to $7,500 (Hawaii State Energy Office, 2018). The state ranks second in the nation for electric vehicles per capita after California (Drive Electric Hawaii, 2018), and in 2017 had the fourth highest market share of electric vehicles (EVAdoption, 2018).

Tallinn

Tallinn is the capital city of Estonia and has a population of approximately 450,531 (Tallinn, 2018). Its particulate matter figures are 12 ug/m^3 for PM_{10} and five ug/m^3 for $PM_{2.5}$. Estonia is an EU member state and therefore subject to EU air quality legislation.

Legislation/regulation measures

Tallinn has few regulations relating to pollution from urban traffic. There are no low or zero emission zones in the city, no bans on diesel or petrol cars and no restricted idling times (European Commission, 2017-2018). There are also no targeted speed management measures, with speed limits of approximately 31mph in built up areas and between 56 and 68mph on motorways (Republic of Estonia Road Administration, 2018).

Soft power measures

In 2013 public transport in Tallinn was made free at point of use, following a referendum in which the public voted in favour of the proposal. Registered Tallinn residents can purchase a personal "green card" for €2 which allows free access to the city's bus, tram, trolleybus and train network (Shearlaw, 2016). One year after introduction there was a 14% increase in the use of public transport, implying that the scheme has achieved its goal of increasing public transport usage. Conversely, an unanticipated effect of the scheme has been a decrease in walking in favour of public transport use (Cats et al., 2017). According to the Head of the Tallinn European Union Office, the €2 green card scheme has generated an income surplus. As of 1st July 2018, every county in Estonia has the option of implementing free public transport, with the help of additional funding from the national government (Gray, 2018). Tallinn is not the only municipality to have established some form of free public transport, as similar schemes have existed in cities across the world with varying success (Perone, 2002). The German government have announced plans to trial free public transport in five main cities by the end of 2018 in an effort to cut pollution levels to EU standards (Oltermann, 2018).

Tallinn also has a relatively extensive network of cycle paths and a small bicycle sharing scheme of approximately 100 bicycles (Sixt, 2018). However, an extremely low proportion (one per cent) of the population commute by bicycle (Cats et al., 2017). The city's relatively poor weather conditions may be one of the factors influencing whether people decide to cycle.

Financial measures

Estonia has a petrol tax of 56.3 euro cents per litre and a diesel tax of 49.3 euro cents per litre (Republic of Estonia Tax and Customs Board, 2018). These taxes are roughly the averages for Europe.

Between 2011 and 2014 the national government offered subsidies on electric vehicle purchase, up to a maximum of €17,000. This was accompanied by setting up a network of 167 superfast charging stations, which take less than half an hour to recharge a car, in comparison with eight hours for most UK charging points, at a distance of no more than 60km apart. Between 2010 and 2015, Estonia was the EU member state with the second highest number of electric vehicle registrations as a share of total car registrations (Thiel et al., 2015). The number of electric cars purchased fell significantly when the scheme ended; only 43 electric vehicles were sold in 2017, equalling a market share of 0.17% of GDP per capita (ACEA, 2018a). The figures suggest that the scheme was both instrumental in encouraging electric vehicle uptake (Sahuquillo, 2017), but also did not establish enduring behavioural change regarding vehicle purchase choices.

Edinburgh

As the capital city of Scotland, Edinburgh is subject to EU air quality regulations, and like Wales, also falls under the UK Government Air Quality Strategy (2007). Despite low annual mean PM_{10} (nine ug/m^3) and $PM_{2.5}$ (six ug/m^3) concentrations (World Health Organisation, 2018), Edinburgh has suffered from high $N0_2$ levels, with five $N0_2$ related air quality management areas currently in operation in the city (Air Quality in Scotland, 2018). Edinburgh has an approximate population of 512,150 (National Records of Scotland, 2018).

Legislation/regulation measures

There are no current restrictions on the circulation of petrol or diesel cars in the city, however, the Scottish Government has announced plans to introduce low emission zones in Edinburgh, Glasgow, Aberdeen and Dundee by 2020 (Air Quality in Scotland, 2018b). This complements the government's commitment to phase out sales of new diesel and petrol cars by 2032 (Khan, 2017). Speed management measures are employed, with 20mph speed limits introduced in phases since 2015 for residential roads, shopping streets and the city centre (The City of Edinburgh Council, 2018). Idling times are also restricted according to Edinburgh Council's Air Quality Action Plan (2008), although, similarly to Honolulu, it is unclear whether the restrictions are comprehensively enforced.

Soft power measures

Edinburgh has good public transport provision, with a network of buses in operation 24 hours a day, along with 8.7miles of tram lines (Edinburgh Trams, 2018). Public transport is paid for by the user, with the exceptions of those over 60 years old and certain people with disabilities who receive free bus passes (The City of Edinburgh Council, 2018b). The city also has a relatively extensive cycle path network, and £12million funding has recently been dedicated for its extension (Edinburgh Evening News, 2017). A bicycle sharing scheme is scheduled for launch in September 2018 (Dalton, 2018).

Financial measures

In 2011 Transport Scotland launched a scheme of interest free loans for electric vehicle purchase of up to £35,000, and up to £10,000 for electric motorbikes or scooters. Although very few applications were made to the scheme during the first few years (just 18 loans were issued between 2012 and 2014), it is growing in popularity and there are plans for it to be expanded next year (Peterkin, 2018). The fuel duty in the UK is one of the highest in Europe. The tax is the same for petrol and diesel and since 2011 it has been 58 pence per litre (Department for Transport, 2017), or 63.8 euro cents per litre.

Conclusion

This short report affords an overview of the strategies and technologies for tackling air pollution worldwide, with a focus on pollutants from road transport. It also examines the policies enacted by three cities that rank highly for air quality: Honolulu, Tallinn and Edinburgh. The report findings suggest that a key way of improving urban air quality involves discouraging private use of petrol and diesel fuelled cars, and encouraging alternative forms of transport, including public transport, cycling, and electric vehicles, although electric vehicles will only reduce air pollution from tailpipe, not from tyre and break wear or road abrasion. The policy measures consistent across all three cities were: good public transport coverage, a good cycle network and financial incentives for electric vehicle purchase. With respect to the other policy measures evaluated, there was a lack of consistency between the cities, providing evidence for the intuitive claim that there are a wide variety of possible ways to achieve good air quality.

Findings also show that a combination of complementary initiatives is key to creating impact in both the short and longer term. Initiatives with evidence of positive impacts on air quality in the short term include roadside barriers and speed management measures. In the longer term, behavioural change strategies to move people away from private car use are required. There is no convincing evidence that measures which retrospectively remove pollution from the air are effective in either the short or longer term.

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Annex 1: Literature search method

Research for this report was conducted according to the principles of a systematic literature search, whilst not forming a systematic review. Both academic and “grey” literature sources (such as government and think-tank, trade press and professional associations’ publications) were consulted.

The research process was as follows:

1. The Google search engine was used to identify relevant grey literature and media sources.
2. A search of the “web of science” database was conducted using the following search terms:
    - TS=("air quality" AND technolog* AND "best practice" NOT indoor)
    - TS=("air quality" AND polic* AND "best practice" NOT indoor)
    - TS=(international AND "air quality" AND polic* AND government* NOT indoor)
    - TS=(international AND "air quality" AND polic* AND example* NOT indoor)
    - TS=(international AND "air quality" AND polic* NOT indoor)
    - TS=("air pollution" near/3 technolog* NOT indoor)
    - TS=("air quality" near/5 technolog* NOT indoor)
    - TS=("air pollution" near/3 polic* NOT indoor)
    - TS=("air quality" near/3 polic* NOT indoor)
    - TS=("air pollution" AND strateg* AND improve* NOT indoor)
    - TS=("air pollution" AND strateg* AND improve* NOT indoor)
3. Relevant articles were identified and saved to a reference management software. Articles were deemed relevant if they considered policies or technologies relating to emissions, air pollution, or air quality. Articles were considered not relevant if they discussed the health impacts of air pollution without consideration of policy responses, or if they focused exclusively on greenhouse gases. After duplicates were removed, there were 172 articles.
4. Abstracts were reviewed and the most relevant articles were identified. A “snowballing” process followed as other relevant articles were identified from reference lists.

Annex 2: Additional city examples

The following cities often feature in air quality literature and discussions: Copenhagen, Freiburg and Singapore. Here we provide a brief indication of their main air quality policy initiatives.

Copenhagen, Denmark, has created a successful narrative around air quality to accompany their practical initiatives. The municipality has publicly emphasised its intention to become the world's best cycling city by 2025 and conducted publicity campaigns to promote the image of cycling as a safe, fun and fast mode of transport (City of Copenhagen, 2012). This marketing strategy is combined with investment in cycling infrastructure, for example creating cycle superhighways and integrating bus, train and metro links to facilitate movement between different modes of transport. The so called "green wave" innovation ensures that cyclists travelling at 20mph have priority over other traffic and do not have to stop at traffic lights. LED lights integrated into the tarmac along cycle routes light up when a cyclist is travelling at 20mph to indicate that the next traffic light will be green when they reach it (Gössling, 2013). Urban planning regulations also dictate that commercial buildings provide 0.5 bicycle spaces per employee, and residential buildings have 2.5 bicycle spaces per 100 metres squared (Centre for Cities, 2018). As a result of this combination of initiatives, 62% of the population use bicycles as their primary transport on their daily commutes, and 41% of all trips to and from the city are made by bicycle (Centre for Cities, 2018). Copenhagen's promotion of cycling, however, began much earlier than most other cities, and so their successes must be considered in this context (Santos et al., 2010).

Freiburg, Germany, is engaged in a long-term strategy to reduce private car ownership by making it expensive and inconvenient, whilst making public transport cheap and convenient (Centre for Cities, 2018). In parts of the city, building regulations prevent parking spaces being built with new houses. Instead, car parking is expensive and restricted to designated car parks on the outskirts of the residential area. To make up for these inconveniences, housing and public transport costs are subsidised, and there is an easily accessible car sharing system. As a result, over the past three decades public transport use has doubled and trips by bicycle have tripled, although the reduction in trips made by car has been more modest- down from 38% to 32% (Centre for Cities, 2018).

As a micro island state, Singapore's policies may not be directly applicable to the context of Wales. Nonetheless, it is worth acknowledging Singapore's handling of air quality as it often features in air quality literature.

Singapore has a precedent of using a combination of financial and legislative measures to reduce private car use, with the primary aim of lessening traffic congestion. A variety of taxes are in place both for purchasing and using private vehicles, including registration fees, import duties, and an innovative electronic road pricing scheme to name but a few (Santos et al., 2004). These are combined with significant investment in public transport, and there is an integrated network of trains, buses, walking paths and cycle lanes. There are currently plans to increase the number of integrated transport hubs where people move between forms of transport (UN, 2016). These measures have created a "virtuous cycle" effect, in which increased public transport use has led to a better service, which in turn increases usage (Santos et al., 2004).

The state has also encouraged feelings of community ownership over environmental issues through public and stakeholder engagement. For example, "Community and Youth for the Environment" days are held annually, and private sector partnerships have been created, including the "Energy Efficiency Network" (Hesketh et al., 2017).

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