Garbage In, Gospel Out? - Air quality assessment in the UK planning system

Dr Ashley Mills, Professor Stephen Peckham

Centre for Health Services Studies, University of Kent, UK

Abstract

In the United Kingdom, the planning process requires applicants to submit an air quality impact assessment wherever an impact on national limit compliance is likely, and this factors into the resultant decision. We identify flaws in the current methodological frameworks and policies associated with this process that in the worst cases could lead to poor decision making. We give examples of how inaccurate data is certified as good through unsuitable pre-processing, how these errors are then amplified by bad modeling practice, and how the final data is judged against metrics that are ill informed to arrive at decisions. We then discuss the implications and propose a way forward.

Keywords: Air quality, AQMA, UK regulation, Planning

1. Introduction

In the United Kingdom, local authorities have the power to decide on planning applications within their district boundaries and for infrastructure under their control. After an applicant submits a planning application along with supporting documentation the case is put out for a period of public and statutory consultation before being decided by the authority's planning committee to make a decision (note that some minor developments can be decided immediately by powers delegated to the planning officers).

Planning decisions, and in particular objections, cannot be based on arbitrary or subjective arguments, but must be linked directly to tangible material conditions. These conditions are outlined by the government in its National Planning Policy Framework (NPPF) document [1], and by each lo-

Email address: ajsm@kent.ac.uk (Dr Ashley Mills)

cal authority in its respective Local Plan document. Air quality is one of these conditions.

Following the EU's 2008 Ambient Air Quality Directive [2] the UK government was in agreement to reduce the levels of key pollutants to specified annual limit values by 2010. Failing to do this, the The Air Quality Standards Regulations 2010 [3] redefined these limits and extended the deadline to 2020. The government is obliged to define an Air Quality Strategy (AQS) with a view to achieving this.

In order for the UK to meet the imposed limits, every location in the UK where the public are significantly exposed, must meet the imposed limits. It is for this reason that practical responsibility for fulfilling this obligation is distributed to local authorities.

Local authorities are required under part IV of the Environment act 1995 [4] to assess their compliance to the national AQS objectives by engaging in Local Air Quality Management (LAQM). This requires them to identify areas of concern, known as Air Quality Management Areas (AQMA), that either exceed or are likely to exceed national limits. These AQMAs once identified must then be the subject of a defined Air Quality Action Plan (AQAP) whose goal is to eliminate the identified concerns.

The law states that both the AQMA and associated AQAP's must be regularly reviewed and the local authority must submit an Annual Status Report (ASR).

The NPPF lists air quality as a direct material consideration and requires that air quality must be considered whenever there is a likely impact on an AQMA or on the observance of limit values, and a local authority should ensure that developments are consistent with its AQAP.

There is robust evidence linking exposure to air pollution to a variety of negative health outcomes [5, 6], and the emerging evidence base reviewed in [7] indicates that the harms attributed to air pollution may apply to a wider variety of health indicators and diseases than is currently assumed.

In the UK, the Committee on the Medical Effects of Air Pollutants (COMEAP), managed by Public Health England, is tasked with regularly reviewing the health effects of air pollution [8]. The implementation of the regulations discussed above, as enacted through Defra technical guidance [9, 10], relies heavily on NO_2 measurement. Whilst the specific effects of NO_2 are hard to untangle from co-varying pollutants such as PM mass, it is clear that annual NO_2 measurements are a marker for pollution severity and the associated severity of health effects [11].

It is important therefore that the air quality impact assessment methodology used by local authorities, which relies heavily on NO_2 measurement, produces outputs which reflect the actual risks to health, so that appropriate mitigation may be sought, or in the worst cases, planning refused.

Defra's technical guidance documents, both the general technical guidance [9], and the NO_2 specific guidance [10] are used routinely as standards against which to judge a planning applicant's air quality impact assessment. These documents undergo no formal blind peer-review process and contain some advice without empirical support. The general technical guidance implicitly and explicitly allows for the use of data with large uncertainties, and makes no requirement for empirical measurement of current pollution or traffic levels as a basis for pollutant prediction. It is reasonable to ask therefore whether the application of this guidance could lead to suboptimal planning decisions being made.

In this paper we identify and describe three specific methodological failures. We begin in Section 2 by revealing how much of the data used to make decisions not only has a high degree of uncertainty, but that these uncertainties can be increased by following the guidance. In Section 3 we explain how these data are then used to model the impact of developments and how the guidance permits the amplification of any uncertainties. In Section 4 we explain how the standards against which the resultant impact assessment is judged fall far short of their stated goal of protecting public health. In Section 5 we discuss the implications of these findings and outline the way forward. Section 6 concludes.

2. Diffusion tubes as an authoritative data source: garbage in - gospel out?

A phrase which has been popularised by computer and mathematical sciences is garbage-in garbage-out. The phrase serves to underline the importance of using accurate data in modeling and decision processes, both because of the obvious importance of the truth of initial assumptions as well as the tendency of mathematical approximation systems to amplify errors. A mutation of this phrase garbage-in, gospel-out refers to the situation where computer outputs are treated as unquestionable facts without proper understanding of the transformative processes involved or their relation to the veracity of the inputs [12].

The main source of empirical data for pollution modeling and decision making is NO_2 diffusion tubes. Diffusion tubes are cheap and easy to use which allows cost-effective indicative monitoring on a wide spatial scale. The problem is that they are indicative: Defra's diffusion tube guidance [10] states that *"NO_2 diffusion tubes are an indicative monitoring technique"*. This diagnosis is confirmed by a systematic review concluding an accuracy of around $\pm 25\%$ [13] with a tendency of them to over-estimate relative to reference equipment [14].

Whilst it would be unfair to call NO_2 diffusion tube data garbage, they have a high degree of uncertainty. Given the heavy use of diffusion tubes to directly inform planning and air quality management decisions it should be of concern that such large uncertainties are permitted. Section 7.179 to Section 7.199 of Defra's general technical guidance [9] describes a methodology to compensate for this uncertainty.

This methodology is useful as it creates a normalised view of indicative measurements taken across a wide variety of environments and conditions. This is a helpful low-cost addition to the air quality measurement toolbox, particularly when observing annual changes in well-established AQMAs. Over time it is also a useful way to build evidence for identifying novel areas of concern. However, when it is used without proper consideration, and particularly when it is used with short-term measurements it has the potential to lead to an amplification of errors as explained below.

To compensate for under/over estimation in results local authorities are encouraged, although not required, to co-locate diffusion tubes (usually three, known as a triplicate) with a continuous monitor for at least 3 months. This serves to assess the diffusion tube intra-variability, known as precision, as well as accuracy.

By comparing the averages of co-located tubes with those of the reference equipment a "bias factor" can be derived for the diffusion tube measurements which, when applied, minimises the difference between them and the reference measurements for the given site.

Local authorities are encouraged to send their bias factors to Defra who maintains a database of results, partitioned by measurement year, local authority, tube preparation strategy, and analytical laboratory employed.

Section 7.195 of Defra's general technical guidance [9] states that "local authorities should compare the results of correcting data by the locally derived factor" and look out for differences. In the case of significant difference the same guidance advises "the national factor is likely to be more reliable".

Laboratory	**Method**	**Smallest Bias**	**Largest Bias**	**Bias Spread**	**Num Studies**
Staffordshire Scientific Services	20% TEA in water	-30.4	46.7	77.1	19
Gradko	20% TEA in water	-7.9	59.2	67.1	39
Gradko	50% TEA in acetone	-31.4	28.4	59.8	25
ESG Didcot	50% TEA in acetone	0.9	58.6	57.7	30
Edinburgh Scientific Services	50% TEA in acetone	10	57.3	47.3	6

Table 1: Smallest bias, largest bias, and computed bias spread for the five laboratory/method combinations with the largest intra-group difference. Number of studies are also shown.

Defra provides a spreadsheet interface to this database called the "National Diffusion Tube Bias Adjustment Factor Spreadsheet" [15] which allows a local authority to select the analytical laboratory employed, tube preparation strategy, and measurement year to obtain the "orthogonally" averaged bias factor across submitted results [16].

Examination of the variability of results in this spreadsheet highlights the potential for errors in accuracy. Using the September 2018 spreadsheet, statistics were computed for each combination of laboratory and tube preparation method to assess the potential for error in using this spreadsheet tool. The five results with the biggest in-group differences are shown in Table 1

In the worst case, for Staffordshire Scientific Services / 20% TEA in WATER, diffusion tubes were found to under-estimate the reference by 30.4% (bias factor 1.44) in one study where they were used and over-estimate by 46.7% (bias factor 0.68) in another study. The orthogonal average, and thus recommended bias correction is given as 0.88 for the 19 studies.

In practice if this tool were blindly applied by a developer or local authority to a diffusion tube average of 30 µg/m^{3}the recommended bias correction would yield 26.4 µg/m^3. But we know from the evidence above that the actual case could potentially be 20.4 µg/m^{3}for the worst over-estimator, and 43.2

µg/m^{3}for the worst under-estimator. This is significant because 40 µg/m^{3}is the annual limit value for NO_2 and the value at which the instantiation of an AQMA would be required. The tool has the potential to make the same measurement look either nothing to worry about or a great concern, and thus is not very informative.

This isn't just a theoretical concern, and to give just one example: the Greater Manchester Combined Authority submits a single ASR encompassing the results for ten sub-authorities. The NO_2 results in the ASR for 2016 [17] are bias-corrected using the national factor derived from the Defra spreadsheet, and ignore the locally computed bias factors for each sub-authority. One of the sub-authorities is a contributor to the Defra tool, and appears in Table 1 as a worst case example. The conclusions of the report might therefore be based on misleading data as a result of the recommended processing.

Although the worst case examples are important, and as demonstrated above are directly influencing policy, it is interesting to ask what the general likelihood of data misinterpretation is when using the Defra spreadsheet.

We have seen that in the tool each laboratory/analysis type tuple provides a bias adjustment against which the guidance encourages that other results in the same category should be corrected toward. The dataset allows us to compute for each locally computed analytical result that contributes to a given category, the difference between the recommended bias adjustment and the locally computed result.

We can ask the question for each category, and for each contributory local result: if we assume that after correction with the locally computed bias the local result would equal 40 µg/m^3, then what would the local value look like if corrected using the category bias adjustment? This way we can construct a distribution plot for each category centered around the national limit of 40 µg/m^{3}to get an overall view of the practical effect of the tool for the measurement points provided. A histogram of this computation is shown in Figure 1.

We can now ask the question, how likely is it that a 40 µg/m^{3}threshold based decision will be "incorrect" based on correction with the national bias adjustment instead of the locally derived bias adjustment? Approximately 46% of the national bias spreadsheet corrections, underestimate NO_2 with relative to the locally derived bias correction.

Table 7.1 of Defra's general technical guidance [9] lists criteria for screening road traffic sources of pollution for air quality management significance, and recommends that roads within 10% of objectives should be considered for

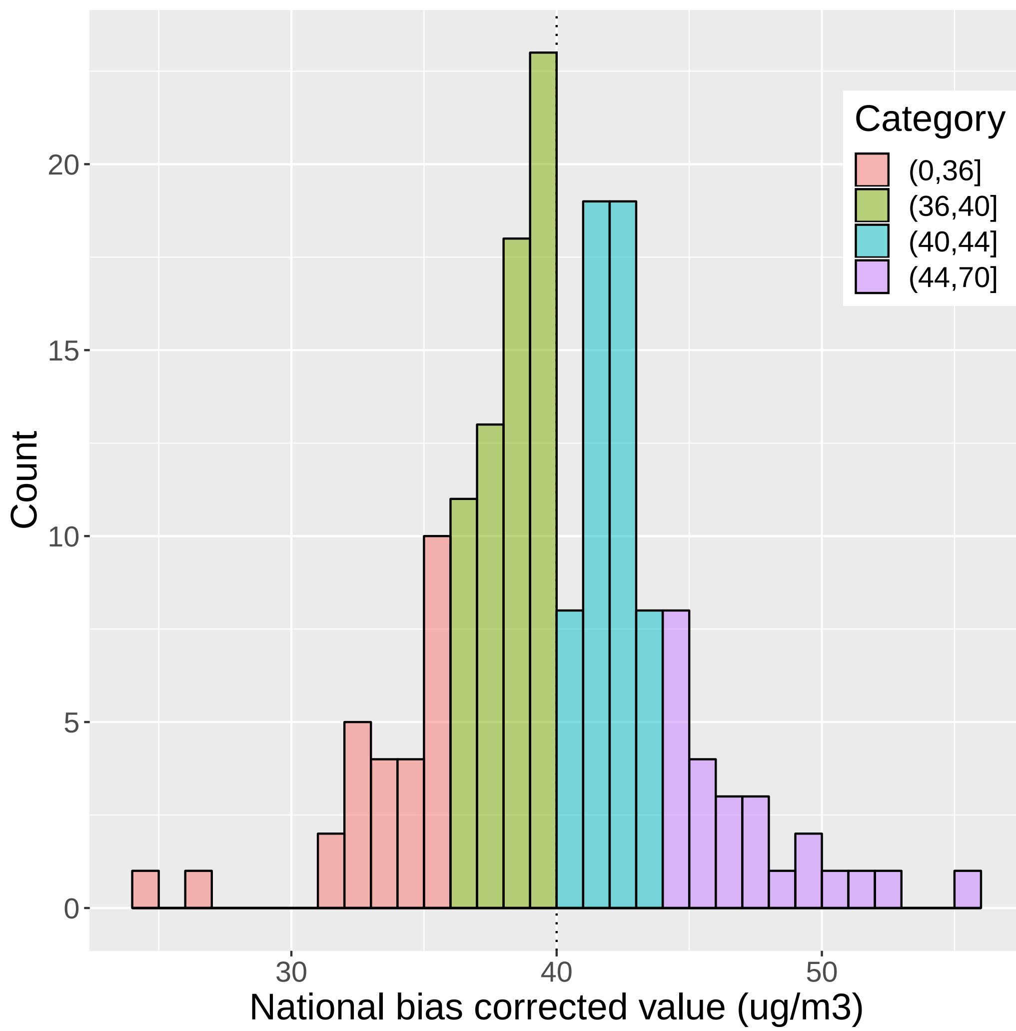

Figure 1: National bias spreadsheet "correction" applied to all current Defra tool contributory result values that would correct to 40 µg/m^{3}if the locally derived bias correction were used.

further assessment. This is a more conservative position, and is favourable for health. Still in this case, 15% of national bias spreadsheet corrections would fall out of consideration despite having a value of 40 µg/m^{3}after correction with the locally derived bias correction. In total 30% of values after correction with the tool are outside of 10% of the actual value.

The Defra bias correction spreadsheet is always based on the latest annual local authority co-location results submitted, which for the tool examined above was 2017. The tool however embeds all local-authority submissions for every previous version of the tool since 2011, a total of 2376 submissions, 2329 of which have computed bias adjustment factors associated with them.

Each local authority submission lists the co-location result against the automatic analyser result, so it is possible to compare the error associated with no bias-correction with that of correcting with the recommended bias adjustment factor. Table-2 summarises the results of this computation using the 2017 data only (171 studies) and the complete available dataset.

	Mean Absolute Error (µg/m^3)	**Error Variance**
2017 before correction	6.70	32.6
2017 after correction	3.35	8.47
2011-2017 before correction	6.87	43.4
2011-2017 after correction	3.63	10.5

Table 2: Comparison of pre and post bias adjustment errors for the Defra spreadsheet tool using only the 2017 data (latest tool incarnation), and all of the data contained in the tool.

The tool has the effect of reducing both the mean absolute error and also the error variance. Figure 2 provides a density plot of the complete dataset before and after bias correction.

The figure illustrates that diffusion tubes tend to over-estimate NO_2 relative to automatic analysers, but that the correction methodology, whilst reducing the error spread, results in an increase in the number of points that under-estimate NO_2 relative to automatic analyzers.

Finally we can compare the error pre and post adjustment for each study location, and quantify the extent to which the Defra spreadsheet improves accuracy. The results of this are shown in Table 3

In the majority of cases, the tool results in an improvement in accuracy relative to no bias correction, but in about 30% of cases, the tool degrades accuracy. Figure 3 plots the error distributions for the instances where the Defra bias adjustment tool improves or degrades accuracy relative to no bias adjustment.

The figure illustrates that when the Defra bias adjustment tool improves accuracy, it tends to increase the original NO_2 measurement, whereas when it degrades accuracy it tends to reduce the original NO_2 measurement.

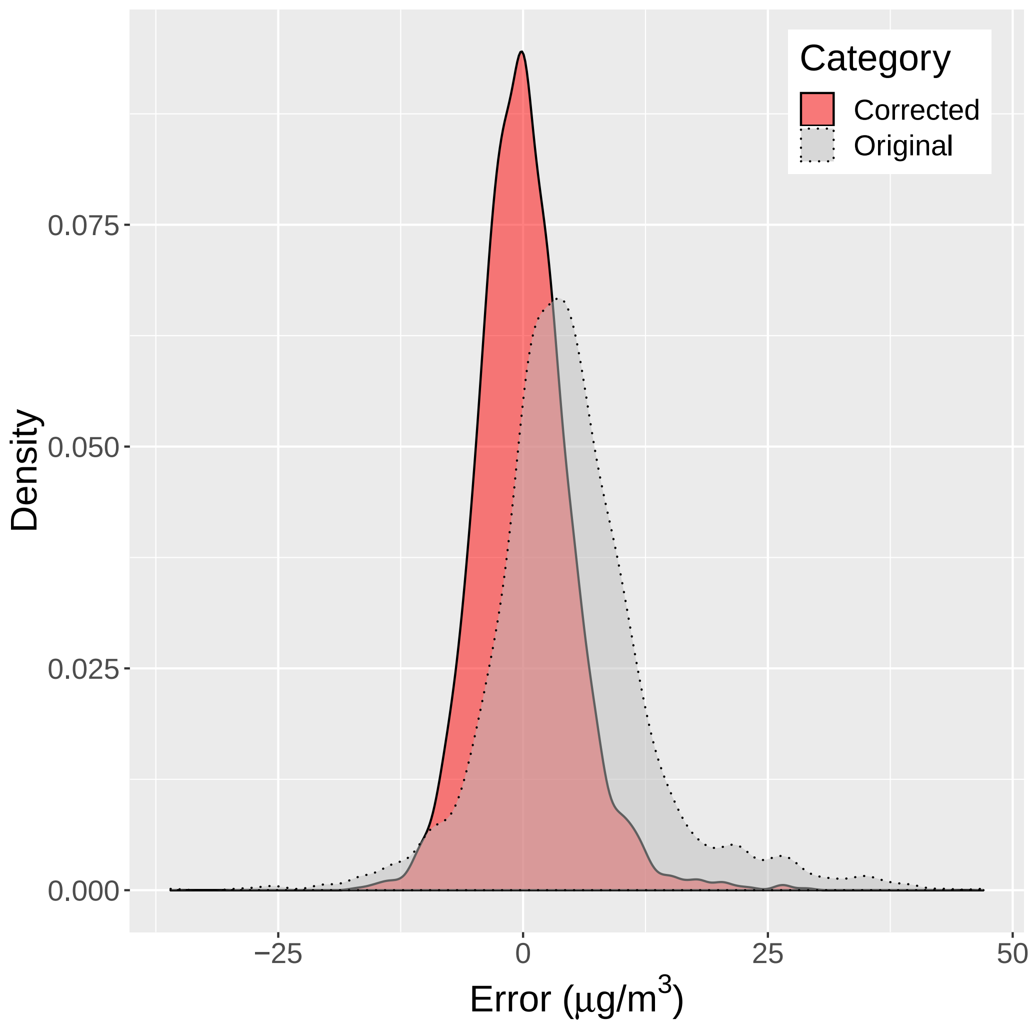

Figure 2: Complete Defra bias adjustment spreadsheet dataset density plot, comparing error before and after bias adjustment according to the tool recommendations

	% of studies improved by tool	**Mean improvement (µg/m^3)**	**% of studies worsened by tool**	**Mean degradation (µg/m^3)**
2017	71.3	7.08	28.7	4.36
2011-2017	67.5	7.18	32.2	3.81

Table 3: Performance of Defra's bias adjustment tool relative to no bias correction

What could possibly be causing such large variations in bias calculation even within tubes from the same laboratory and preparation method? In many cases, the co-located tubes are triplicated to rule-out intra-batch inconsistencies so it would seem that the exposure conditions themselves are to blame.

One study that argues for the validity of the UK diffusion tube methodology [18] by comparing diffusion tubes with chemiluminescent analysis, found differences in some cases of more than two standard deviations, which highlights the large errors individual locations may be subject to relative to reference equipment. Another study which looked at roadside vs background biases found only a small difference between the two conditions [19], but the scatter plot for the complete dataset showed large bias factor variances overall, consistent with those observed in the Defra tool data.

At the present time there is no complete explanation for the observed bias factor variances. Meteorological variables can have a significant impact [20], and local gas interactions are thought to contribute [21]. In general however, it seems apparent that bias factors can be location specific which calls into question the very idea of applying a bias correction from one location, to another, which is how local authorities correct their diffusion tube datasets at present.

The Defra spreadsheet, by collating results and deriving an orthogonal average, hides these location effects. This doesn't make any sense since we are interested in the actual value at a given location, not a corrected value that takes into account the idiosyncrasies of every other location used to derive the bias factor.

The situation is worsened by the frequent absence of diffusion tube data for the areas proposed for developments. To give an example, the 4000 home Mountfield development proposed for Canterbury covers 565 acres on the outskirts of the town: an area not currently monitored by the local authority.

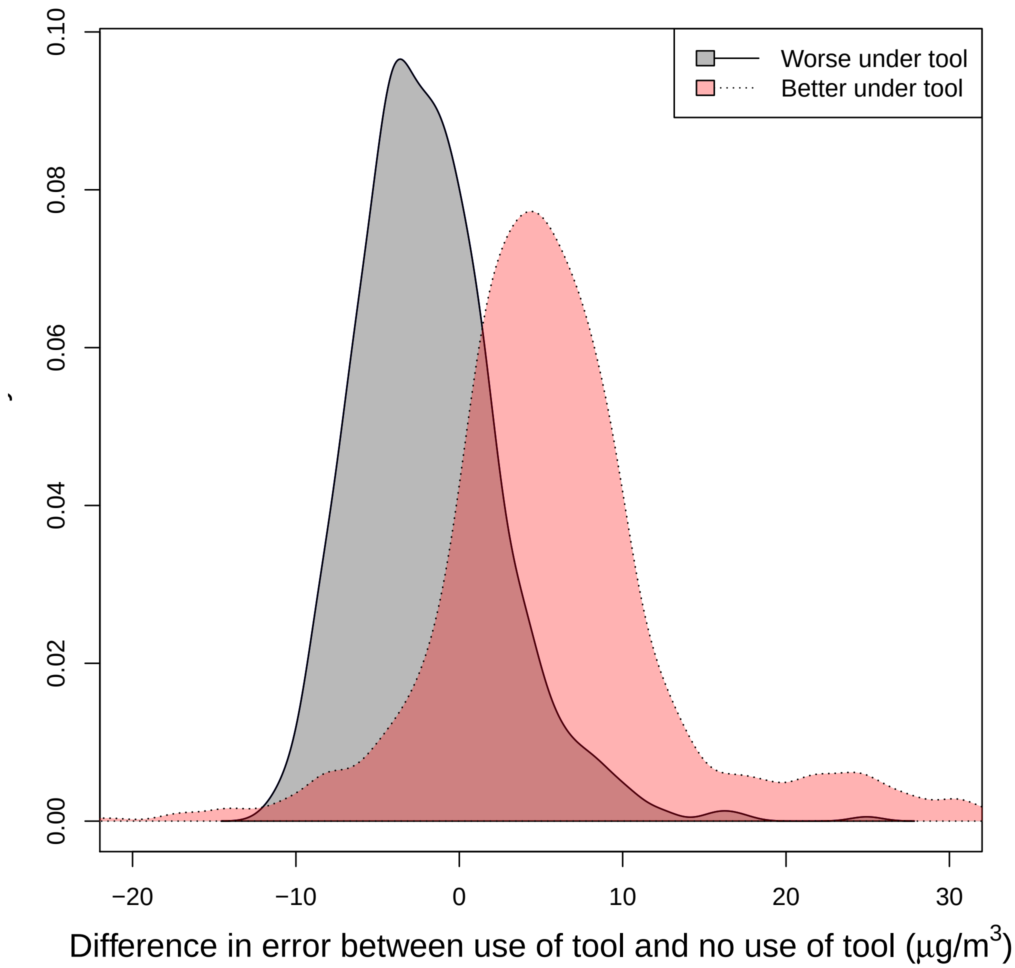

Figure 3: Comparison of errors for the cases where the Defra bias adjustment tool improves accuracy relative to no bias adjustment, and those where it reduces accuracy.

This means that the data available is not only inherently uncertain, but also not location relevant to the area being modeled.

The problem outlined here stems from the use of an inaccurate technology: diffusion tubes, applied to a decision making process that treats the outputs as if they were accurate: uncertainty in, gospel out. In the absence of being able to properly account, and correct, for the difference between diffusion tubes and reference locations, a task that is probably impossible due to their inherent uncertainty, the only solution is to use a more accurate technology.

3. Amplifying errors - using uncertain data with permissive modeling

An air quality impact assessment from a planning applicant will contain predictions of key pollutants at representative "receptors" within and around the proposed development based on estimates (or measurements in rare cases) of current levels.

Predicted outcomes depend heavily on assumptions made about current pollutant and traffic levels, and predictions based on unsound assumptions are likely to be wrong. The last section looked at the inherent flaws in the use of NO_2 diffusion tube data: how diffusion tubes are both inherently inaccurate and how correctly following the Defra guidance documents and spreadsheet tool can in some instances lead to further uncertainty. This section explains how NO_2 diffusion tube data (and sometimes other data) is used as a basis for modeling and how the general technical guidance [9] permits the amplification of input uncertainties

First we outline the air quality modelling approach recommended by Defra [9], and which is adopted by most planning applicants. This is to give context for the illustration which follows of how the guidelines allow errors to be amplified.

3.1. An overview of the air quality modeling process

Air quality modeling is necessary for two reasons:

1. To estimate the value of a given pollutant at locations where it is not measured.
2. To estimate the value of a given pollutant for a time period (usually the post-development future) other than the current time.

It is easier to understand these as two separate activities although they are often combined into one process. Estimating the value of a given pollutant at a location where it is not measured is performed as follows:

1. Current values of the pollutant are measured at (preferably multiple), known roadside locations, or historic measurements at known locations are obtained.

2. Traffic flows are apportioned to the road network within the modelled area according to measured traffic counts and then extrapolated to roads for which counts are unavailable according to models of expected vehicle behaviour based on observed route probabilities.
3. A vehicular Emissions Factors Toolkit provided by Defra [22] is used to predict pollutant values from the expected traffic flows and observed fleet composition. This gives a model of pollution based on roads (line sources).
4. Dispersal software is used to predict how pollution generated by the line sources computed in the last step, spreads out to the surrounding area. Typically this is done to give values for a number of specific locations known as "receptors".
5. The model is calibrated by comparing its predictions against reference locations where the pollutant values are actually measured, to derive a linear scaling factor that minimises any discrepancy.
6. The scaling factor is applied to all predictions given in step 4 to give a final prediction for each receptor site.

To estimate future pollutant values from current measured and modelled values:

1. Background values for the given pollutant are obtained using values provided by Defra [23].
2. The difference between the background and measured/predicted roadside levels as computed in the above process is taken to be the traffic contribution.
3. Traffic growth estimates are obtained from local authority predictions or the Department for transport [24]
4. The traffic contribution calculated in step 2 is scaled according to the obtained growth estimate
5. The estimated future background level is obtained from Defra [23]
6. The predicted future traffic contribution is added to the estimated background level to give the predicted future total pollutant concentration

3.2. How the guidance permits amplification of input errors

As explained above, road dispersal software is used to predict the value of a pollutant based on emission from a series of line sources (to represent roads) [25]. Evaluation of commonly used road dispersal software has shown that they can both under and over predict pollutant values [26, 27]. To correct for this a linear model is regressed, that is a coefficient is determined for a line such that it minimises the distance between modeled and actual pollution, for a number of known data points.

Box 7.14 of Defra's general technical guidance [9] states that:

"In order to provide more confidence in the model predictions and the decisions based on these, the majority of results should be within 25% of the monitored concentrations, ideally within 10%"

Since this guidance makes no strong requirements, in the worst case all of the points that underestimate the pollutant could be at -24.9% relative to the actual value and and all of the points that overestimate the pollutant could be at +24.9% relative to the actual value.

From the perspective of establishing AQMAs the presence of receptors within 10% of the national AQS limits would motivate an argument for extension of an AQMA. So in the worst case, there will be actual underestimates of upto 25% that would fall by a significant margin of any consideration for creation of an AQMA, yet if their actual values were observed, they would exceed the AQS limits.

In addition to a permissive attitude toward large modeling uncertainties, the general technical guidance offers no protection against poor calibration. The general technical guidance states in Section 7.562 that NO_2 predictions should be validated using regression against continuous monitoring sites, and in there absence, diffusion tube results. This guidance states that it "*is considered better to have multiple sites at which to verify results rather than just one*" but without strong requirements, this is in practice ignored. For example, air quality modeling for a planning application in Borden Village, Kent [28] used only two diffusion tube sites to verify its model. The planning application was approved.

The lack of a strong requirement for validation opens the door for planning applicants to pick the comparison points to create an overall picture favourable to themselves, either willfully or through ignorance.

Dispersal modelling also requires accurate wind speed and direction [25]. Section 7.476 of Defra's general technical guidance [9] says of meteorological data: "*It is particularly important that the data are representative of the area under study.*". Since this is guidance and not a legal or statutory framework, it is possible for data to be used that is not representative, for example in the planning case previously mentioned, a wind rose from 2 years prior to the application date and 45 miles away from the site was used. This showed a different prevailing wind direction and rose shape than that of locally available weather data from Borden grammar school.

We have seen that the technical guidance not only permits the use of highly uncertain data, but allows it to be used carelessly due to a lack of strong requirements, as demonstrated with reference to a specific planning application. In the next section we will look at how these data are examined to arrive at decisions.

4. Unhealthy decision making - the gulf between regulatory limits and health risks

The annual regulatory limits for NO_2, PM10, and PM2.5 in the UK (and EU) are 40 µg/m^3, 40 µg/m^3, and 25 µg/m^{3}respectively [29]. The World Health Organisation reviewed the health risks associated with key pollutants in 2005 [30] and, adopted 40 µg/m^{3}as a guideline for NO_2, the same as the UK limit, but adopted 10 µg/m^{3}for PM2.5 and 20 µg/m^{3}for PM10, that is half the respective UK limits for particulates.

Since 2005 the research picture has changed significantly, and a 2016 comprehensive review by the Royal College of Physicians concluded that *"Neither the concentration limits set by government, nor the World Health Organisation's air quality guidelines, define levels of exposure that are entirely safe for the whole population."* [5]

Fundamentally, the air quality regulatory framework in the UK does not protect population health. There are an estimated 40,000 annual deaths attributed to air pollution in the UK [5] under the current regulatory regime, and despite repeated calls for action by medical authorities [31, 32], there is no scheduled adjustment to the limit values.

The significance of this with respect to planning is that anything under these thresholds is considered "safe" and not cause for concern, this is reflected in comments made by planning applicants, using [28] as an example:

"NO_2 and PM10 concentrations are predicted to be below the relevant objective limits across the Site, therefore the impact with regards to new exposure would be low."

The planning inspector's final report [33] for this application echoes these sentiments, making reference to PM10 averages of 17.2 µg/m^3:

"The values are so low as to make them not significant compared with the guideline value of 40 µg/m^3."

Despite not being significant to the local authority, calculating PM10 mortality using WHO's AirQ+ tool [34] indicates that an extra 1 or 2 deaths per year are attributable to air pollution at current levels in the parish where the application was approved.

This disregard for sub-limit levels of pollution is codified in planning guidance adopted by many local authorities in Kent [35] where the screening criteria essentially exclude non-major developments and developments that fall outside of existing AQMAs from requiring detailed impact assessment.

5. Discussion

We have shown in Section 2 that inputs to air quality impact assessments are often derived from NO_2 diffusion tubes which have large uncertainties and we saw that the recommended means of "correcting" uncertainty, increases uncertainty in about 46% of cases. Section 3 showed that modeling using these inputs follows a methodology that allows for the amplification of this uncertainty, and finally in Section 4 we saw that the resultant output is judged against criteria which are divorced from the known public health risks. In this section we discuss the implications of these problems an outline an approach to solving them.

5.1. Suboptimal outcomes

The identified flaws arise out of a natural conflict between methodologies which are designed to average out uncertainties over space and time, and their application to problems which assume that point predictions are both timely and location specific.

When a planning application is considered, the predicted pollutant values at receptor points with exact locations and at exact times matter. It isn't acceptable to employ methodologies that are based in large uncertainties and then apply the outputs so deterministically.

The findings here also have implications for air quality management: AQMAs must be setup wherever annual exceedances of limit values are observed. A new location may be measured for NO_2, for example, for one year and after correction with a bias factor, the local authority may conclude that conditions are satisfactory and discontinue monitoring. But we know that it is to some extent a matter of luck whether the bias factor used will accurately represent the appropriate correction for this location: a potential injustice to the local community.

Whilst we focused on NO_2 diffusion tubes as a source of uncertainty, there are other examples we could have used: Section 7.68 of Defra's general technical guidance [9] recommends using Defra background maps [23] at a resolution of 1km x 1km for model calibration in the absence of local measurements. In [36] the impact of using 0.1km x 0.1km maps to calibrate air quality models was compared with co-location calibration and results were found to differ by about 30%.

The use of background map data is very common for PM10 and PM2.5 since they are usually only monitored at continuous sites, which a local authority might have one or two of, if at all: the nearest PM2.5 monitoring station to Canterbury for example is 45 miles away. Section 2.65 of Defra's general technical guidance [9] makes a specific point of providing a list of alternatives for PM2.5 in the absence of local data. The general issue here is a lack of accurate and relevant data.

The current situation then is one where in the worst cases decisions may be informed by data that has a high degree of uncertainty, which may have been transformed in ways that increase uncertainty. But as long as the processes followed are compliant with the Defra guidance documents [9, 10], the outputs can be treated as accurate representations of reality without further scrutiny.

This is encoded in Chapter 3 of the Defra technical guidance [9] which outlines exactly how Annual Status Reports should be prepared by local authorities, which in-turn contributes to the Air Quality Action Plan framework, which is a direct consideration for planning decisions according to the NPPF.

The Environment Act 1995 [4] gives power to the secretary of state to force a review of an action plan or action if it is judged "that the actions, or proposed actions, of a local authority in purported compliance with the provisions of this Part are inappropriate in all the circumstances of the case" (Section 85, 3(c))

A Freedom of Information request addressed to Defra asking for the instances when this power has been exercised [37] reveals that as of May 2019 *"The reserve power has never been used in relation to local air quality management."*

A Freedom of Information request addressed to Defra asking to whom a local authority is held responsible to for air quality management activities [38] elicited the response *"Local authorities are responsible for developing action plans and are accountable to their electorate rather than to central*

Government."

At every level of air quality management therefore: from the precision of monitoring tools, the interpretation of data by local authorities, through to the lack of accountability and oversight by central government, there is need for improvement. We now provide some suggestions on how to move forward. In the next sections we visit the three categories discussed above in reverse order, starting with the pollutant regulatory framework which underpins the entire system.

5.2. Health-centred impact assessment and mitigation

Planning and other local authority decisions are currently being made based on comparison to limit values first enacted into law [2] in 2008. The limit for NO_2 is defined as an annual average of 40 µg/m^{3}but Public Health England, in a 2018 review of the long-term health effects of NO_2 states that long-term mortality associations have been found in *"cohorts in which the range of outdoor levels reaches as low as 5* µg/m^3 *annual average* NO_2 *concentration."*. The author committee was divided on whether to extrapolate mortality coefficients to zero but the report provides mortality coefficients defined per 10 µg/m^3. In addition, the authors estimate that by reducing mean NO_2 by 1 µg/m^{3}that *"1.6 million life years could be saved in the UK over the next 106 years, associated with an increase in life expectancy of around 8 days."*

Similarly for PM2.5 and PM10, the limits are defined as annual values of 25 µg/m^{3}and 40 µg/m^{3}respectively, whereas the World Health Organisation's 2005 air quality exposure guidelines [30] despite acknowledging that *"there is little evidence to suggest a threshold below which no adverse health effects would be anticipated"* arrives at guidelines of 10 µg/m^{3}and 20 µg/m^{3}annual averages for PM2.5 and PM10 respectively. This is challenged by a recent Royal College of Physicians review [5] which concludes that *"Neither the concentration limits set by government, nor the World Health Organizations air quality guidelines, define levels of exposure that are entirely safe for the whole population"*.

The lives of residents are directly impacted by local authority decisions, but decisions are being made using air quality thresholds which exceed the levels at which harms to health are acknowledged. This permits neglect of areas that fall short of these thresholds despite their potentially having a high health burden.

Besides the obvious health implications, local authorities are awarded Section 106 monies [39] as mitigation for air quality impacts and Defra provides damage cost guidance [40] which provides material cost estimates for each ton of NOx and PM2.5 that a development will contribute. These costs are calculated based on the estimated traffic and boiler emissions from the development, and not on the predicted pollution changes. Furthermore, there is no requirement to demonstrate that the mitigation monies be spent on actions that will actually offset the extra pollution. We argue that mitigations should be targeted toward actions that can be shown to have an impact.

In general it is necessary to move towards limit values that reflect health risks. This would undoubtedly mean that more areas would fall under AQMAs, but in many present municipalities AQMAs have existed for years without action that leads to revocation. The government maintains a register of AQMAs [41] from which we can compute that a total of 900 AQMAs have been declared, 220 of which have been revoked. Of the remaining 680 active AQMAs, the mean duration (as of 22/05/2019) is 11.6 years, the minimum 140 days, and the maximum over 20 years. Only 143 of these have ever been amended, with those having never been amended having a mean duration of 11.7 years.

Increasing the number of AQMAs to update our perception of the situation to match the health reality, should therefore be combined with a systematic government review into the effectiveness of AQMAs as a mechanism to achieve timely reductions in key pollutants.

We recommend adopting appropriate health based thresholds combined appropriately spaced stepped targets tending towards zero for 2050 to encourage aggressive action.

Further research needs to be carried out to understand the relationship between short term exposure, cumulative exposure and health outcomes since long-term averages are not necessarily representative of actual pedestrian exposure profiles: for example in [42] it was estimated that children walking to school in their study obtained 20% of their black carbon daily dose (according to U.S EPA regulations) over a time period that accounted for only 6% of the day.

Air quality relevant activities such as planning decisions can also occur on shorter timescales than a single year so it would be useful to be able to characterise the health risk of a location without having to monitor for a year.

5.3. Modeling regulations rather than guidance

We saw in Section 3 that Defra's general technical guidance [9] permits amplification of input errors by permissive bounds on model accuracy. This is a combination of permitting a large margin for error, and allowing a small number of reference points for calibration. We would recommend that:

1. Model predictions must be within 10% of all reference points
2. Calibration of the model against at least 6 reference points

At present the guidance can be interpreted to suit the follower, and without the teeth of a legislative framework, there is little or no comeback for residents and even authorities. Defra should work towards creating a legislative instrument in place of the current guidance document which all local authorities and planners must adhere to.

There is currently too much reliance on out-of-area measurements or background maps to predict development impacts. Regulation should see the introduction of stricter controls on data immediacy, and should require measurement for major developments.

This would allow for a consistent appraisal of planning applications and AQMA assessment that is just across the board. 5.4. Data that is accurate at the point of collection

Most local authorities operate a small number of reference equipment stations, where chemiluminescent analysis is applied to measure NO_2 and either gravimetric, beta-emission based, or optical methods are used to measure particulates [43] . Local authorities are encouraged to use equipment that is MCERTS certified [44] for accuracy and Defra's AURN network uses only MCERTS certified equipment. This type of equipment is however too expensive for wide applicability, and is physically impractical often requiring its own cabinet housing and power supply. These sites are static and cumbersome to re-locate.

This has led to the proliferation of NO_2 diffusion tube use by local authorities, which are cheap, easy to use, and easy to re-locate. They have become the defacto standard for air quality management and calibration of air quality impact assessment models.

But as we have seen, diffusion tubes suffer from inherent uncertainty that is not effectively addressed by present diffusion tube guidance [10] or correction with Defra's diffusion tube bias spreadsheet [15]. It is also the case that diffusion tubes are not capable of measuring short-term changes, exposure profiles and peak levels, or the dynamic bearing that traffic management or other mitigation might have on pollution.

It seems unlikely that improvements in diffusion tube methodology can underwrite their inherent uncertainty. Correction for meteorological and location effects would likely require in-situ measurement of the relevant variables using electronic equipment, which casts doubt on their ongoing viability as a standalone technology pathway.

Diffusion tubes only monitor NO_2 and there is no equivalent technology for particulates: the latter only being monitored at reference sites: an enormous data deficit.

Recently the market has seen the introduction of so-called near-reference equipments [45, 46, 47, 48], which aspire to bridge the gap between indicative equipment such as diffusion tubes, and reference equipment such as a chemiluminescent analysers. Whilst considerably more expensive than diffusion tubes, they are priced at around 10% the cost of reference equipment but like diffusion tubes they are pole-mountable, portable, and easy to use.

Most near-reference equipment combines electrochemical gas sensors with optical particle counting for particulates. Co-location studies show promising accuracy for both low cost NO_2 [49, 50] and PM sensors [51, 52, 53, 54]. Because the sensors are electronic and have temporal resolutions on the order of minutes rather than months, it is possible to take account and attempt to correct for meteorological variables and pollution concentrations. Such equipment is particularly good for comparative analysis as the intra-variability is very low.

Defra has issued guidance on the use of low cost sensors [55] and whilst it doesn't at present provide equipment specific recommendations it points out that there is a wide variability of quality in low-cost sensors, cautions users to understand the accuracy and stability of a given piece of equipment in the context of each use case and it advocates for in-situ calibration and regular re-calibration. With all the caveats aside the guidance speculates that *"as the technology evolves applications will arise where they do bring new insight to air pollution issues."*

The World Meteorological Organisation has issued a more detailed appraisal [56] of low cost sensors, again highlighting the wide variability in technology and the lack of ongoing calibration in most cases. They summarise their applicability: *"low-cost sensors are not currently a direct substitute for reference instruments, especially for mandatory purposes; they are however a complementary source of information on air quality, provided an* *appropriate sensor is used."*

NO_2 is currently measured using diffusion tubes which are known to be inaccurate, and have no obvious technology evolution pathway, and particulates are usually only measured at reference sites. If we are to move toward accurate and low-cost electronic measurement, it is necessary to begin to adopt these technologies to feed the development pipeline.

Local authorities, with caution, should therefore begin to replace the ubiquity of indicative with diffusion tubes with appropriately sourced electronic near-reference equipment, which over time will become increasingly accurate as the technology is more widely adopted and improved upon. This will lead to decisions being based on local pollution measurements with known error bounds.

This is a particularly important step for particulates since they are currently measured only at reference sites, yet are responsible for the worst health impacts. Predictions and decisions are being made in many instances using Defra background maps to validate models instead of locally measured data.

6. Conclusion

We have shown, with reference to specific examples that the current methodologies employed for air quality assesement in the planning and air quality management arenas, allow for unsound data to receive a stamp of approval despite flaws that would allow for amplification of uncertainty, providing an unsound basis for decision making. We have explained how this problem can be addressed by taking into consideration the whole picture when it comes to health instead of just regulatory compliance, by adopting legislative instruments instead of guidance, and by improving equipment accuracy.

7. References

[1] Ministry of Housing, Communities & Local Government, National Planning Policy Framework (Jul. 2018) [cited 11/06/20199]. URL https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/740441/National_Planning_Policy_Framework_web_accessible_version.pdf

[2] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe, p. 144 (Nov. 2008) [cited 11/06/2019].
URL https://eur-lex.europa.eu/eli/dir/2008/50/oj

[3] The Air Quality Standards Regulations 2010 No. 1001 (2010) [cited 11/06/2019].
URL http://www.legislation.gov.uk/uksi/2010/1001/made

[4] Environment Act 1995. c.25 (1995) [cited 11/06/2019].
URL http://www.legislation.gov.uk/ukpga/1995/25/contents

[5] Every breath we take: the lifelong impact of air pollution. Report of a working party., Tech. rep., Royal College of Physicians, London (2016) [cited 11/06/2019].
URL https://www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution

[6] S. T. Holgate, Every breath we take: the lifelong impact of air pollution a call for action, Clinical Medicine 17 (1) (2017) 8–12. `doi:10.7861/clinmedicine.17-1-8`.

[7] P. J. Landrigan, et al., The Lancet Commission on pollution and health, The Lancet 391 (10119) (2018) 462–512. `doi:10.1016/S0140-6736(17)32345-0`.

[8] P. H. England, Reports and statements from the Committee on the Medical Effects of Air Pollutants (COMEAP) [cited 11/06/2019].
URL https://www.gov.uk/government/collections/comeap-reports

[9] D. for Environment Food & Rural Affairs, Local Air Quality Management Technical Guidance (TG16) (Feb. 2018) [cited 11/06/2019].
URL https://laqm.defra.gov.uk/technical-guidance/

[10] AEA Technology Plc, Diffusion Tubes for Ambient NO2 Monitoring: Practical Guidance for Laboratories and Users. Report to Defra and the Devolved Administrations ED48673043. Issue 1a (Feb. 2008) [cited 11/06/2019].
URL https://laqm.defra.gov.uk/documents/0802141004_NO2_WG_PracticalGuidance_Issue1a.pdf

[11] Associations of long-term average concentrations of nitrogen dioxide with mortality, Tech. rep., Public Health England (Aug. 2018) [cited 11/06/2019].
URL https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/734799/COMEAP_NO2_Report.pdf

[12] M. Ault, Combating the Garbage-In, Gospel-Out Syndrome, Radiation Protection Management 4 (4) (1987) 1–7.

[13] K. Stevenson, T. Bush, D. Mooney, Five years of nitrogen dioxide measurement with diffusion tube samplers at over 1000 sites in the UK, Atmospheric Environment 35 (2) (2001) 281–287. doi:10.1016/S1352-2310(00)00171-0.

[14] M. R. Heal, M. A. ODonoghue, J. N. Cape, Overestimation of urban nitrogen dioxide by passive diffusion tubes: a comparative exposure and model study, Atmospheric Environment 33 (4) (1999) 513–524. doi:10.1016/S1352-2310(98)00290-8.

[15] Department for Environment Food & Rural Affairs, Diffusion Tube Bias Adjustment Factors Spreadsheet (Sep. 2018) [cited 11/06/2019].
URL https://laqm.defra.gov.uk/assets/databasediffusiontubebiasfactorsv0918final.xlsx

[16] Air Quality Consultants on behalf of Defra, Methodology used in the Survey of Diffusion Tube Collocation Studies (Mar. 2006) [cited 11/06/2019].
URL https://laqm.defra.gov.uk/documents/NO2-Diffusion-Tube-Collocation-Methodology.pdf

[17] 2016 Air Quality Annual Status Report (ASR) for Greater Manchester. GMASR2016, Tech. rep., Greater Manchester Combined Authority (Jul. 2017).
URL http://www.manchester.gov.uk/download/downloads/id/25718/greater_manchester_air_quality_annual_status_report_asr_2016.pdf

[18] T. Bush, S. Smith, K. Stevenson, S. Moorcroft, Validation of nitrogen dioxide diffusion tube methodology in the UK, Atmospheric Environment 35 (2) (2001) 289–296. doi:10.1016/S1352-2310(00)00172-2.

[19] Air Quality Consultants, The Relationship Between Diffusion Tube Bias and Distance From the Road, Tech. rep., Department for Environment Food & Rural Affairs (Jul. 2006).
URL https://uk-air.defra.gov.uk/assets/documents/reports/cat05/1006161140_Bias_Adj_Dist_Road_Rept_Final.pdf

[20] H. Plaisance, A. Piechocki-Minguy, S. Garcia-Fouque, J. C. Galloo, Influence of meteorological factors on the NO2 measurements by passive diffusion tube, Atmospheric Environment 38 (4) (2004) 573–580. doi:10.1016/j.atmosenv.2003.09.073.

[21] M. R. Heal, C. Kirby, J. N. Cape, Systematic Biases in Measurement of Urban Nitrogen Dioxide using Passive Diffusion Samplers, Environmental Monitoring and Assessment 62 (1) (2000) 39–54. doi:10.1023/A:1006249016103.

[22] Department for Environment Food & Rural Affairs, Emissions Factors Toolkit (EFT) [cited 11/06/2019].
URL https://laqm.defra.gov.uk/review-and-assessment/tools/emissions-factors-toolkit.html

[23] D. for Environment, Background Mapping data for local authorities.
URL https://uk-air.defra.gov.uk/data/laqm-background-maps

[24] Department for Transport, Road traffic forecasts 2018 (Sep. 2018) [cited 11/06/2019].
URL https://www.gov.uk/government/publications/road-traffic-forecasts-2018

[25] M. G. Snyder, A. Venkatram, D. K. Heist, S. G. Perry, W. B. Petersen, V. Isakov, RLINE: A line source dispersion model for near-surface releases, Atmospheric Environment 77 (2013) 748–756. doi:10.1016/j.atmosenv.2013.05.074.

[26] R. F. Patterson, R. A. Harley, Evaluating near-roadway concentrations of diesel-related air pollution using RLINE, Atmospheric Environment 199 (2019) 244–251. doi:10.1016/j.atmosenv.2018.11.016.

[27] A. Dėdelė, A. Miškinyė, The statistical evaluation and comparison of ADMS-Urban model for the prediction of nitrogen dioxide with air

quality monitoring network, Environmental Monitoring and Assessment 187 (9) (2015) 578. doi:10.1007/s10661-015-4810-1.

[28] Entran Limited, Quinn Estates Ltd Land at Southwest Sittingbourne, Kent Environmental Statement: Updated Air Quality Chapter (Planning ref 17/505711/HYBRID), Tech. Rep. 1.3, Swale Borough Council. URL https://pa.midkent.gov.uk/online-applications/applicationDetails.do?keyVal=OYOXGETY0XJ00&activeTab=summary

[29] Department for Environment Food & Rural Affairs, National air quality objectives and European Directive limit and target values for the protection of human health [cited 11/06/2019]. URL https://uk-air.defra.gov.uk/assets/documents/Air_Quality_Objectives_Update.pdf

[30] Air quality guidelines. Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide, Tech. rep., World Health Organisation (2005) [cited 11/06/2019]. URL https://www.who.int/airpollution/publications/aqg2005/en/

[31] G. Iacobucci, Urgent action on UK air pollution is needed, say experts, BMJ 352 (2016) i1099. doi:10.1136/bmj.i1099.

[32] T. Lancet, Scale of Europe's air pollution problem demands more action, The Lancet 388 (10061) (2016) 2714. doi:10.1016/S0140-6736(16)32459-X.

[33] EXTRA-ORDINARY PLANNING COMMITTEE 30 JANUARY 2019 PART 2 Report of the Head of Planning, Tech. rep., Swale Borough Council (Jan. 2019) [cited 11/06/2019]. URL https://pa.midkent.gov.uk/online-applications/files/9579A52AE1CC5181F2C21776B08076F9/pdf/17_505711_HYBRID-Planning_Committee_Report-4490154.pdf

[34] World Health Organisation, AirQ+: software tool for health risk assessment of air pollution [cited 11/06/2019]. URL http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/activities/airq-software-tool-for-health-risk-assessment-of-air-pollution

[35] Air Quality Planning Guidance (Mitigation Option A), Tech. rep., Kent & Medway Air Quality Partnership (Dec. 2015) [cited 11/06/2019].
URL http://kentair.org.uk/documents/k&maqp_air_quality_planning_guidance_mitigation_option_a.pdf

[36] H. Khreis, K. de Hoogh, J. Zietsman, M. J. Nieuwenhuijsen, The Impact of Different Validation Datasets on Air Quality Modeling Performance, Transportation Research Record 2672 (25) (2018) 57–66. doi:10.1177/0361198118780682.

[37] Department for Environment, Food and Rural Affairs (Defra), REQUEST FOR INFORMATION: Air Quality Management - FOI2019/08443 (May 2019) [cited 11/06/2019].
URL https://www.whatdotheyknow.com/request/568959/response/1367538/attach/html/2/FOI2019%2008443%20response.pdf.html

[38] Department for Environment, Food and Rural Affairs (Defra), How are local authority Air Quality action Plans (AQAP) assessed for accuracy and practicality - A Freedom of Information Request (Nov. 2018) [cited 11/06/2019].
URL https://www.whatdotheyknow.com/request/538907/response/1288698/attach/html/2/TO%202018%2027115%20AQAP.docx.html

[39] Town and country planning act 1990 c. 8 part iii - other controls over development - section 106 (1990) [cited 11/06/2019].
URL https://www.legislation.gov.uk/ukpga/1990/8/section/106

[40] Department for Environment Food & Rural Affairs, Air quality damage cost guidance, Tech. rep. (Jan. 2019) [cited 11/06/2019].
URL https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770576/air-quality-damage-cost-guidance.pdf

[41] Department for Environment, Food and Rural Affairs (Defra), List of Local Authorities with AQMAs- Defra, UK [cited 11/06/2019].
URL https://uk-air.defra.gov.uk/aqma/list?la=all&country=all&pollutant=all

[42] M. Alvarez-Pedrerol, I. Rivas, M. Lpez-Vicente, E. Suades-Gonzlez, D. Donaire-Gonzalez, M. Cirach, M. de Castro, M. Esnaola, X. Basagaa,

P. Dadvand, M. Nieuwenhuijsen, J. Sunyer, Impact of commuting exposure to traffic-related air pollution on cognitive development in children walking to school, Environmental Pollution 231 (2017) 837–844. doi:10.1016/j.envpol.2017.08.075.

[43] Department for Environment Food & Rural Affairs, EU Standard Methods for monitoring and UK Approach [cited 11/06/2019]. URL https://uk-air.defra.gov.uk/networks/monitoring-methods?view=eu-standards

[44] CSA Group, MCERTS - The Environment Agencys Monitoring Certification Scheme for equipment, personnel and organisations [cited 11/06/2019]. URL https://www.csagroupuk.org/services/mcerts/

[45] Environmental Instruments Ltd, AQMesh small sensor air quality monitoring system [cited 11/06/2019]. URL https://www.aqmesh.com/

[46] Earthsense Ltd, Earthsense Zephyr Air Quality Monitor [cited 11/06/2019]. URL https://www.earthsense.co.uk/zephyr

[47] Envirowatch Ltd, The E-MOTE - Air Quality and Noise Pollution Monitoring [cited 11/06/2019]. URL http://www.envirowatch.ltd.uk/e-mote/

[48] Vaisala Ltd, Vaisala Air Quality Transmitter AQT420 [cited 11/06/2019]. URL https://www.vaisala.com/en/products/instruments-sensors-and-other-measurement-devices/weather-stations-and-sensors/aqt420

[49] E. S. Cross, L. R. Williams, D. K. Lewis, G. R. Magoon, T. B. Onasch, M. L. Kaminsky, D. R. Worsnop, J. T. Jayne, Use of electrochemical sensors for measurement of air pollution: correcting interference response and validating measurements, Atmospheric Measurement Techniques 10 (9) (2017) 3575–3588. doi:https://doi.org/10.5194/amt-10-3575-2017.

[50] A. Bigi, M. Mueller, S. K. Grange, G. Ghermandi, C. Hueglin, Performance of NO, NO_2 low cost sensors and three calibration approaches

within a real world application, Atmospheric Measurement Techniques 11 (2018) 3717–3735. doi:10.5194/amt-11-3717-2018.

[51] A. Narayanan, H. Paskov, N. Z. Gong, J. Bethencourt, E. Stefanov, E. C. R. Shin, D. Song, On the Feasibility of Internet-Scale Author Identification, in: 2012 IEEE Symposium on Security and Privacy, 2012, pp. 300–314. doi:10.1109/SP.2012.46.

[52] S. Steinle, S. Reis, C. E. Sabel, S. Semple, M. M. Twigg, C. F. Braban, S. R. Leeson, M. R. Heal, D. Harrison, C. Lin, H. Wu, Personal exposure monitoring of PM2.5 in indoor and outdoor microenvironments, Science of The Total Environment 508 (2015) 383–394. doi:10.1016/j.scitotenv.2014.12.003.

[53] D. M. Holstius, A. Pillarisetti, K. R. Smith, E. Seto, Field calibrations of a low-cost aerosol sensor at a regulatory monitoring site in California, Atmospheric Measurement Techniques 7 (4) (2014) 1121–1131. doi:https://doi.org/10.5194/amt-7-1121-2014.

[54] L. R. Crilley, M. Shaw, R. Pound, L. J. Kramer, R. Price, S. Young, A. C. Lewis, F. D. Pope, Evaluation of a low-cost optical particle counter (Alphasense OPC-N2) for ambient air monitoring, Atmospheric Measurement Techniques (2018) 709–720.

[55] Department for Environment, Food and Rural Affairs (Defra), 'Low-cost' pollution sensors - understanding the uncertainties- Defra, UK [cited 11/06/2019].
URL https://uk-air.defra.gov.uk/library/aqeg/pollution-sensors/understanding-uncertainties.php

[56] Low-cost sensors for the measurement of atmospheric composition: overview of topic and future applications, Tech. rep., World Meteorological Organisation (May 2018) [cited 11/06/2019].
URL http://www.wmo.int/pages/prog/arep/gaw/documents/Low_cost_sensors_18_Oct.pdf