Enhancing *Local Air Quality Management* to maximise public health integration, collaboration and impact in Wales, UK: a Delphi study

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Abstract

Background
Outdoor air pollution is a significant public health problem. The UK Local Air Quality Management (LAQM) regime is intended to protect public health through a prescribed process of assessment and collaborative action. Despite its intention and underpinning principles, public health bodies and specialists do not interact with or support LAQM as much as they could or should. This study aimed to explore and understand this disconnect, to inform action that can resolve problems and maximise public health integration, collaboration and impact in this important public health work.

Methods
The Delphi technique was used to elicit multiple viewpoints from a range of experts on this complex problem in Wales, UK. Over three iterative feedback-interspersed survey rounds, 86 expert panellists generated opinions and formed consensus on the role of public health bodies and specialists in LAQM and the added value that might be achieved as a result of increased integration and collaboration. Linked opportunities, barriers and solutions were also described. Qualitative data were subject to thematic analysis; quantitative data were analysed using descriptive statistics to assess consensus, and the Wilcoxon matched-pairs signed-ranks test to assess response stability.

Results
Consensus opinion confirmed the public health role in LAQM should support both broader mainstream risk assessment and management, and also enabling functions such as communications, research and evidence appraisal, advocacy and leadership. Linked opportunities, barriers and solutions were described so as to facilitate change. Panellists suggested that the added value of increasing integration and collaboration would be more efficient, creative and productive collaboration, meaningful risk assessments and effective action.

Conclusions
The significant role of public health in LAQM is rarely recognised or realised. The findings of this study present a convincing evidence-based case for directing and supporting much-needed change to LAQM so as to increase public health integration, collaboration and impact.

Not only has this study generated new evidence to enhance LAQM policy and practice, it has also confirmed the applicability of the Delphi method in investigating complex environmental public health problems. While some opinions generated related to Wales' unique circumstances, most were general in context and will have relevance and importance across the UK and in countries beyond where air quality management and public health policy and practice are disconnected.

Key words:

Local Air Quality Management; Air pollution; Public health; Integration; Collaboration; Delphi

Background

Outdoor air pollution poses significant public health risks. Exposure to pollutants such as particulate matter and nitrogen dioxide increases mortality and morbidity from heart disease and strokes, respiratory diseases, lung cancer and other effects (World Health Organization, 2013). The associated health and financial burdens are substantial; in the UK, the equivalent of around 40,000 annual deaths are attributed to exposure to these pollutants (Royal Colleges of Physicians and Paediatrics and Child Health, 2016) and life expectancy is reduced by 7-8 months on average for everyone (Department for Environment, Food and Rural Affairs, 2007). Through health service costs and reduced productivity from lost work-days, air pollution costs the UK about £20 billion per year (Royal Colleges of Physicians and Paediatrics and Child Health, 2016).

With air pollution regarded as the most significant environmental determinant of health (Lim *et al*., 2012), having in place an effective air quality management framework – to assess and reduce air pollution, health risks and inequalities – must be a priority. In the UK, the approach to air quality management is set out in the Air Quality Strategy for England, Scotland, Wales and Northern Ireland (Department for Environment, Food and Rural Affairs, 2007). This commits to ensure access to good quality outdoor air for all UK citizens through the implementation of two complementary approaches: i) national policy measures that drive tighter standards, technology advances and cleaner transport and industry, and ii) a statutory effects-based Local Air Quality Management process [as required by Part IV of the Environment Act 1995 (HM Government, 1995)] to support local-level collaborative action to assess and reduce air pollution to protect population health.

This paper focuses on the second of these – the Local Air Quality Management (LAQM) regime – which recognises that pollution sources are best managed at the lowest administrative level through proportionate, joined-up action that takes account of the local context (Department for Environment, Food and Rural Affairs, 2007). To tackle multi-faceted air pollution problems, LAQM relies on multi-discipline commitment and action from all relevant sectors, including transport, planning, regulation and health. Despite its public health intentions and underpinning principles, previous research has highlighted that public health bodies and specialists do not interact with or support LAQM as much as they could or should (Brunt *et al*., 2016a). Identified LAQM 'structure' and 'process' weaknesses may help explain why this is so. For example, because the public health role in LAQM has been poorly defined, public health engagement in and commitment to LAQM are limited. This has led to a growing disconnect between air quality management and wider public health policy and practice which is doing little to tackle known interactions across public health problems and solutions e.g. promoting and facilitating active travel in a population to reduce physical inactivity and achieving co-benefits of reducing vehicle use and cutting transport-related air pollution emissions. Problems are compounded by the prescribed LAQM risk assessment and action planning processes being narrow in scope; they fail to encourage the consideration of air pollution problems and solutions in a broad public health context (aligned with tackling linked wider determinants of health). Addressing these shortfalls such that LAQM becomes more public health driven and supported could, in turn, increase its effectiveness, reach and impact (Brunt *et al.*, 2016a).

This paper presents a Delphi study to explore, understand and generate new evidence to help resolve these problems. Its objectives were to form expert consensus to: clarify the role of public health bodies and specialists in LAQM, describe opportunities for, and added value resulting from, improved integration and collaboration, and highlight linked barriers and solutions. The study setting was Wales - a UK country with a population of approximately 3.1 million people. Wales was selected

because: LAQM and 'health' responsibilities are devolved from UK Government and so there is autonomy and opportunity to bring about change tailored to the country's needs; the primary public health body and its specialists form part of the National Health Service (NHS); and local government bodies – which co-ordinate LAQM implementation on behalf of stakeholders – all hold equal status. Finally, and perhaps most importantly, the Welsh Government has recently passed in Wales the pioneering Wellbeing of Future Generations (Wales) Act 2015 ("WFG Act") which calls for sustainable action, based on principles of collaboration, integration, involvement, long-term and prevention, to improve the economic, social, environmental and cultural well-being of Wales through achieving seven well-being goals (Fig.1) (Welsh Government, 2015). The WFG Act places responsibilities on all public bodies in Wales to work in these new ways through multi-agency local Public Services Boards to act to ensure the needs of the present are met without compromising the ability of future generations to meet their own needs.

Given that reducing air pollution, health risks and inequalities can help make a contribution to most if not all well-being goals, the WFG Act presents unique and significant opportunities to support LAQM enhancement and bring about necessary policy and practice change.

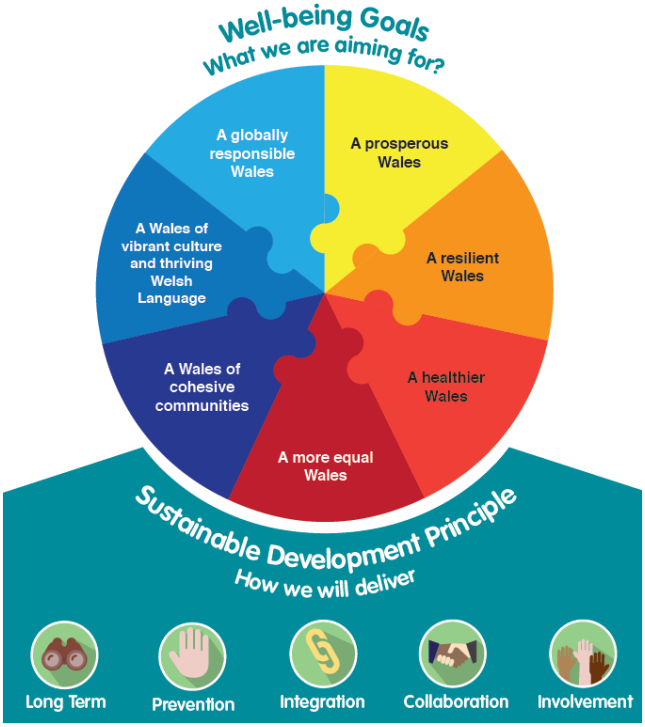

Fig.1. Wellbeing of Future Generations (Wales) Act 2015 – well-being goals

While this study considered the LAQM and public health context in Wales, the methods and findings presented will likely have relevance and importance to other parts of the UK and in countries beyond.

Methods

This study used the Delphi technique because, of all methods to generate, develop consensus of, and understand group opinion, it is asserted to be the most reliable (Moynihan *et al*., 2015; Keeney *et al*., 2011). Delphi is a mixed-methods multi-stage systematic research method that solicits real-world opinions from a panel of experts to generate, understand and form consensus on group opinion around a complex issue (Dalkey and Helmer, 1963). It is multi-stage insofar as it involves iterative survey rounds interspersed with controlled feedback; each stage builds on the preceding one and the whole process is guided by principles of democratic participation and anonymity (Day and Bobeva, 2005). It assumes that group opinion - especially of experts - is more valid and reliable than individual opinion(s) (Keeney *et al*., 2011). In this study, to strike an appropriate balance between forming consensus and risking expert attrition, the number of survey rounds was restricted to three (Fig.2) (Bloor *et al*., 2015; Radestad *et al*., 2013; Boulkedid *et al*., 2011).

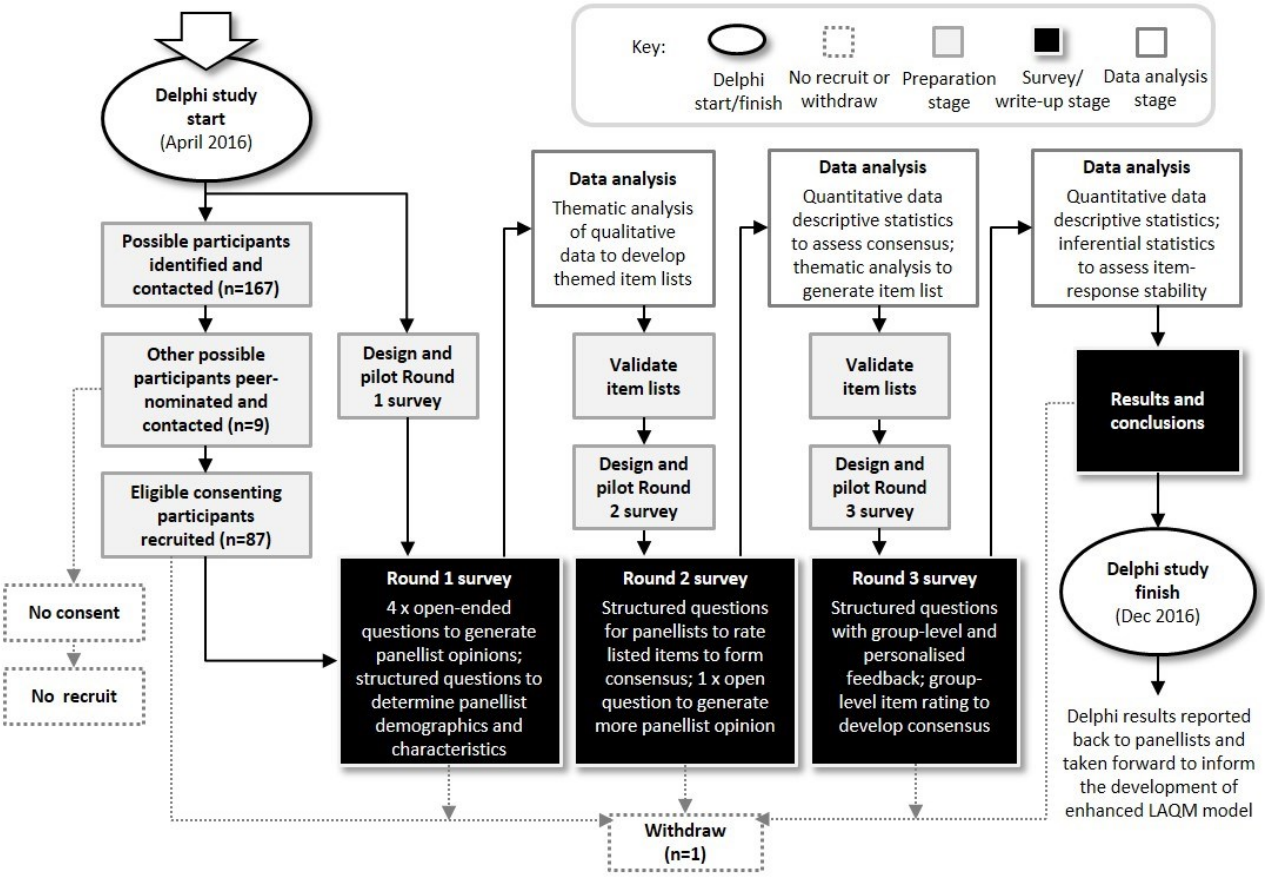

Fig. 2. Three-round Delphi method overview

It is accepted that there rarely exists just one definable community as a source of expertise, knowledge and opinion for complex problems, and that Delphi participants need not be representative of the target population nor have specialist knowledge of the entire issue under review (Devenish *et al*., 2012; De Meyrick, 2003). As such, in this study, 'information-rich' participants were purposefully selected using a *knowledge resource nomination* process which helped identify and categorise possible participants and ensured no source of expertise was

overlooked (see Okali and Pawlowski, 2004). This identified a heterogeneous and geographically dispersed group of 167 possible participants from different disciplines, in an attempt to achieve a broad spectrum of opinion on the subject under investigation (Keeney *et al.*, 2011). Each potential participant was e-mailed an invitation, information pack and consent form, in line with recommended best practice (McKenna, 1994). The information pack provided important background information and context relating to: air pollution epidemiology, air quality management (with a specific emphasis on the role of LAQM), and a summary of the evidence that informed the research problem under investigation here (Brunt *et al*., 2016a). Other supporting information described the study aim, objectives and the Delphi process, and specified participant requirements and the following eligibility criteria:

- Specialist air quality management, environmental health and/or public health qualification;
- Minimum five years post-qualification work experience;
- Have experience of undertaking public health and/or air quality management work in Wales at any point in the last five years;
- Motivated to address the problem under investigation;
- Interest, capacity and willingness to participate.

Assurances around data collection, security and governance, and anonymity were also given. Emphasis was placed on there being no obligation to take part; participants could decline/withdraw at any time (with no penalty) even after consenting (Fig.2).

Through the invitation process, nine additional possible participants were peer-nominated and contacted. Of 176 possible participants, 87 returned consent forms and met eligibility criteria but one immediately withdrew (Fig.2). Ultimately, 86 experts were recruited to the Delphi panel and assigned by the research team to one of three sub-panels in order to facilitate comparison of different groups' perspectives. The sub-panels – 'public health', 'air quality management' and 'other' – mirrored the expertise categories used in the knowledge resource nomination exercise. Briefly, the 'public health' sub-panel comprised health service-employed public health practitioners, the 'air quality management' sub-panel comprised local authority-employed air quality management and environmental health professionals (who have statutory responsibility for LAQM co-ordination and implementation in Wales), and the 'other' sub-panel comprised all other experts employed by organisations with a vested interest in public health and/or air quality e.g. policy makers, academics, regulators. More information on sub-panel composition is presented in the Results section.

Delphi survey pilot

Prior to being issued, Delphi surveys were piloted amongst a small group of known air quality management and public health experts from the University of West of England, Bristol City Council and South Gloucestershire Council. These exercises helped assess the extent to which survey questions were appropriate, concise and clear, and any supporting information and instructions were meaningful and helpful. For each survey, pilot group members were asked to provide feedback on the helpfulness of survey completion instructions, aspects of the survey that were liked and/or disliked, question clarity, and survey completion time. Surveys were refined to take account of the feedback received.

Delphi Round 1

Data were collected through an English-language online survey designed using Bristol Online Survey software (www.onlinesurveys.ac.uk) and distributed via personalised e-mail. Panellists were given three weeks to complete it. As recommended by Schmidt (1997), to maximise chances of unearthing important and contextualised issues not captured in the literature, open-ended questions were asked: 1) *What is the role of public health bodies and specialists in LAQM in Wales?* 2) *What opportunities are there to improve public health integration and collaboration?* 3) *What barriers stand in the way?* 4) *What added value could result?* Panellists were asked to provide at least three ideas/opinions in response to each question along with a one-sentence explanation. Closed questions were asked about demographics, employment, expertise and experience (Day and Bobeva, 2005).

Individual-level qualitative data were subject to thematic analysis (Keeney *et al*., 2011; Braun and Clarke, 2006). This recursive staged approach made it possible to group and theme data, combining sufficiently similar ideas/opinions (referred to from here on as 'items') into as few as possible without changing meanings or losing information (Braun and Clarke, 2006; Denscombe, 2003). Doing this offered an insight into the broad areas of panel opinion which meant that outcomes could legitimately inform subsequent survey design (Nadin and Cassell, 2007; Schmidt, 1997; Glaser and Strauss, 1967). Ultimately, four themed lists of 20 items each were produced and validated with panellists to ensure contributions were accurate and fairly represented.

Delphi Round 2

The round 2 survey was distributed as before. Panellists were asked to indicate their level of agreement with each listed item using a five-point Likert scale. While seven- (De Vet *et al*., 2005), nine-(Gijsbers, 2016) and eleven-point (Phillips *et al*., 2014; Banks *et al.*, 2009) scales may have been selected, the five-point agree-disagree scale used in this study is believed to yield the highest quality data (Revilla *et al*., 2014; Becker *et al*., 2009) and was the preferred choice of those who piloted the survey. Five fully-labelled response options were offered to participants – 1 ('strongly disagree'), 2 ('disagree'), 3 ('indifferent'), 4 ('agree'), 5 ('strongly agree') – and, to minimise any potential confusion, brief descriptions of response options were provided in the survey completion instructions. Further, one more open-ended question was asked: *Having seen the group opinion around barriers to increasing public health integration and collaboration in LAQM, what do you think the solutions are?* This question was asked in the second round because panellists needed to be aware of suggested *barriers* before proposing *solutions*.

Individual-level qualitative data obtained from the open-ended question were subject to thematic analysis as in the first round. Quantitative data generated for each item listed (i.e. Likert scale responses) were analysed at the sub-panel level; this approach prevented one group's opinions influencing other's (and consequently biasing outcomes), facilitated ultimate sub-panel comparison and captured differences in group perspectives that may have important implications for policy and practice in different disciplines (Keeney *et al*., 2011).

Consensus was measured using descriptive statistics rather than pre-agreed agreement levels (or majority rule); the latter are often arbitrary and considered subjective and scientifically questionable (Von der Gracht, 2012). The *median* (the 50th percentile) was selected as the measure of central

tendency since it is the appropriate measure to use for ordinal data from scales with more than a few values and avoids problems associated with data outliers (Argyrous, 2005; Gordon, 2003; Jacobs, 1996). The *inter-quartile range* (IQR) - considered the most objective and rigorous method of determining consensus (von der Gracht, 2012) - was used to measure data dispersion around the *median* and represented the extent to which the middle 50% of all panellists agreed with one another. An IQR of 1.0 was interpreted as 'good' consensus having been achieved on a five-point Likert scale (De Vet, 2005; Linstone and Turoff, 2002; Rayens and Hahn, 2000; Raskin, 1994); in other words, more than 50% of all opinions fall within one point on the scale. An IQR value <1.0 indicated 'very good' consensus, whereas an IQR value >1.0 indicated no consensus achieved. In summary then, consensus was assessed for each item at the sub-panel level using a combination of *median* and IQR descriptive statistics. Any items failing to achieve consensus, or achieving it with a response of 3 ('indifferent'), were carried forward to the next round to be reconsidered by panellists.

Delphi round 3

In the round 3 survey, distributed as before, panellists were asked to rate their agreement with listed items; these comprised those carried over from the previous round as well as new suggested *solutions*. For new items, consensus was measured as in round two. For carried-over items, panellists were asked to re-evaluate, and if they wished, revise their rating response. To help, participants were given statistical feedback (which comprised sub-panel-level median score and inter-quartile range for each listed item) and reminded of their responses to the previous round.

Panellists' response stability for each carried-over item was assessed (at sub-panel level) using the non-parametric Wilcoxon matched-pairs signed-ranks test. This approach has been used in other Delphi studies (e.g. Kalaian and Kasim, 2012; Banks *et al*., 2009; De Vet *et al*., 2005) The test uses paired data from the same group of individuals to derive a 'before and after' comparison that quantifies whether any difference in group opinion between survey rounds is statistically significant. Where the test *z*-statistic asymptotic *p*-value is <0.05, responses are considered unstable (Privitera, 2012; Argyrous, 2005; Riley *et al*., 2000). In this study, paired data were a panellist's responses to the same item in rounds 2 and 3; it should be noted that 58 (67%) Delphi participants responded to both survey rounds 2 and 3. The use of the Wilcoxon test was appropriate because the number of responding sub-panel experts was below 30 and data were not normally distributed (Kalaian and Kasim, 2012).

Results

Panel characteristics and response rates

Round 1 feedback revealed that most (75%) panellists worked in Wales permanently, at practitioner level (41%) and were employed by the NHS (48%) (Fig.3). While 77% of panellists reported undertaking public health-related work daily, just 23% said they did air quality management work at the same frequency. The Delphi panel comprised an experienced group of experts; 70% had >10 years relevant work experience, and 77% held masters-level or higher qualifications.

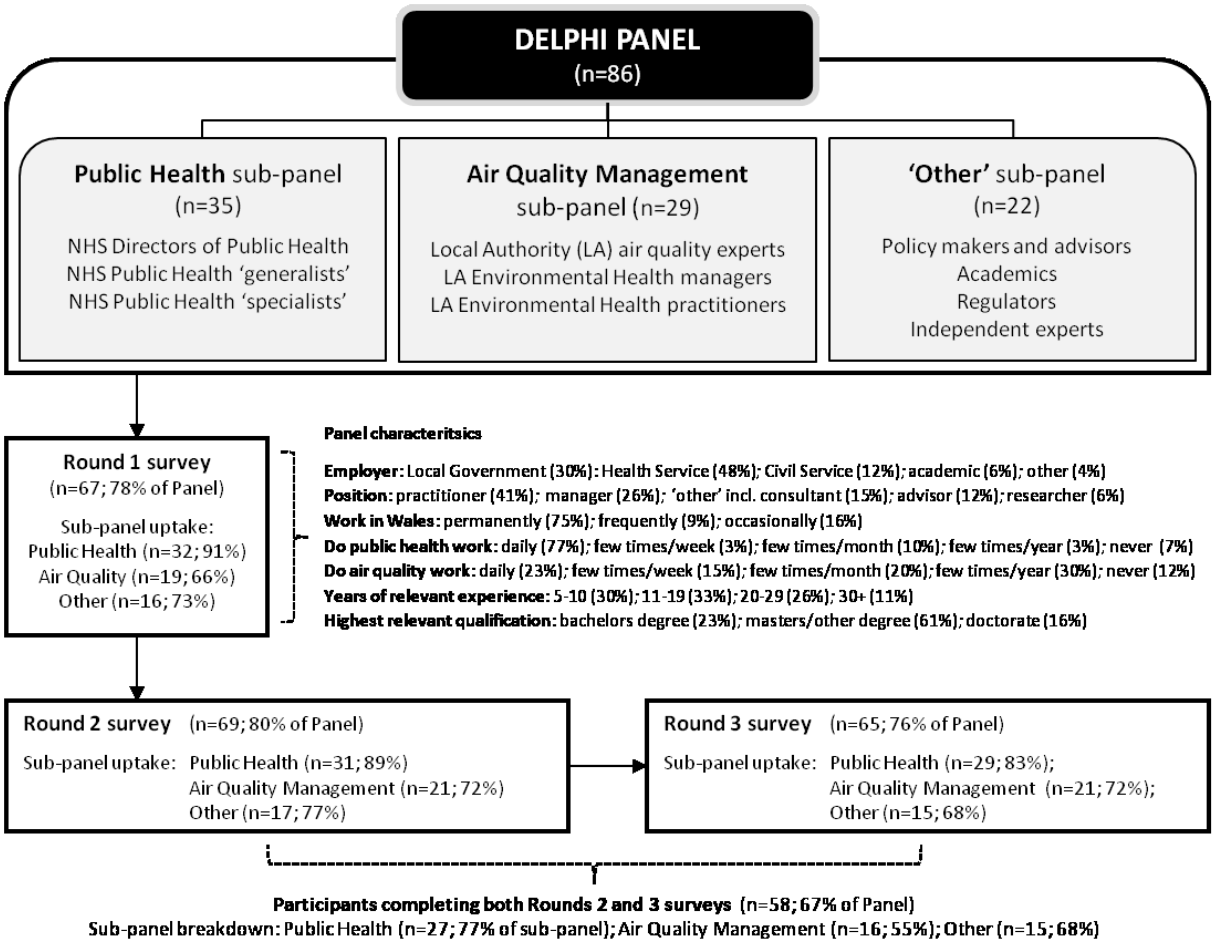

Fig 3. Delphi Panel composition and extent of participation by survey round

Panel response rates were 78%, 80% and 76% in rounds 1, 2 and 3, respectively. Sub-panel response rates across survey rounds ranged from 83% to 91% in 'public health', 66% to 72% in 'air quality management', and 68% to 77% in 'other'. Despite decreasing over consecutive survey rounds, uptake was consistently highest in the 'public health' sub-panel.

Opinions on roles of public health bodies and professionals in LAQM

In round 1, suggested roles of public health bodies and specialists in LAQM included the need to support broader mainstream risk assessment and management efforts and enabling functions such as communications, evidence appraisal and research, advocacy and leadership (Table 1).

In round 2, the median response value to each suggested role item was at least 4 ('agree') in each sub-panel. Two suggested roles relating to evidence interpretation and raising public and professional awareness (items 1.4 and 1.12) scored universal median response values of 5 ('strongly agree'). Good consensus – indicated by the symbol '+' in Table 1 – was achieved across all sub-panels for 17 (85%) items. Very good consensus – denoted by the symbol '++' in Table 1 – was achieved for items relating to risk assessment, understanding broader public health consequences and developing health-focused policy and practice in the 'other', 'public health' and 'air quality management' sub-panels, respectively (items 1.3, 1.7 and 1.15). The 'public health' sub-panel failed to reach consensus agreement on items linked with undertaking new research and providing independent scrutiny of action (1.6 and 1.8), and the 'other' sub-panel on the statement about public health acting as champions for environmental sustainability improvement (1.11). These three items – marked with an asterisk after the item number in Table 1 – were taken forward for reconsideration in Round 3.

In Round 3, the three carried-over items were unanimously agreed, with good consensus and response stability, the latter being annotated with a '✓' symbol. Ultimately, all 20 suggested role items were agreed by sub-panels.

Opinions on opportunities to increase integration and collaboration

In Round 1, suggested opportunities to increase public health integration and collaboration included: influencing Government LAQM policy development, calling for air pollution problems and solutions to be considered in a broader public health context, and action to extend beyond localised 'hotspots' (Table 1). Panellists commented that reducing air pollution and risks should not be regarded as an isolated priority; they felt that integrating LAQM with broader public health policy and practice can increase opportunities for joint work-planning around shared problems, effective collaboration, informed policy development and co-ordinated action. Opportunities offered by the requirements of Wales' WFGA were specifically mentioned. Finally, it was considered that the high levels of interest in air pollution and health matters amongst professionals, politicians and public also presented worthwhile opportunities to raise awareness, engage stakeholders and stimulate further debate.

In Round 2, median response values for each item were at least 4 ('agree') across 'public health' and 'air quality management' sub-panels. In the main, this was the case in the 'other' sub-panel, except for a median response of 3 ('indifferent') for item 2.19 which was concerned with willingness to share data and other information. Good response consensus was achieved within each sub-panel for the same 16 (80%) items, including item 2.19. Consensus was not achieved for items relating to opportunities offered through devolved responsibilities, the WFG Act and wider NHS action (2.4, 2.6, 2.9) in the 'other' sub-panel, and through the Welsh Air Quality Forum (2.11) in the 'public health' sub-panel.

In Round 3, three of the five carried-over items relating to devolved responsibilities, the WFG Act and the contribution of the wider NHS (2.4, 2.6 and 2.9) achieved stable consensus agreement in each sub-panel. The remaining two items (2.11 and 2.19) failed to reach universal stable consensus agreement. Ultimately, all sub-panels agreed with, and achieved good and stable consensus on, 18 (90%) items.

Opinions on the added value of increased integration and collaboration

In Round 1, panellists reported that increasing public health integration and collaboration in LAQM could add real value. This may be in the form of, for example, more efficient, creative and productive collaboration, more meaningful risk assessment, better-informed action, connected and integrated policy and practice, effective communications, and robust research and evaluation (Table 1).

In Round 2, median response values for each item were at least 4 ('agree') across all sub-panels. Good consensus was achieved universally for 14 (70%) items. There was no dissent in agreement amongst 'air quality management' sub-panel members for items highlighting added value resulting from linking LAQM with other public health priorities, sharing priority-setting and work-planning, connecting policy and practice around universal and targeted action, undertaking new research, improving LAQM transparency, and applying learning from LAQM enhancement to other public health priorities (3.6, 3.9, 3.10, 3.16, 3.18 and 3.20). The same was true in the 'other' sub-panel for these latter two items, as well as another relating to the benefits of defining the role of public health in LAQM (3.1). The 'air quality management' sub-panel failed to reach consensus agreement on item 3.1, the 'public health' sub-panel on items 3.2 (increased capacity), 3.8 (more efficient and effective ways of working) and 3.20 (applying learning from LAQM enhancement elsewhere), and the 'other' sub-panel on items 3.10 (connecting policy and practice around universal and targeted action) and 3.14 (reducing healthcare service burdens).

In Round 3, all six carried-over items achieved good consensus agreement across sub-panels, but responses over rounds 2 and 3 were unstable for two of these – the item concerned with increasing capacity (3.2) in the 'air quality management' sub-panel, and the item relating to more efficient and effective ways of working (3.8) amongst 'public health' experts. Ultimately, all sub-panels agreed with, and achieved good stable consensus on, 18 (90%) suggested added value items.

Ref.	Role of public health bodies and specialists in LAQM	Pub. Health			Air Qual.			Other		
		R	C	S	R	C	S	R	C	S
1.1	Help others assess air pollution risks in the broadest possible public health context	5	+		5	+		4	+	
1.2	Use expertise and resources to share, link and analyse data to assess risks and impacts	5	+		5	+		4	+	
1.3	Determine how air pollution-related risks vary *between* and *within* communities	5	+		4	+		4	++	
1.4	Interpret evidence, and use it to set shared priorities and inform others' decisions	5	+		5	+		5	+	
1.5	Advocate for, and support evidence reviews to, assess intervention effectiveness	5	+		4	+		4	+	
1.6*	Undertake new research to evaluate the air pollution *and* health impacts of action	4	+	✓	4	+	✓	4	+	✓
1.7	Understand broader public health consequences of action to reduce air pollution/risks	5	++		5	+		4	+	
1.8*	Provide independent scrutiny of evidence-based and innovative action	5	+	✓	4	+	✓	4	+	✓
1.9	Work with others to promote and facilitate active-travel for all	5	+		4	+		4	+	
1.10	Work with others to improve public health and reduce susceptibility to air pollution	5	+		4	+		5	+	
1.11*	Champion the principles of environmental sustainability in and beyond the NHS	5	+	✓	4	+	✓	4	+	✓
1.12	Raise professional and public awareness of air pollution as a health priority	5	+		5	+		5	+	
1.13	Let others know 'what works' to reduce air pollution and associated risks	5	+		4	+		5	+	
1.14	Work with others to provide timely advice to the public on how to minimise risks	5	+		5	+		4	+	
1.15	Help others locally to develop health-focused LAQM policy and practice	4	+		4	++		4	+	
1.16	Use local-level learning to inform national-level policy development	4	+		4	+		4	+	
1.17	Connect LAQM policy and practice with other public health priority work areas	4	+		4	+		4	+	
1.18	Advocate for, and support, integrated air pollution/public health action everywhere	4	+		4	+		5	+	
1.19	Advocate for, and support, targeted action in 'high risk' areas to reduce inequalities	4	+		4	+		5	+	
1.20	Help shape others' policy and practice to reduce air pollution-linked health risks	4	+		4	+		5	+	
	Opportunities to increase public health integration and collaboration in LAQM									
2.1	Capitalise on political, media and public interest in air pollution as public health priority	4	+		5	+		4	+	
2.2	Evidence of no 'safe' air pollution exposure level encourages action beyond 'hotspots'	4	+		5	+		4	+	
2.3	Evidence calls for air pollution problems/solutions to be considered in broader context	5	+		4	+		5	+	
2.4*	LAQM responsibilities are devolved; opportunities exist to enhance the regime in Wales	4	+	✓	4	+	✓	4	+	✓
2.5	Welsh Government is reviewing existing LAQM arrangements so influence is timely	4	+		4	+		4	+	
2.6*	The WFGA 2015 calls for environmental sustainability action that can support LAQM	5	+	✓	4	+	✓	4	+	✓
2.7	In Wales, there is a focus on prevention; 'treating' effects is no longer acceptable	5	+		4	+		5	+	
2.8	Wales' national air quality indicator can help inform local action and evaluations	4	+		4	+		4	+	
2.9*	Public Health Wales is well-placed to encourage action across wider NHS and beyond	4	+	✓	4	++	✓	4	+	✓
2.10	Good rapport between Welsh Government and other bodies can facilitate change	4	+		4	+		4	+	
2.11*	The Welsh Air Quality Forum offers opportunities to increase collaboration and action	4	-	✓	4	+	✓	4	+	✗
2.12	WFGA Public Service Boards are required to agree and address joint priorities	5	+		4	+		4	+	
2.13	Public bodies are encouraged to work regionally on priorities that cross boundaries	4	+		4	+		5	+	
2.14	Understanding broader links can help align public health and LAQM action	4	+		4	+		5	+	
2.15	Increasing collaboration (especially academics) can create research opportunities	4	+		4	+		5	+	
2.16	Communicating messages in a public health context can influence broader audiences	4	+		4	+		4	+	
2.17	Good, less technical, communications can increase understanding and engagement	4	+		4	++		4	++	
2.18	Good quality local-level data can inform risk assessments, surveillance and action	4	+		5	+		5	+	
2.19*	There is currently an increased willingness to share data, intelligence and expertise	3	+	✓	4	-	✓	4	+	✓
2.20	Public health specialists have expertise to support Local Authority-led risk assessments	4	+		4	+		4	+	
	Added value of increased public health integration and collaboration in LAQM									
3.1*	Defining the public health role in LAQM can increase expertise, confidence and support	4	+	✓	4	++	✓	4	++	✓
3.2*	Increased public health support for Local Authorities can help increase capacity	4	+	✓	4	++	✗	4	+	✓
3.3	Improved public health support can facilitate broader air pollution risk assessment	4	+		4	+		4	+	
3.4	Understanding risks in a broader context can improve communications and their reach	4	+		4	+		4	+	
3.5	'Big picture' evidence can help link air pollution with other local public health priorities	4	+		4	+		5	+	
3.6	Making links with other priorities helps public health integrate LAQM with the 'day job'	4	+		4	++		4	+	
3.7	A broader outlook on LAQM helps connect it with 'prevention-focused' WFGA practice	4	+		4	+		4	+	
3.8*	Connecting policy and practice can create more efficient and effective ways of working	5	+	✗	4	+	✓	4	+	✓
3.9	Better integration can inform shared objective-setting, work planning and action	4	+		4	++		4	+	
3.10*	Better connection can encourage action to reduce risks for all *and* target 'at risk' areas	4	+	✓	4	+	✓	4	+	✓
3.11	Greater collaboration can lead to more creative and innovative solutions to problems	4	+		4	+		4	+	
3.12	Using public health to inform, educate and empower others can link 'whole systems'	4	+		4	+		4	+	
3.13	Effective LAQM policy and practice has potential to deliver multiple health co-benefits	4	+		4	+		4	+	
3.14*	Protecting public health through LAQM can reduce the burden on NHS services	5	+	✓	5	+	✓	4	++	✓
3.15	Better collaboration (especially academics) can create opportunities for new research	4	+		4	+		4	+	
3.16	New research in Wales can add to the evidence-base on intervention effectiveness	4	+		4	++		4	+	
3.17	Positive LAQM impacts can encourage future prevention-focused service investment	4	+		4	+		4	+	
3.18	Improving public health involvement can increase LAQM inclusiveness and transparency	4	+		4	++		4	++	
3.19	Raising LAQM's profile reduces the likelihood of missing opportunities to connect policy	4	+		4	+		4	+	
3.20*	Enhancing LAQM can act as an exemplar for evolving policy and practice in other areas	4	++	✓	4	+	✓	4	++	✓

R = RESPONSE median (Likert scale: 1 = strongly disagree; 2 = disagree; 3 = indifferent; 4 = agree; 5 = strongly agree)
C = CONSENSUS extent (- = consensus not achieved (inter-quartile range (IQR) = >1.0); + = good consensus (IQR = 1.0); ++ = very good consensus (IQR = <1.0))
S = STABILITY of round 2→3 responses (✓ = no significant change, *p*-value = >0.05; ✗ = significant change, *p*-value = <0.05)
***** = item did not achieve consensus in survey round 2 and was carried over to round 3; only round 3 result shown

Table 1. Suggested public health roles in LAQM; opportunities and added value of increased integration and collaboration

Opinions on barriers to increasing integration and collaboration

In Round 1, suggested barriers that hinder increasing public health integration and collaboration in LAQM included air pollution being regarded as an isolated problem, and being perceived to be too technical and complicated for many to understand and resolve locally (Table 2). Additionally, Local Government bodies and the NHS have assigned it low priority status with little accompanying support resource, and there is no formal requirement to act on problems beyond localised 'hotspot' areas.

In Round 2, median responses across sub-panels for 13 (65%) items were at least 4 ('agree'). For remaining items, at least one sub-panel had a median response value of 3 ('indifferent'). Good consensus was achieved across sub-panels for 10 (50%) items; the level of consensus achieved for item 4.8 (LAQM being too reactive) was universally very good. All sub-panels failed to reach consensus on item 4.19 which related to the position of the main public health body in Wales outside local authority structures.

In Round 3, four of 11 carried-over items reached good consensus agreement across sub-panels with response stability. For each of the remaining seven items, at least one sub-panel failed to agree, reach consensus or deliver stable responses. Ultimately, all sub-panels agreed with, and achieved good stable consensus on, 13 (65%) suggested barriers.

Opinions on solutions to increasing integration and collaboration

In Round 2, panellists suggested a range of solutions to highlighted barriers, including: specifying the role of public health bodies and specialists in LAQM and increasing engagement through multi-sector local/regional air quality management groups; evolving policy to extend LAQM's scope to consider air pollution in the context of wider health determinants; encouraging universal risk reduction action alongside more-targeted intervention; integrating LAQM with the 'day job' across the public health workforce; appraising evidence; communicating risks, behaviour change and action effectiveness; and, making work placements and funding available to facilitate investment and action (Table 2).

In Round 3, median response values for most items were at least 4 ('agree') across all sub-panels. The exceptions were: the suggested solution of shifting LAQM accountability from local authorities to WFG Act Public Services Boards (which all sub-panels reached consensus disagreement with), and another concerning tightening statutory national air quality standards (which the 'air quality management' sub-panel was 'indifferent' about. Ultimately, consensus agreement was achieved for 15 (75%) items across all sub-panels.

Ref.	Barriers to increasing public health integration and collaboration in LAQM	Pub. Health			Air Qual.			Other		
		R	C	S	R	C	S	R	C	S
4.1	Air pollution has a relatively low profile in Local Authorities and across the NHS in Wales	4	++		4	++		4	+	
4.2	Most people, especially politicians and public, are unaware of problem scope/solutions	4	+		4	++		4	+	
4.3*	The NHS in Wales also perceives air pollution to be 'someone else's problem'	4	+	✓	4	+	✓	4	+	✓
4.4*	Too often, air pollution is seen as an isolated problem, rarely linked to other priorities	4	+	✓	4	++	✗	4	-	✓
4.5*	Air pollution is too technical; most people lack understanding and confidence to engage	4	+	✓	4	++	✓	4	+	✓
4.6*	LAQM is disconnected from many relevant aspects of public health policy and practice	4	+	✓	4	+	✗	4	++	✓
4.7	LAQM action is only required in areas where Air Quality Objectives are/likely breached	4	+		4	++		4	+	
4.8	LAQM is reactive; proactive public health/air pollution action is not encouraged	4	++		4	++		4	++	
4.9*	LAQM's risk assessment and action planning processes are cumbersome and confusing	4	+	✓	4	++	✓	3	+	✓
4.10	There is lack of guidance on comprehensive air quality public health risk assessments	4	+		4	+		4	+	
4.11*	Information governance and IT data systems/policies discourage data sharing/linking	4	++	✓	3	+	✓	3	+	✓
4.12	Information on air pollution mitigation intervention [cost] effectiveness is lacking	4	+		4	+		5	+	
4.13*	There is no 'one size fits all' answer to air pollution problems; solutions are complex	4	+	✓	5	+	✓	4	+	✓
4.14	It is perceived that air pollution needs a national solution and little can be done locally	4	+		4	++		4	+	
4.15	LAQM aims to reduce air pollution; it ignores complementary risk reduction approaches	4	+		4	+		4	++	
4.16*	It is becoming increasingly difficult to secure 'buy-in' from essential LAQM stakeholders	4	-	✓	4	+	✓	4	+	✓
4.17	Public health is disengaged from LAQM; role and expected contribution poorly defined	4	+		4	+		4	+	
4.18*	Public health specialists have received no training/guidance on how to support LAQM	4	++	✓	3	+	✓	3	+	✓
4.19*	Public health is part of NHS Wales and sits outside of Local Authority structures	4	+	✓	4	+	✓	4	+	✓
4.20*	Local Authorities tend not to engage with public health and academics on LAQM issues	3	-	✓	3	-	✓	3	+	✓
	Solutions to barriers to increase public health integration and collaboration in LAQM									
5.1	Extend the scope of LAQM to require targeted *and* universal local action	4	++		4	++		4	++	
5.2	Shift LAQM accountability from Local Authorities to WFGA Public Services Boards	2	+		2	+		2	+	
5.3	Statutorily require Public Health Wales and Health Boards to support all parts of LAQM	4	-		4	++		4	-	
5.4	Specify the LAQM role of NHS public health bodies and specialists in supporting LAQM	4	++		4	++		4	++	
5.5	Prescribe a broader LAQM risk assessment approach to stimulate NHS interest/action	4	++		4	++		4	+	
5.6	Promote LAQM integration with the 'day job' for health specialists (all disciplines)	4	+		4	++		4	++	
5.7	Target action in poor air pollution *and* health areas to reduce risks and inequalities	4	+		4	+		5	+	
5.8	Fully integrate Health Impact Assessment principles and processes with LAQM action	4	+		4	++		4	+	
5.9	Tighten Air Quality Objectives to support delivery of an extended LAQM regime	4	+		3	+		4	+	
5.10	Create multi-sector local or regional LAQM groups	4	+		4	+		4	+	
5.11	Raise profile of LAQM in/across Welsh Government to improve cross-sector working	4	+		4	+		4	+	
5.12	Use independent public health voice to advocate for LAQM change, as necessary	4	+		4	+		4	+	
5.13	Invest in technology; making it easier to 'see' air pollution can stimulate interest/action	4	+		5	+		4	-	
5.14	Establish recurring funding stream for air quality and environmental sustainability work	4	+		4	+		4	++	
5.15	Make public health bodies statutory consultees in planning processes	4	+		4	+		4	-	
5.16	Interpret and communicate evidence, and encourage new research and evaluation	5	+		4	+		5	++	
5.17	Work closer with communities to raise awareness; undertake 'citizen science' research	4	++		4	++		4	++	
5.18	Train all public health specialists on LAQM risk assessment, management and evaluation	4	+		4	+		4	+	
5.19	Raise awareness amongst public bodies, policy-makers, politicians and public	4	+		4	+		4	+	
5.20	Create and support air pollution/health placements and projects across public bodies	4	+		4	++		4	+	

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C = CONSENSUS extent (- = consensus not achieved (inter-quartile range (IQR) = >1.0); + = good consensus (IQR = 1.0); ++ = very good consensus (IQR = <1.0))
S = STABILITY of round 2→3 responses (✓ = no significant change, *p*-value = >0.05; ✗ = significant change, *p*-value = <0.05)
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Table 2. Suggested barriers and solutions to increasing public health integration and collaboration in LAQM

Sub-panel consensus variation, convergence and divergence

In summary, agreement with good consensus (and response stability where appropriate) was achieved across all sub-panels for 84/100 items. Those experts in the 'public health' sub-panel reached agreement with consensus on 93 items, 'air quality management' experts on 91 items, and 'other' experts on 90 items (Table 3).

	Delphi sub-panel	No. items agreed, with consensus (Round 2)	No. items carried	No. items agreed, with consensus and stability (Round 3)	Final no. items agreed, with consensus and stability
Suggested roles	public health	17 of 20	3	3 of 3	20
	air quality management	17 of 20		3 of 3	20
	other	17 of 20		3 of 3	20
Suggested opportunities	public health	19 of 20	5	3 of 5	18 (not 2.11, 2.19)
	air quality management	17 of 20		4 of 5	19 (not 2.19)
	other	16 of 20		4 of 5	19 (not item 2.11)
Suggested added value	public health	17 of 20	6	5 of 6	19 (not 3.8)
	air quality management	19 of 20		5 of 5	19 (not 3.2)
	other	18 of 20		6 of 6	20
Suggested barriers	public health	15 of 20	11	9 of 11	18 (not 4.16, 4.20)
	air quality management	15 of 20		6 of 11	15 (not 4.4, 4.6, 4.11, 4.18, 4.20)
	other	12 of 20		6 of 11	15 (not 4.4, 4.9, 4.11, 4.18, 4.20)
Suggested solutions	public health	19 of 20 (not 5.3)	N/A		
	air quality management	18 of 20 (not 5.2, 5.9)			
	Other	17 of 20 (not 5.3, 5.13, 5.15)			

Table 3. Summary of Item opinion convergence and divergence by sub-panel

A total of 25 items failing to achieve consensus agreement in Round 2 were carried over for reconsideration in Round 3. Of these, 14 (56%) subsequently achieved universal consensus

agreement with response stability. This result is characteristic of the Delphi process where participants have regard to the opinions of others in the sub-panel and gradually move closer to agreeing as a group. Overall, 47% of responses to Round 3 carried-over items were revised by participants; this broke down as 37%, 44% and 69% in the ‘public health’, ‘air quality management’ and ‘other’ sub-panels, respectively.

Discussion

Main findings

The Delphi method proved successful in eliciting multiple viewpoints from a range of experts on this complex research problem. It helped generate valuable evidence that can be used to inform the future development of LAQM to maximise public health integration, collaboration and impact.

Experts in each sub-panel ultimately achieved consensus agreement on all suggested roles for public health in LAQM. These included: supporting risk assessments that consider air pollution problems and solutions in a broad public health context, integrating action to reduce air pollution and risks with the 'day job' to help address linked priorities, undertaking research and evaluation, and appraising and interpreting evidence. Experts agreed that these roles, together with the application of other core public health skills such as authoritative communication, advocacy and leadership, could inform evidence-based LAQM policy development and more effective implementation. The only item (in the entire Delphi study) to achieve universal strong agreement with consensus was the suggested public health role to raise professional and public awareness of air pollution as a health priority.

Experts reached consensus agreement (and where appropriate, response stability) on the majority of suggested opportunities to increase public health integration and collaboration. These included transferring existing public health expertise to help: improve air quality risk assessments and surveillance, communicate with broader audiences in less technical ways to raise awareness and encourage stakeholder 'buy in', and influence policy development. Some policy advances in Wales that require public bodies to work collaboratively in more sustainable ways across regions, and encourage universal action to complement targeted intervention to reduce air pollution, risks and inequalities, were also seen as positive drivers for change. Two suggested items were not universally accepted:

- Experts in all three sub-panels agreed that the existing Welsh Air Quality Forum (which helps local authorities translate LAQM policy into consistent practice across Wales) could increase public health collaboration and action, but public health and 'other' experts could not reach consensus and/or response stability on this item. Since the Welsh Air Quality Forum partnership is local authority and LAQM compliance-focused, this finding suggests that very few non-local authority experts know about it or are engaged in its work.
- Neither public health nor air quality management experts were confident that an increased willingness to share data, intelligence and expertise existed. Possible explanations for this include public health experts not understanding the LAQM process and air quality experts being unfamiliar with the type of data and analytical capability that public health can offer.

The possible added value of increased public health integration and collaboration was considered significant. It included: increased public health expertise, confidence and LAQM support, improved risk assessment and understanding, evidence-based universal and targeted action to reduce inequalities, and better alignment of action with other public health interventions. In turn, more creative and productive collaboration could result, along with more effective communications, good opportunities for research and evaluation, connected policy, and prevention-focused investment. Two suggested items were not universally accepted:

- Despite strongly agreeing (with good consensus) that better connected policy and practice could create more effective and efficient ways of working, public health expert responses were unstable. This result suggests that the majority of public health experts came into the Delphi process with only a limited understanding of how their work linked with air quality management, but over time – learning from others' opinions and changing their own – started to identify overlaps and recognise opportunities for greater connection and collaboration.
- Air quality management experts achieved consensus agreement (without response stability) with the item proposing that increased public health support for local authorities would help increase capacity. It is possible that this finding stems from the majority of air quality management experts being unfamiliar with the role of public health experts since relatively few actively support LAQM at present and they struggled to grasp what any increased support and capacity might look and feel like for them in reality.

Several barriers were believed to hinder action in this area. The following items achieved consensus agreement (with response stability where appropriate): the public health role in LAQM is poorly defined, air pollution has a low profile in local authorities and health services, the topic is perceived as being too technical and too complicated to attempt to resolve locally, disconnected policy, the scope of the LAQM prescribed process is too narrow and required action only in areas which breach air quality standards. Some suggested barriers failed to achieve agreement and/or consensus and/or response stability too. These included: public health specialists receiving limited training and guidance, problems sharing and linking data, weak relationships with public health and academic partners, and LAQM processes being too cumbersome. It is possible that some experts raised uncertainty around these latter points because they felt that others were better placed to consider them, or were not sufficiently familiar with LAQM processes and lacked confidence to comment. Whatever the reason, these findings add weight to the argument that LAQM (and its relevance in a broader public health context) is not as well understood across relevant professional groups.

Finally, to address identified barriers, a number of solutions were proposed and agreed by experts with consensus. These included: extending the scope of LAQM, improving communications to raise the profile of air pollution as a public health priority (linked with others), and letting people – both professionals and the public – know what can be done to tackle it, and making funding available to support prevention-focused investment and sustainable action. Other suggested solutions, specific to public health expert development, included: clarifying the role of public health in LAQM, highlighting opportunities for a broader public health audience to integrate aspects of LAQM with the 'day job', and providing training and resources to support work in this area. Just one item achieved universal disagreement with consensus; this was concerned with shifting LAQM accountability responsibilities away from local authorities to WFG Act Public Services Boards.

Prior understanding of the research problem

Prior to this study, only general context evidence was available on the public health aspects of, perspectives on, and extent of engagement in, LAQM. A critique of the available literature is presented elsewhere (Brunt *et al*., 2016a) but is summarised here.

LAQM is underpinned by the principle that good collaboration is key to tackling diverse and complex local air pollution problems. To support this, the roles of various stakeholders have been specified

(e.g. environmental health, planning, transport, regulation and sustainable development). However, the valuable contribution of public health bodies and specialists to the regime has never been defined, despite being highlighted previously (Laxen *et al*., 2014; In-house Policy Consultants, 2010; Welsh Government 2009; Defra, 2007; Longhurst *et al*., 2006; Beattie *et al*., 2001; Lindley *et al*., 1996). This failing has likely created the present-day disconnect between LAQM and public health (Leksmono *et al*., 2009; Longhurst *et al*., 2006) and compromised the evolution of integrated public health and air pollution management policy and practice. This disconnect, along with a lack of training, has meant that most public health specialists have a relatively poor appreciation of air pollution problems, their links with wider health determinants, and risk management solutions. Little has been done to investigate or address why this is so; historic reviews assessing LAQM stakeholder interactions have largely ignored public health specialists (In-house Policy Consultants, 2010; Hayes *et al*., 2009).

As corroborated by this study, the effects-based approach of LAQM has previously been described as narrow in scope (Everard *et al*., 2013). This is because the current approach encourages LAQM work to take place in isolation; there is no requirement to acknowledge the significant overlaps that exist with other public health priorities and work to tackle wider health determinants at population level. It is important to understand air pollution problems and solutions in this broader public health context to maximise health gain and reduce health inequalities (Brunt *et al.,* 2016b; Jerrett *et al*., 2001) since acting on a limited understanding of scope and relationships, or worse ignoring them altogether, might exacerbate or create new problems (Bowen, 2002). The 'big picture' evidence needed to inform LAQM risk assessments and action can be generated by drawing upon public health expertise around data sharing, linkage, analysis and interpretation (Brunt *et al*., 2016a).

The regime also has a history of poor, low-profile risk communications which can be improved if better-informed and supported by public health specialists (Barnes *et al*., 2014; Beattie *et al*., 2001). Also, there is the need to draw upon public health expertise around evidence appraisal, research and evaluation to improve LAQM impact by communicating information about what actions, in what combination(s), are most effective (Policy Exchange, 2013).

As for the Delphi technique, this has evolved into a valid, reliable and widely-accepted research method. As was the case here, the approach is best suited for use in circumstances where scientific knowledge of an issue is scarce, (Crutzen *et al*., 2008), where research problems cannot be precisely analysed but benefit from subjective opinion, and where study populations are not easily reached as they are geographically and professionally diverse (Green *et al.*, 1999). Delphi has been used with success in other areas of environmental and public health research (e.g. Moynihan *et al*., 2015; Bailey *et al*., 2012; Aarts *et al*., 2011; Ratnapradipa *et al*., 2011; Waterlander *et al*., 2009) as well as policy evaluation and development (e.g. Hsueh, 2015; Sherriff, 2014; Frewer *et al*., 2011).

Evolving the evidence-base

This study makes a substantial contribution to the evidence-base in this research field. There have been previous calls for the reorientation of LAQM such that public health is a core driving principle rather than merely a hopeful outcome (Brunt *et al.*, 2016a). In response, this study has generated much-needed, previously unavailable, evidence to inform and support future LAQM enhancements that could maximise public health integration, collaboration and impact.

The Delphi method confirmed and clarified the significant contribution that public health bodies and specialists could and should make to LAQM. This essential guidance has been lacking since the regime's inception – its absence is largely responsible for the growing disconnect between LAQM and public health agendas evident today. The added value arising from a more public health focused and supported LAQM regime is also presented, and is considerable.

This study goes beyond role specification. Expert opinion elaborated on opportunities, barriers that might hinder and solutions that might enable 'real world' policy and practice change. On occasion, panellists' opinions were specific to the situation in Wales e.g. highlighting the importance of seizing unique opportunities offered by joining up LAQM, public health and broader wellbeing and environmental sustainability (WFG Act) legislation and policy to facilitate action. However, most findings were sufficiently generic to have relevance outside Wales e.g. consensus opinion suggested that integration and collaboration could be increased by extending LAQM's scope and encouraging universal action to reduce risks for all alongside more-targeted intervention. These enhancements could increase LAQM-related interest and importance amongst a wider public health workforce and pave the way for better integration of LAQM into the core responsibilities of many more specialists. Greater opportunities could result for connected policy development, aligned planning and action, effective communication, multidisciplinary research, and change advocacy, leadership and management.

The findings of this study resonate well with the requirements of the WFG Act in Wales. Enhancing the LAQM regime in the ways suggested aligns with the sustainable development principles of collaboration, integration and involvement to facilitate long-term, prevention-focused action. Seizing opportunities to recognise and realise synergies, and create and adopt more effective and efficient ways of working across LAQM and public health agendas, can only serve to help to achieve the Act's broader Well-being Goals too. For example, increasing public health integration and collaboration in LAQM can support joined-up action (where air pollution problems and solutions are considered in context alongside broader public health priorities) that has the potential to deliver multiple positive health impacts amongst the Welsh population. Further, broadening the scope of LAQM can help identify and reduce air pollution and associated health inequalities to create a fairer Wales. In turn, these improvements can increase population resilience, productivity and prosperity, and community cohesion, and contribute to Wales being a globally responsible country.

In addition to generating new evidence to inform and support LAQM policy and practice development, this study highlights the usefulness and applicability of the Delphi technique in supporting complex environmental public health research.

Limitations

The possible limitations of this study relate to the application of the Delphi technique in this research context. The strength of the Delphi approach is that it is underpinned by principles of anonymity and democratic participation, where all panellists have equal opportunity to influence the process (Day and Bobeva, 2005). However, some aspects are open to interpretation, and so it is important to reflect on the steps taken in this study to assure validity and reliability, as follows:

- *How many survey rounds*? To instill confidence and rigour, a general rule is for researchers to commit to provide feedback to panellists over at least two survey rounds (Day and Bobeva,

2005). This study had three rounds, and a 'classic' design was selected over other Delphi variants because existing evidence was limited and a first idea-generation round was required.

- *Who is an 'expert'*? Appropriate selection of panellists is a critical process; selection bias introduced by choosing the wrong experts can seriously affect study validity and reliability. To minimise bias here, only 'professional' experts were engaged (through a process of systematic identification and peer-recommendation) who met pre-agreed eligibility criteria. Involving participants with diverse backgrounds avoided 'illusory expertise' skewing results (Linstone and Turoff, 2002).
- *What is the optimal number of Delphi panellists*? Most panels comprise 10-50 experts (Keeney *et al*, 2011) but it is generally accepted that larger panels enhance study reliability and reduce error (Cochran, 1983). Panel make-up also influences decisions with homogeneous panels requiring fewer participants than heterogeneous panels (Paliwoda *et al*., 1983). The latter also needs homogeneous sub-panels comprising at least ten experts, to facilitate comparisons of different groups' perspectives (Okali and Pawlowski 2004; Parente and Anderson-Parente, 1987). To maximise credibility here, a heterogeneous panel of experts was recruited, with each of the three homogeneous sub-panels having more than 10 experts.

On this latter point, it is noteworthy that Delphi studies are sometimes criticised because findings from small numbers of experts are not considered representative (Yousuf, 2007). Such criticism is ill-informed. It is not appropriate, nor intended, to generalise findings given their derivation from an expert panel with unique characteristics. That said, this study's panel size, diversity and response rates may mean that opinions *were* a valid representation of expert views on this particular subject.

Another possible criticism is that Delphi can achieve only quasi-anonymity as researchers know panel members and their responses. It is possible that experts knew each other, but this was unavoidable. Perversely, this may have helped increase response rates - the perception of being in an elite expert 'club' may have motivated participation. This is important; Delphi's effectiveness is dependent upon ongoing participation. Other factors likely helped improve response rates too, e.g. panellists' interest in the research area, administering surveys electronically in non-holiday periods, regular communications, reiterating contribution importance, and setting a three-round study limit.

It is also important to acknowledge that participants' views may be influenced by group opinion. While this is the whole point of Delphi's iterative consensus-forming process interspersed with controlled feedback, unlike in alternative group research methods (such as interviews, focus groups or nominal group technique), participants are under no pressure to change their minds as the process evolves. This is because Delphi is based on democratic participation and anonymity. If participants wish to revise responses in light of group feedback, they can; but if they are not swayed by the group opinion statistical feedback presented, they need not change their mind. In this study, 47% of Round 2 responses were revised in Round 3. Interestingly, it was the public health experts that changed their minds the least (37%); while this group of experts probably knew relatively little about LAQM compared with others, this result may be explained by public health experts feeling more confident with their responses because the research problem under investigation was public health-focused.

In addition to study-design issues, possible data collection and analysis-related limitations should be acknowledged. For example, it is possible for data collection instruments to confuse panellists and,

through the use of leading questions, compromise the collection of balanced responses. To avoid this, and to ensure surveys asked clear, concise and unambiguous questions, each round was piloted and refined accordingly.

In terms of qualitative data analysis, measures were taken to mitigate the possibility of panellists' contributions not being captured or interpreted correctly, especially extreme outlier responses. While the thematic analysis approach adopted in this study may not hold the same 'kudos' as full discourse analysis or grounded theory, it is no less credible, having been used successfully in other health-related research (Allen and Foulkes, 2011; Fade and Swift, 2011; Braun and Clarke, 2006). To minimise data misinterpretation risks, several recommended steps were taken: seeking brief explanations of opinions submitted, having different research team members independently review panellists' responses, and validating summary item lists directly back with panellists (Dubois and Graff, 2011; Linstone and Turoff, 2002).

As for quantitative data analysis, determining consensus is often the most controversial aspect of any Delphi study. Consensus is defined as "a condition of homogeneity or consistency of opinion among panellists" (Graham *et al*., 2003 p. 1152), but achieving it does not mean the correct answer has been found, rather panellists have reached agreement on something. Unhelpfully, because consensus measurement criteria are lacking, a variety of methods have been used previously e.g. aggregating response judgments, setting pre-determined consensus levels, applying measures of central tendency. Here, consensus assessment was based on the latter approach using objective statistical techniques and not the application of arbitrary levels of agreement. The combined use of data *median* and *inter-quartile range* measures is believed to be the most robust method for measuring consensus in Delphi studies (Murphy *et al*., 1998) and so was used here.

To further strengthen study reliability, consensus measurement was complemented by stability assessment using a statistical test recommended for use with ordinal data that are not normally distributed (Von der Gracht, 2012; Banks *et al*., 2009; Crisp *et al*., 1997). It is important to have regard for convergence or divergence of opinions over successive rounds (as a separate component to consensus) since the concept of stability indicates whether agreement was there always, developed through the Delphi process or changed between rounds (Dajani *et al*., 1979; Scheibe *et al*., 1975). Participants do change their views as the Delphi evolves; this is the value of the iterative process, but stability assessment makes sure this is not so significant that the response is rendered meaningless.

Conclusion

Public health bodies and specialists have a significant role to play in LAQM, but this is rarely recognised or realised. This study confirms the importance of, and added value that could result from, addressing this disconnect, and proposes enhancements that could maximise LAQM public health integration, collaboration and impact.

For the first time, using the iterative consensus-forming Delphi method, expert opinion has clarified the public health role in LAQM. Briefly, this involves greater support for broader mainstream risk assessment and integrated management efforts, and enabling functions such as communications, research and evidence appraisal, advocacy and leadership. To facilitate change, a range of linked opportunities, barriers and solutions are suggested. The added value resulting from evolving a more public health-focused and supported regime is also highlighted.

While some opinions relate to Wales' unique circumstances, most are general in context and so are likely to be both relevant and useful in other parts of the UK and in countries beyond where there is a recognised disconnect between air quality management and public health policy and practice.

Given the strengthening evidence linking ill-health with air pollution exposure, action to bring together LAQM and public health policy and practice must be prioritised. This is currently supported in Wales by increased professional, political and public interest in this subject, and a willingness and commitment amongst stakeholders (supported by the WFG Act) to do things differently to make a difference. While the findings of this Delphi study proffer strong and well-informed expert consensus rather than indisputable fact, they present a convincing evidence-based case to direct and support much-needed LAQM policy and practice change. This Delphi study's findings have since been shared and discussed further with Delphi panel members and the wider air quality management and public health community through an interactive 'research with impact' workshop. This workshop sought to engage a broad audience to collectively determine how enhancements suggested in this study could be taken forward in practice. For each LAQM enhancement, enablers have been specified to inform next-step practical actions (such as direct practice change, guidance development, policy connection, training, advocacy and leadership).

Not only has this study generated new evidence to enhance LAQM, it also highlights the applicability of the Delphi method in investigating complex environmental public health problems.

Acknowledgements

The authors would like to thank Prof Jimi Irwin (University of the West of England) for his support, advice and guidance.

Declarations

Ethics approval for this study was obtained from the University of West of England in February 2016 (ref. FET/16/02/028). This study was part-funded by Public Health Wales.

No competing interests declared.

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