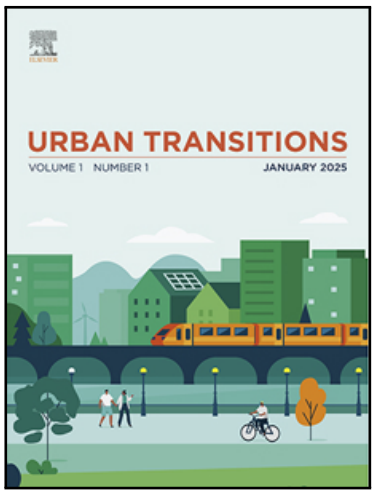
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Structured decision making: a tool for systems insights into the barriers, synergies and co-benefits for urban air quality action

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PII: S3050-6972(25)00005-3
DOI: https://doi.org/10.1016/j.ubtr.2025.100005
Reference: UBTR 100005

To appear in: *Urban Transitions*

Received date: 29 January 2025
Revised date: 6 June 2025
Accepted date: 11 June 2025

Please cite this article as: Nicole Hannah Cowell , Aoife Kirk , Hannah Murdock , Edward Sudall , Audrey de Nazelle , Structured decision making: a tool for systems insights into the barriers, synergies and co-benefits for urban air quality action, *Urban Transitions* (2025), doi: https://doi.org/10.1016/j.ubtr.2025.100005

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Structured decision making: a tool for systems insights into the barriers, synergies and co-benefits for urban air quality action

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Declaration of Interests

The authors have nothing to declare.

Acknowledgements

We would like to thank Roderick Weller at the World Economic Forum for facilitating the collaboration between Imperial College London and World Economic Forum and for supporting the workshops as a notetaker and facilitator. We would also like to thank the following PhD students at the Centre for Environmental Policy, Imperial College London for acting as notetakers and facilitators during the online workshops: Hannah E. Murdock, Edward Sudall, Rongjin Gao, Olivia Crowe, Jonathon Swinney and Yurong Yu.

Author contributions

NC: Conceptualization, Methodology, Investigation, Validation, Formal Analysis, Data Curation, Writing- Original Draft, Visualization, Project Administration. AK: Investigation, Data Curation, Project Administration, Writing- Review and Editing. HM: Data Curation, Writing- Original Draft, Writing- Review and Editing ED: Data Curation, Writing- Review and Editing. AD: Conceptualization, Methodology, Data Curation, Supervision, Writing- Review and Editing, Funding Acquisition.

Funding

This research was supported by the World Economic Forum Hoffmann Fellowship programme, which part-funds Nicole's time and research expenses.

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Abstract

Despite synergies between action for air pollution and action for health, climate and social wellbeing in cities, siloed thinking and the "wicked" nature of urban air pollution limit optimal decision-making. Systems approaches offer opportunities to identify barriers and opportunities for action towards cleaner air, and to bolster solutions that optimize benefits and limit unintended consequences. Structured decision-making was adapted into participatory workshops as an engagement tool to develop systems insights into the barriers and opportunities for clean air action. 24 participants from 15 countries and a mix of non-governmental organizations, academia, public and private sectors partook in an online workshop. The aim was to understand the synergies and conflicts between stakeholders, and to identify the actions that stakeholders believe are feasible and provide co-benefits for climate, health and social wellbeing. Workshops identified "human health and wellbeing", "equity" and "planetary health and climate" as shared objectives that drive stakeholders' work. Participants developed over 100 actions to address these objectives. Highlights included the importance of transport and data related solutions, including air quality monitoring, modelling, and transparency. Stakeholders identified collaboration and integrated approaches as co-beneficial, yet they didn't consider these particularly feasible. We identified a gap between the call for systems approaches and the evidence on how to implement systems thinking in decision-making practice. Structured decision-making enabled co-production and evaluation of objectives and actions, and promoted cross-sectoral networking between participants. It offers potential as a novel tool for engaging stakeholders and integrating systems insights and multisectoral perspectives into solutions to complex "wicked" problems.

Key words *Systems thinking, structured decision-making, urban air pollution, co-benefits, barriers, opportunities*

Highlights

- Structured decision-making is adapted for systems insights for clean air
- Stakeholders have shared objectives including improving human and planetary health
- More than 100 actions were identified by stakeholders, including data and transport solutions
- Barriers to action include public perception, siloed thinking and data challenges
- There is a lack of evidence on how to implement systems thinking in practice

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1. Background

1.1 Urban Air Pollution: A wicked problem

Air pollution is one the great challenges facing urban environments today. In 2019, over 4 million premature deaths were attributed to ambient air pollution and 99% of the global population was living in areas where the WHO air quality guidelines were not being met (World Health Organization, 2022). There is a wide array of actions to address air pollution, and not a singular solution to the problem due to the heterogenous nature of pollution and its sources (Okello et al., 2023). Air pollution is a typically wicked problem in that it comprises of many interdependencies and uncertainties, involves a large range of stakeholders with conflicting interests and is inequitable in terms of exposures, health effects, and contributions to the problem (Rossa-Roccor et al., 2021, Hooper and Kaufman, 2018, Tessum et al., 2019, Barnes et al., 2019).

Air pollution is an environmental health problem; but it also has complex relationships with climate change and economic growth making it an urgent issue to address to ensure resilient and sustainable cities (Vyas et al., 2023, Alahmad et al., 2023). There is a clear transdisciplinary nature to air pollution; where action for air pollution can create co-benefits and trade offs across a wider city system. Air quality improvement is often posed as a co-benefit of climate action within cities, with synergies between air pollution and climate change strategies (Xian et al., 2024). The co-benefits of actions and synergies across systems could encourage alliances and collaborations across sectors, and thus efficiencies and innovations within cities' policymaking (Okello et al., 2023, de Nazelle et al., 2021). However, the relationship between air pollution and climate is complex, actions that benefit one don't always relate to benefits for the other. This complexity makes the call for systems thinking stronger- to truly understand the impact and potential outcomes of actions we need to engage across sectors and disciplines.

Despite the transdisciplinary nature of air pollution solutions, this approach isn't always translated into the decision-making process. Policies for environmental challenges and city planning are often addressed

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with siloed thinking - individual agencies or departments make decisions which affect a range of other areas outside of their own interest without optimizing actions for system-wide benefits and trade-offs (Negev et al., 2022b). Research has indicated that co-created frameworks between stakeholders could help resolve siloed thinking, and that integrating a diverse range of stakeholders into decision-making will optimize co-benefits (World Health Organization, 2021, Negev et al., 2022b, Giles-Corti et al., 2016). Moreover, inclusive, transparent decision making encourages trust which in turn reflects public buy-in to actions. Research shows that general members of the public trust local government and scientists (particularly public health) more than they trust central government (Rossa-Roccor et al., 2021, Carmichael, 2019). How to implement systems thinking in practice, and the potential impacts of integrated decision-making for improving public health and wellbeing are not yet clear (Riley et al., 2021, Giles-Corti et al., 2016, Negev et al., 2022b, Okello et al., 2023).

New approaches to decision-making and engaging across a system could offer novel opportunities for solving air quality challenges in cities. This research aims to understand urban air quality action from a systems thinking lens, using structured decision making as a tool to gain insight into preferred action. The research is guided by the following research questions:

1) What are the synergies and points of conflict between stakeholder objectives in relation to urban air pollution?
2) When engaged in collaborative decision making, what type of actions would stakeholders co-create to address air pollution?
3) What co-benefits do stakeholders identify from such air pollution actions, and which actions do they believe are most co-beneficial for climate, health and social wellbeing?
4) What are the barriers to action identified by stakeholders across the urban air quality system?

Using structured decision-making as a tool to leverage insight, this research presents the qualitative outputs from a short series of multi-stakeholder workshops around the challenge of urban air quality.

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1.2 Systems thinking

Systems comprise of many interacting elements which together form a whole (Kirkpatrick et al., 2023, McAlister et al., 2022). Systems thinking is an increasingly popular mode in which to address complex planetary and public health challenges; it allows governments to handle complexity by traversing different disciplines (Voulvoulis et al., 2022, Nguyen et al., 2023). It can be viewed as a conceptual framework, which explores the elements, processes, relationships, inter-relationships and perspectives at play across a system (Iyer et al., 2021, Nguyen et al., 2023).

Systems thinking approaches are an opportunity for novel collaboration between sectors to develop and improve solutions whilst optimizing co-benefits and avoiding negative trade-offs, which are needed for the resolution of wicked problems such as air pollution . By engaging across a system in the decision-making process, paradigm shifts can be made ensuring transitions towards sustainability and overcoming the barriers of siloed decision making (Voulvoulis et al., 2022).

1.2.1 Structured decision-making

Structured decision-making can be applied to gain system thinking insights, to solve complex challenges by engaging diverse stakeholders into a collaborative and transparent decision-making process (Failing et al., 2013, Tiernan et al., 2022). It is developed from multi-attribute utility theory for decision-making under uncertainty, and works on the basis of creating a hierarchy of importance and value within the decision making process (Failing et al., 2013, Wilson and McDaniels, 2007). Structured decision-making is designed to be inclusive, as it engages participants from a wide array of interested backgrounds. It emphasizes addressing multiple perspectives and engaging with diverse viewpoints to foster rigorous, inclusive, defensible and transparent decision making (Wilson and McDaniels, 2007, Gregory et al., 2012).

The structured decision-making (SDM) process, as adapted from Tiernan et al. (2022), works through 6 key stages (Figure 1), preferably iteratively:

Stage 1 clarifies the decision context, defining the problem or challenge being addressed within the decision making process. It is important as it draws focus to the problem for discussion.

Stage 2 involves identifying participants' objectives and creating an objectives' hierarchy. This hierarchy is developed by establishing means and fundamental objectives. Fundamental objectives are the overarching goals or desired outcome that give insight into the ultimate reasons behind decisions, whilst means objectives are interim objectives and steps which work towards achieving the fundamental objectives (i.e. means to an end). The objectives' hierarchy is inherent to the SDM process, as it allows stakeholders to identify where they have synergies (and conflicts) with regards to what they are trying to achieve, and provides objectives to evaluate actions against when monitoring for progress in stage 6.

Stage 3 invites the participants co-create potential actions to achieve their objectives and allows stakeholders to understand the different opportunities for action across the system.

Stage 4 asks participants to evaluate the actions that they have suggested. In the context of this paper we had specific focus specifically on co-benefits, tradeoffs and feasibility as part of the evaluation. This is a useful way of understanding how actions may cause ripple effects across a system, trade-offs for other stakeholders or could potentially be mutually beneficial for multiple stakeholder objectives before implementing them and causing unintended consequences (identified in stage 2).

Stage 5 participants select actions following their discussion, choosing the actions which have group consensus. This encourages participants to apply learnings around the actions that could best benefit the wider system.

Finally **Stage 6** considers the implementation and monitoring of action, thereby allowing for evaluation against the stakeholders objectives from stage 1, considering how effective they are before adjusting and reconsidering the problem as the cycle starts again.

(Tiernan et al., 2022)

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For this research, we adapted the SDM process to gain systems thinking insights through a future visioning approach (Figure 1). Visioning and back casting are powerful tools that can be used to identify the aspirations of stakeholders and is a popular method for gaining insight into sustainable transitions (Lundsgaard-Hansen et al., 2024, Gray et al., 2024, Gaziulusoy and Ryan, 2017, Soria-Lara and Banister, 2017). Stakeholders identify their future visions and work backwards to identify how to reach it. Adapting this into the structured decision-making process means that stakeholder actions are not just based on their current objectives, but also their aspirational futures for cities.

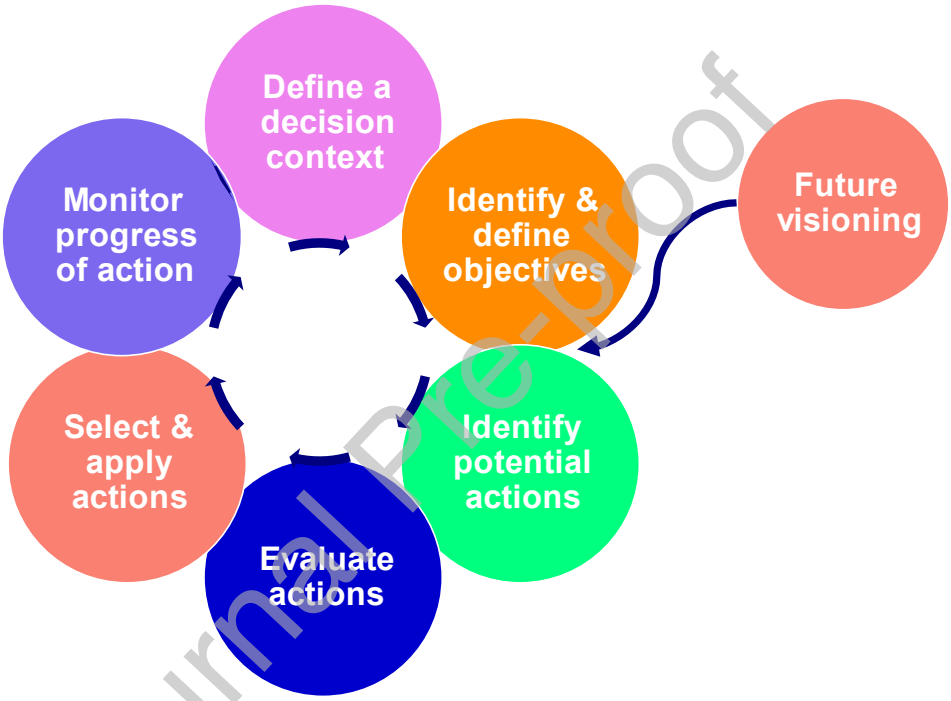


Figure 1- *Overview of the SDM process, adapted from (Tiernan et al., 2022) to also include visioning exercises.*

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2. Methods

2.1 Participant recruitment

24 participants were recruited strategically from the research team's professional networks , including those at the World Economic Forum. Participants were invited via email and offered two different time options to join the workshops to accommodate time zone differences. Some invitees suggested a colleague to attend as they were unavailable. This was generally accepted if the colleague met the following criteria:

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professionals in air quality or air quality adjacent sectors (urban, transport, health, energy, environment, data) and able to join a virtual workshop hosted in English language. We invited participants from non-governmental organizations (NGOs), private industry, policy makers and academia. The study was hosted online so there was no location criteria, and an effort was made to create an inclusive and diverse group from a wide array of nations (see list of participant locations in figure 3).

Participants were given an information form when invited and had to complete a consent form prior to joining the online workshops which included consent to audio visual recording for note taking purposes. Participants were informed that any outputs featuring results from this research will be anonymized and will not name any individual or their organization, but that the research results may state which type of participant shared the information (i.e. Industry expert, Local Government worker, Academic researcher) or from which city the comment is from (e.g. a participant from a city in China, a participant from Rio de Janeiro). Participants also agreed to follow Chatham House rule, meaning they could discuss the workshops externally but should not name any participant or participant affiliation. This was to encourage open discussion while enabling confidentiality. All participants were reminded of these rules at the beginning of each workshop. These procedures were in line with the protocol set out in the ethical approval of this project, provided by the Imperial Research Governance and Integrity Team with reference number 6949509.

2.2 Workshop protocol

The workshop was designed to test the SDM framework as a tool to understand stakeholder objectives, synergies, challenges and opportunities in relation to clean air. The protocol drew the initial framework from Tiernan et al. (2022), working through stages 1-4 outlined above (figure 1). As an online study testing this framework for air pollution with stakeholders from around the globe, we were not able to conduct stages 5-6 of implementation and evaluation . We integrated an additional step of visioning exercises that is not standard in the usual SDM procedure, as explained above.

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Inspired by the design of Tiernan et al. (2022), the workshop consisted of two online sessions, which occurred 5-6 days apart and was repeated in two time slots to accommodate different time zones. The first session lasted two hours and the second session lasted three hours. The outputs from session one directly guided the discussion in session two. Sessions were audio-visually recorded, a transcript was taken by the video call software and notetakers were also present capturing key takeaways from discussions. Mentimeter, an online interactive presentation tool, was used to collect inputs directly from workshop participants. Throughout the sessions, participants were guided through discussions in breakout groups. Each breakout group had a facilitator, at least one notetaker, and 3-5 participants. Within the individual sessions, participants stayed with the same breakout group, however for the second session the breakout groups were rearranged to facilitate intermingling between participants. While optional, participants were encouraged to keep their cameras on to facilitate interactive conversation. Participants were invited to share any additional ideas after the workshop by email to address any potential effect of group-think. Throughout the workshop participants had the option to contribute ideas via the chat function.

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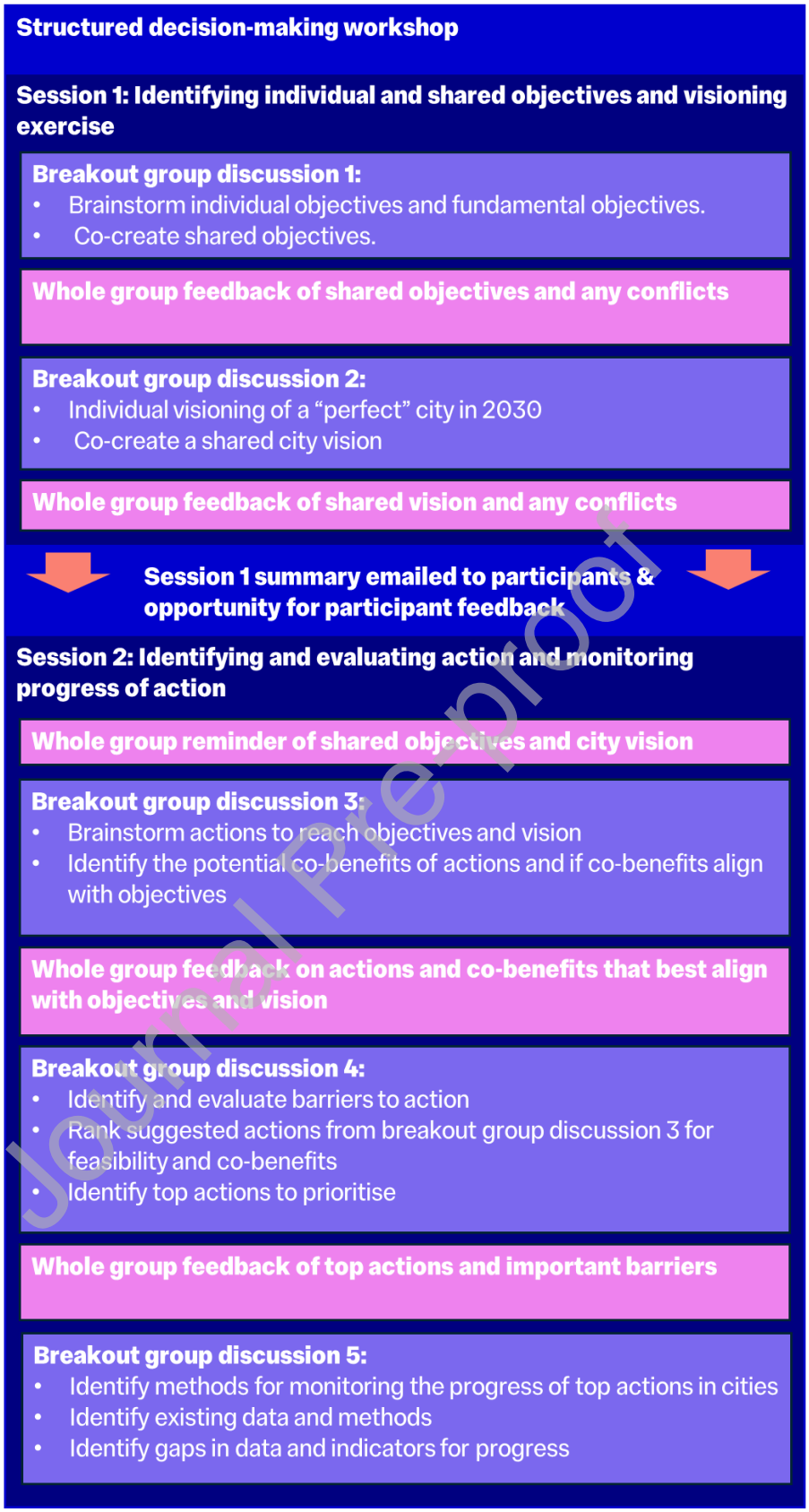


Figure 2- *flowchart demonstrating the workshop protocol*

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The first workshop session focused on creating an objectives' hierarchy (SDM stage 2; Figures 1 and 2). The session started with an introductory presentation, which explained the structured decision-making process and the rules and goals of the workshop. The decision context (stage 1 of the SDM process) was defined as: "What air quality actions could your city take that also support climate, health and social wellbeing benefits?". This question was referred back to throughout the workshop during the steps of structured decision making, to encourage participants to think of how their objectives and actions should be considering urban air pollution and the potential co-benefits.

In breakout group discussion 1 participants were invited to independently brainstorm their individual objectives (i.e. what they want to achieve within their individual professional roles) using Mentimeter. Then facilitators were tasked with leading the group in identifying their individual fundamental objectives (i.e. what they ultimately want to achieve, as opposed to means objectives), using why questioning (i.e. asking the purpose of responses provided) until what was deemed "fundamental" was reached.

Participants were asked to share their inputs and identify the conflicting and shared objectives within the breakout group, and to collaboratively identify key words and phrases that best described any shared objectives. These key words and phrases from each breakout group were fed back to the whole group by the facilitator, with time for feedback from the whole group.

In breakout discussion 2, we tasked facilitators with guiding their groups through creating a city vision, asking the participants to imagine their perfect city in 2030 if there were no barriers to action. Again participants independently brainstormed ideas first on Mentimeter, before discussing and identifying points of consensus and conflict within their group. To pinpoint the key synergies between the stakeholders, we asked them to create a shared city vision by suggesting a concise list of key words that described the ideas with consensus. Although key words cannot capture entirely the complexity of visions (such as the competing aspects of visions, or the contexts of; the science-policy interface, economy, technology, governance and communities that drive visions (Gross et al., 2019)) they encouraged a focused discussion.

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An interim report outlining the shared city vision, objectives, and any key points of conflicting interests that emerged from session one, was circulated to participants between sessions. We thus provided an opportunity for further feedback or insights via email, helping overcoming group thinking and ensuring all voices were heard (Tiernan et al., 2022). These key findings were also presented at the start of session two, to help re-focus minds on the priorly co-created objectives .

Session two aimed at creating and evaluating actions to achieve the shared objectives and city vision (stages 3 and 4 of the SDM framework, Figure 1). In breakout group discussion 3, participants were tasked with independently brainstorming actions to achieve their shared objectives and vision, assuming there were no barriers to action. They then discussed the co-benefits, tradeoffs and barriers for each action, and highlighted most important ones via the identification of key words which (then fed back to the whole group by facilitators) .

During breakout group discussion 4, the action evaluation continued with participants ranking their suggested actions for feasibility and how co-beneficial they were. We designed the ranking activity using Mentimeter and individuals' inputs were updated and collated in real time via the tool, showing each breakout groups' collective rankings. Based on the rankings and their discussion, breakout groups were asked to identify top action(s) for addressing air quality in cities. These were fed back to the whole group before a final breakout discussion (5) in which participants were tasked with identifying the types of data needed to track progress of their top action suggestions, including any data gaps or challenges. We wanted to understand how participants might measure progress had they been able to, even though we ended our co-creation process here. .

2.3 Data and analysis

Following the workshop, the following data was reviewed for data analysis: session transcripts, audio-visual recordings, menti interactive slides and notes from the notetakers. All results are pseudo-anonymized throughout this paper in line with the ethics and consent agreements stated in section 2.1.

Any direct outputs from the activity of the breakout groups (such as suggesting key words to describe their groups synergies) were captured by the notetakers or input directly by participants themselves into the menti slides. All the menti inputs and key words captured by the notetakers were collated to allow for qualitative analysis. The Quanteda package on R and the Microsoft office (Excel & PowerPoint) package were used to create visualizations of the workshop data, including word clouds, likert plots and frequency analysis (Benoit et al., 2018). Transcripts were reviewed for key discussion points as highlighted by prominence in the menti/key word outputs and selected by co-authors as representative of participant ideas and discussions. We recognize the importance of the position of the authorship team in selecting these points. The lead and senior authors are white, female researchers, affiliated with a research institution in a high income country, which will inevitably mean being outsiders to some participants. This affiliation inherently carries some institutional power, which, combined with how we designed the workshops could influence participants responses' and how we interpret results. We had a number of facilitators and notetakers from a variety of cultural backgrounds, from both World Economic Forum (n=2) and Imperial (n=8). They were engaged throughout the workshop design, analysis and feedback, and trained to ensure questioning was standardized as much as possible. The use of Mentimeter interactive slides meant that there was a standardized approach to asking key questions and getting participant insights. We also encouraged participant feedback throughout and following the workshops, through creating verbal opportunities for feedback and questions, as well as offering a chat function, interim report and email address. To elicit different perspectives, we actively sought participants who were from different professions, sectors and experience to the research team. Research intentions were made clear through a participant information sheet ahead of the research. We are mindful that our interpretations of results will be filtered through our own lens of experience, including the lead author's background as an air pollution researcher with detailed knowledge of the atmospheric science and technical aspects of air pollution.

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3. Results

3.1 Participant demographics

The recruitment process generated 24 participants from 15 countries. Due to our strongest network connections being in Europe and North America, there was a concentration of participants from these regions (Figure 3). Participants' professional backgrounds and sectors included (Figure 3 and Table S1):

- 8 (33%) from NGOs from health (including urban and public health), sustainability, air pollution, climate and energy, environment, and water sectors;
- 5 (21%) policy makers representing sectors of environmental health, air pollution and transport;
- 5 (21%) industry participants from urban planning and design, buildings and climate, transport, and sustainable and livable cities;
- 6 (25%) academics, experts in health, air pollution, public health, environmental health and environmental psychology.

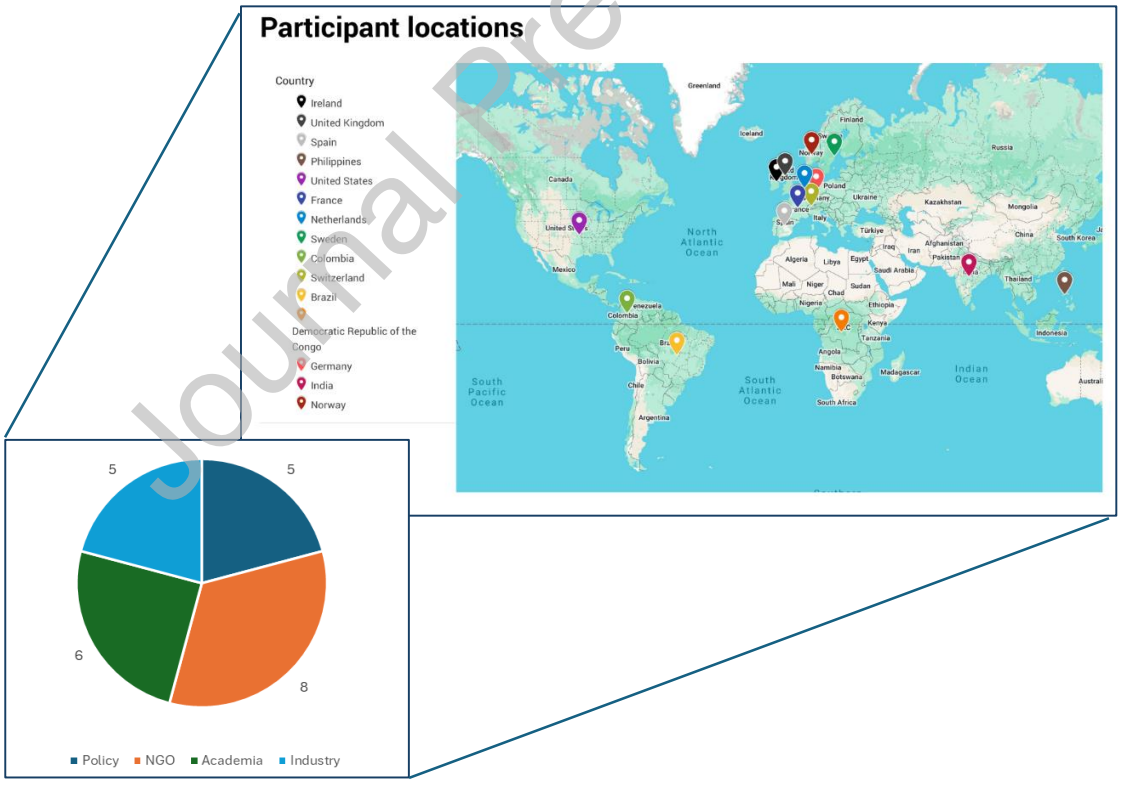


Figure 3- *Participant demographics. Bottom left: number of participants by type. Right: Map of countries where participants are from. Map data created using GoogleMaps 2025.*

3.2 Objectives' hierarchy



Figure 4- *Word cloud showing the individual objectives (top / red) and the agreed upon shared objectives key words (bottom/pink) created by each breakout group. The size of the word increases with its frequency. Words are stemmed to allow for root forms to be clustered and stop words are removed using the Quanteda R package. Stop words were selected using the Quanteda default English stop words which features 174 words. Full details in the supplementary information.*

When participants contributed their independent objectives, unsurprisingly given the context of the workshop, air pollution was a key theme that emerged: "air" alongside the stem word "pollut" (i.e. root of the word pollution) were popular inputs, as shown in the word cloud rendition of the individual (top/red color) brainstorming activity of Figure 4. Many of the objectives suggested by participants in the initial individual brainstorm were means objectives, focusing on specific organizational or legislative targets rather than the underpinning values driving their work. Notably, participants with a policy background tended to mention numerical or legislative targets or to have a focus on their specific cities or regions when stating their objectives (e.g. "Achieve compliance with UK legal limits sooner" or "Dublin Compliance

with current air quality standards and to improve air quality to ensure compliance with WHO guideline limit values by 2030"). Themes around compliance and governance ("complianc", "guidelin", "limit", "polici") and data ("data", "measur", "open") appeared repeatedly when viewing the individual objectives, identifying some commonality between participants objectives. Generating and communicating data and embedding data into action were also common individual objectives contributions (as shown by menti contributions such as "air quality data aggregation and public, open access", "train users to use our data and tools", "demonstrate data-driven clean air action…" and "convince governments to open up their air quality data"). The importance of quantifying the effects of air pollution to support the argument for change was highlighted, with a participant stating "It's just an easier argument with numbers (and deaths) and it's a better argument in my view because you know it's something – it is a shock".

The synergies between participants became clearer when identifying shared objectives within breakout groups, where the most frequent suggestions were fundamental objectives rather than means objectives (Bottom/pink in Figure 5). The objectives' hierarchy in Figure 5 shows the shared objectives created by the breakout groups, with the fundamental objectives reflecting those highlighted by the word cloud. There was clear consensus across participants on 'Human health' as a fundamental objective. Health was raised by every breakout group as a shared objective and was a frequent fundamental objective suggested at the individual level too. Variations in human health as a shared objective included: "Improving public health", "Human Health", "Health", "Health and wellbeing", "Improving health worldwide" and "Improving well-being/health span in addition to lifespan". Health and wellbeing are presented together within our objectives' hierarchy due to the intrinsic link between the two, however we recognize that different participants will be considering different factors when discussing wellbeing. This is in line with the World Health Organization who suggest by definition that wellbeing is an integral part of health (Misselbrook, 2014, World Health Organization, 2024). The second fundamental objective, 'Planetary health and climate', reflects the shared objectives across the breakout group discussions. 5 of the 6 breakout groups featured shared objectives under this theme. 2 breakout groups directly identified "Planetary health" as a

shared objective, with 3 further breakout groups identifying climate and planetary health related shared objectives ("climate", "reducing emissions" and "net-zero and reduce carbon emissions/sustainability"). The third fundamental objective, 'Equity', was also a prominent shared objective (Figure 5) suggested as a shared objective by 4 of the 6 breakout groups.

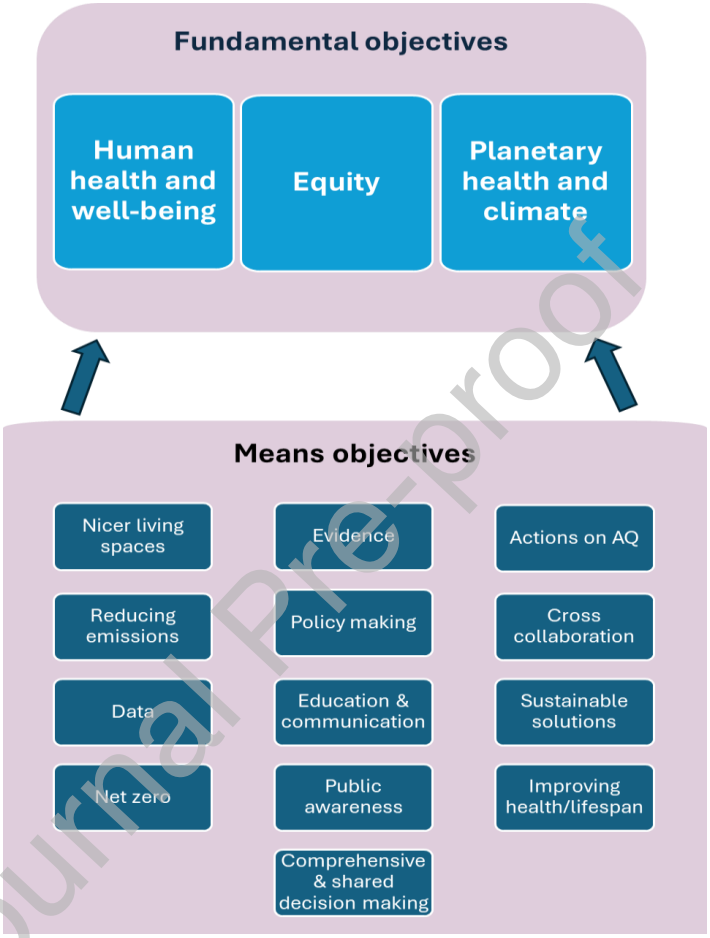


Figure 5- *Objectives' hierarchy created from the shared objectives created by the workshop participants. Fundamental objectives are the overarching aims, whilst the means objectives show the steps to achieve these.*

From the shared objectives created by the breakout groups we can also identify means objectives, and these range from specific objectives such as "reducing emissions" and "net zero" to broader objectives such as "data", "education and communication", "cross collaboration" and "nicer living spaces". When

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asked to discuss and find synergies within their individual objectives, the breakout groups tended to create broader objectives that were less specific and more thematic. For example; education and communication were suggested as shared means objectives, however within breakout groups discussion participants had varying opinions about what education and communication entailed. Some wished to focus on educating the public and advocacy ("public notice", "public understanding" and "advocates"), whilst others suggested more targeted communication such as "communicating air quality improvements as a co-benefit of decarbonization" or creating "south-south dialogue".

There was disagreement raised around education and the implications for who shoulders responsibility for action, policymakers and businesses or individuals. When discussing climate and air pollution education and awareness one participant raised that "These are actually, you know, wicked problems that have deep structural links" which makes individual action challenging and may require education to support structural changes. This shows that whilst there were synergies between stakeholders allowing for broader objectives, their priorities within the objective themes were different.

3.3 Actions

When asked to independently brainstorm actions for air pollution assuming no barriers, participants had over 100 suggestions. Some actions suggested by participants were specific to the participants' roles. We collated these actions into 9 themes, presented in Table 1.

Many actions focused on targeting specific emission sources of pollution (such as buildings and transport). Actions relating to the theme of *Transport* were prominent. The word "transport" and transport related words such as "cycl", "bike", "car" and "street" emerged prominently in suggested actions (see figure 7). There was a variety of transport related actions, from ambitious urban transformations such as "ban cars" and "better public and active transport", to more specific targeted solutions such as "smart traffic lights", "delivery hubs for last mile delivery" and "low emission zones". Low emissions zones were particularly popular suggestions, suggested by 4 different participants. However, geographical context was important

as to whether participants agreed that transport was a priority. One participant argued that the transport focus was euro-centric, stating: “you in Europe for example, you talk about reducing emissions from cars. But as I talk in my introduction is that the raw materials the minerals are coming from Africa, so we have more industries that are polluting environment, but also in my situation for example in the way of extracting mineral”. This suggests the importance of the other themes across non-European environments and the trade offs of European choices on other countries.

Actions captured in the *Buildings and Energy* theme cut across heating and cooking solutions as well as construction and materials related actions. There was a prominence of actions relating to burning within this theme, particularly wood burning and solid fuels, and there were multiple actions relating to banning or phasing out fossil and solid fuel burning. Alternative suggestions included district heating, heat pumps, and renewable energy resources.

The theme of *Data and Evidence* was notable throughout the workshop, and this is explored in detail in section 4.1. There were many suggestions for air quality monitoring, particularly ensuring “open”, “transparency” and “full public access” to datasets. There were also suggestions that AQ data could drive further action, with ideas of “AI based selection of clean air action”, “identify hotspots that need priority for action” and “readjust clean air actions based on (hyper-)local data”. This suggests that data could be an action that unlocks further action.

“Transparency” was also mentioned in the theme of *Communication and Knowledge*, here in the context of transparency around air quality interventions rather than data. These actions suggested improving knowledge, opinion, and public buy-in around air quality but didn’t suggest the specifics as to how to implement this.

Actions in the theme of *Governance* addressed both climate (“GHG emissions”, “Net-Zero”) and air pollution emissions. This theme included policymaking (e.g. Implementing and designing policies to meet the objectives) and the changing practice of policymaking such as “long term view” and “devolved

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responsibilities". In some cases. actions were locally-specific, e.g. "UK grid planning reform, tie funding for local authorities to address Clean Air Strategy and Climate Action plan".

The Collaboration theme had a focus on collaboration between government departments, in particular between environment and health departments. Engagement with the "community" was also considered, and specific actions included giving responsibility to the general public by inviting them to be involved in decision-making or delegating some local responsibilities to community groups, such as promoting clean air action.

Actions under the theme of *Urban Design* included: reallocating space within cities to separate people and pollution; designing streets to promote healthy and safe active travel; protecting vulnerable populations and decontaminating brownfield sites.

The word "green" was frequently mentioned in individual action suggestions (top of figure 7), and actions under the *Nature* theme included increasing access to green space. There was a focus on streets, with "trees" and "green streets" being suggested. Actions under the *Nature* theme linked nature to economy, with suggestion to "prioritize nature over the economy".

The *Resource Management* theme focused on reducing and avoiding burning, either from waste or agriculture. It had the fewest actions; generally waste wasn't discussed in detail within the workshops, areas of discussion tended to focus on the themes with the most actions.

Responsibility for action was also debated within the breakout groups. There were suggestions from some participants that communication, education and advocacy for the general public were particularly important in inciting change. However, other participants highlighted that air pollution is a "wicked problem that has deep structural links". There was some debate around where and when the emphasis should be made, in particular whether advocacy and individual action/behavior change should be pushed before the structural changes to support transitions.

Table 1- *The actions suggested by participants in an independent brainstorming activity.*

Actions suggested by participants individually
Theme: Transport
Low emission zones, zero emission zones, parking fees, better public and active transport, smart traffic lights, route optimization for motorized traffic, good public transport options, AQ based city toll, AQ based incentives on public transport, electrify all public transport, AQ based parking fees, free bike share for last mile mobility, delivery hubs for last mile delivery, technology enablers for transport, low emission zone for transport, improving public transport, ban cars, walk and cycle orientated streets, well designed cycle/pedestrian routes and parking spaces, low emission zones, active travel incentives, incentivize electrification (or switch to hydrogen) for trucks buses and cars, free sustainable transport
Theme: Data and evidence
Open data, AI-based selection of clean air actions, monitor pollutant levels in various locations to raise awareness and help quantify impact of changes, readjust clean air actions based on (hyper-)local data on action successes and failures, enhance monitoring of air quality and local level to better identify hotspots that need priority for action, air quality modelling which allows stakeholders to know future air pollution levels and it's causes in advance, transparency on air quality and air quality heat maps of the city, place air quality monitoring in densely populated areas, air quality monitoring, equity-measured and accountability, air quality monitoring, full public access to AQ data
Theme: Nature
Green streets, Trees on each street, set aside green spaces for people, don't mow lawns, green spaces, organic/nature solutions for clean air/climate/wellbeing, high quality public spaces and goods, improve access to green space, decisions prioritize nature over economy, focus on making the city nature positive
Theme: Communication and knowledge

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Inform public of air quality, public opinion, improving knowledge of air quality in citizens and politicians, communication/transparency, communication (framing of intervention), advocacy campaign, public support and buy in
Theme: Governance
Air pollution mitigation measures, UK grid planning reform, fiscal incentives, life cycle GHG emissions embedded into policy, Net zero pathways mapped out to boost industry confidence, tie funding for local authorities to addressing Clean Air Strategy and Climate Action Plan, targeted interventions in areas of highest needs, planning reform, devolved responsibilities and finances, funding, long term view, set targets
Theme: Collaboration
Government departments working together across environment and health, involve community in the process, integration of different systems, local air quality heroes promoting clean air actions in their neighbourhoods, partnership between local government and local media (to raise awareness), coordination on environment and health, participatory processes, city officials and impacted communities to ensure buy in and relevance, involve national government, delegation of local responsibilities to engaged and informed and inclusive community groups, transform how city actors work together, public private collaboration, collaboration, diversity of thought and inclusive approach, generation stewardship and 7th generation stewardship, citizens directly involved in city decision making
Theme: Buildings and energy
Ban fossil fuel energy generation (in real estate), strategic support for households most in need to switch to home energy efficiency, ban on woodstoves, district heating and heat pumps instead of solid fuels, green energy for households, mandatory renewables on all development sites, rethink materials used in buildings, phase out fossil fuels for cooking, circular building materials and furnishings, ban domestic wood burners and commercial biomass

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Theme: Urban design
Translocate polluting city bound industry (which would also include changing to EV/hydrogen ships in harbour cities), design streets with safe pedestrian and bicycle access involving the community, protected environments for vulnerable groups (schools, hospitals, community centres), cities planned for people, active and sustainability prioritised, decontamination of brownfield land, urban planning, circularity
Waste collection and recycling to avoid waste burning, tackle waste burning and agricultural waste burning



Figure 6- *Word cloud showing the participant independent suggestions for actions towards objectives (if there were no barriers) in green top and the barriers for the suggested actions in grey on the bottom. The size of the word increases with its frequency. Words are stemmed to allow for root forms to be clustered and stop words are removed using the Quanteda R package.*

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3.3.1 Barriers to action

The most commonly featured word in the individual suggestions of barrier to action was “Lack” and the participant suggestions identified a lack of: tools, data, knowledge, cohesion, public awareness, political will, buy-in and legislative framework (bottom/grey of Figure 6). When participants were asked to identify the most important barriers they emphasized: public awareness, perceptions and buy-in; misinformation and disinformation; data access, quality, awareness and communication; challenges of siloed thinking and collaboration; technical abilities and political will (Table S2). Participants recognized the links between these barriers, for example that generating public buy-in was challenging due to lack of awareness, particularly due to the invisible nature of air pollution, which can make it easy to ignore. Moreover, participants identified the connection between public perceptions and political will. One argued that if “public opinion is against certain measures or actions, then it won’t happen” whilst another described the “political fear” of actions that could cause public backlash.

Data was a prominent key word in the individual suggestions for barriers to action: “data access, quality and models” and “technical knowledge and capacity” were suggested as two of the most important barriers from the breakout group discussions. There were multiple barriers identified as preventing data being embedded into decision making due to the complex nature of air quality data. “They don't even have an overview of what they all have. It's [data] all in different formats with different vendors, and now the first challenge is actually getting it all together and harmonizing it” argued a participant from Industry background. Furthermore, workshops raised the challenges of communicating and embedding data into decision making. Where air quality and related data does exist, it isn’t necessarily being used to its full potential. One participant in local government stated “for years and years we had data floating around in local authorities that nobody was doing anything with”, emphasizing the need for both building knowledge and for improving understanding of how to use data effectively.

“Cost” is another term that was frequently raised during discussions on barriers. Funding to cover the costs of actions was discussed, particularly in the context of short-termism. “Most politicians are thinking

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on the short term" argued one participant when discussing money as a barrier, noting that some benefits of the actions are longer term than the upfront costs associated with them . A second financial barrier concerned individual levels of poverty and the distribution of wealth. "If you're poor, you don't have enough food on your table. You're not thinking about air quality or climate change".

3.3.2 Co-benefits

Breakout groups identified co-benefits of action and their importance for supporting the objectives (table S1). Social co-benefits were the most popular, with 12 of the 21 suggested important co-benefits including social aspects, such as "wellbeing", "equity", "accessibility" and "community". Important environmental co-benefits included "climate mitigation", "biodiversity", and "reducing pollution". The economy was only mentioned twice in the discussion on most important co-benefits; "stimulating economy" and "money".

3.3.3 Ranking top actions

There was not a clear consensus around which actions were considered most co-beneficial or feasible. This is partly due to the breakout groups format of the workshop, which led to each breakout group voting on the set of actions they created, rather than a uniform vote across all groups. Two actions were voted by their respective breakout groups as both most feasible and most co-beneficial; "public transport and promotion" and "air quality monitoring, modelling and transparency" (figure 7 and 8). Two actions were also ranked by their breakout groups as simultaneously least feasible and least beneficial; "electrification of transport" and "relocating polluting industry outside of city".

Each breakout group had at least one transport-related action featured within their rankings, but its assessment varied greatly between groups. For example "improving public transport" was ranked as least feasible action by one group, but "public transport and promotion" was ranked both most co-beneficial and most feasible by another group. "Active travel incentives" were ranked least co-beneficial

by one group in contrast to another group ranking "climate and health promoting transport" as most co-beneficial.

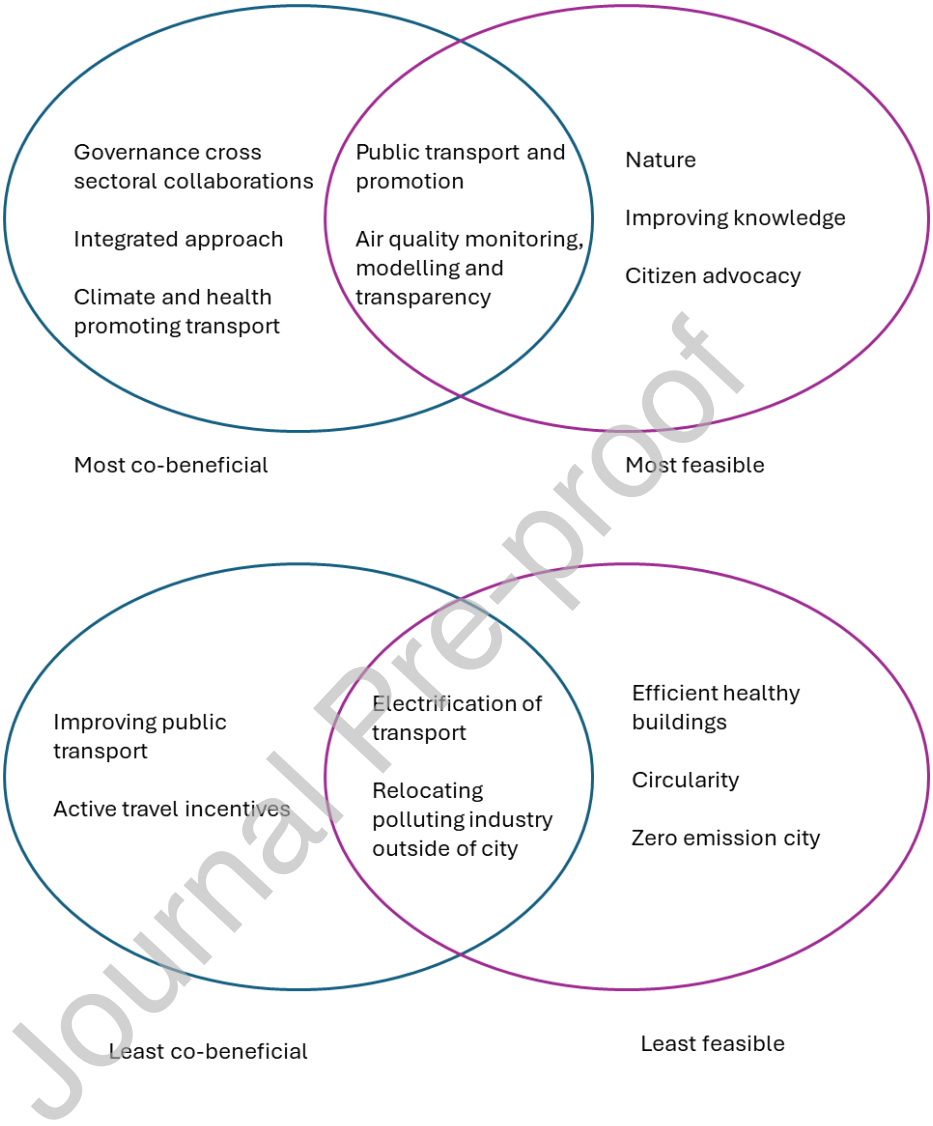
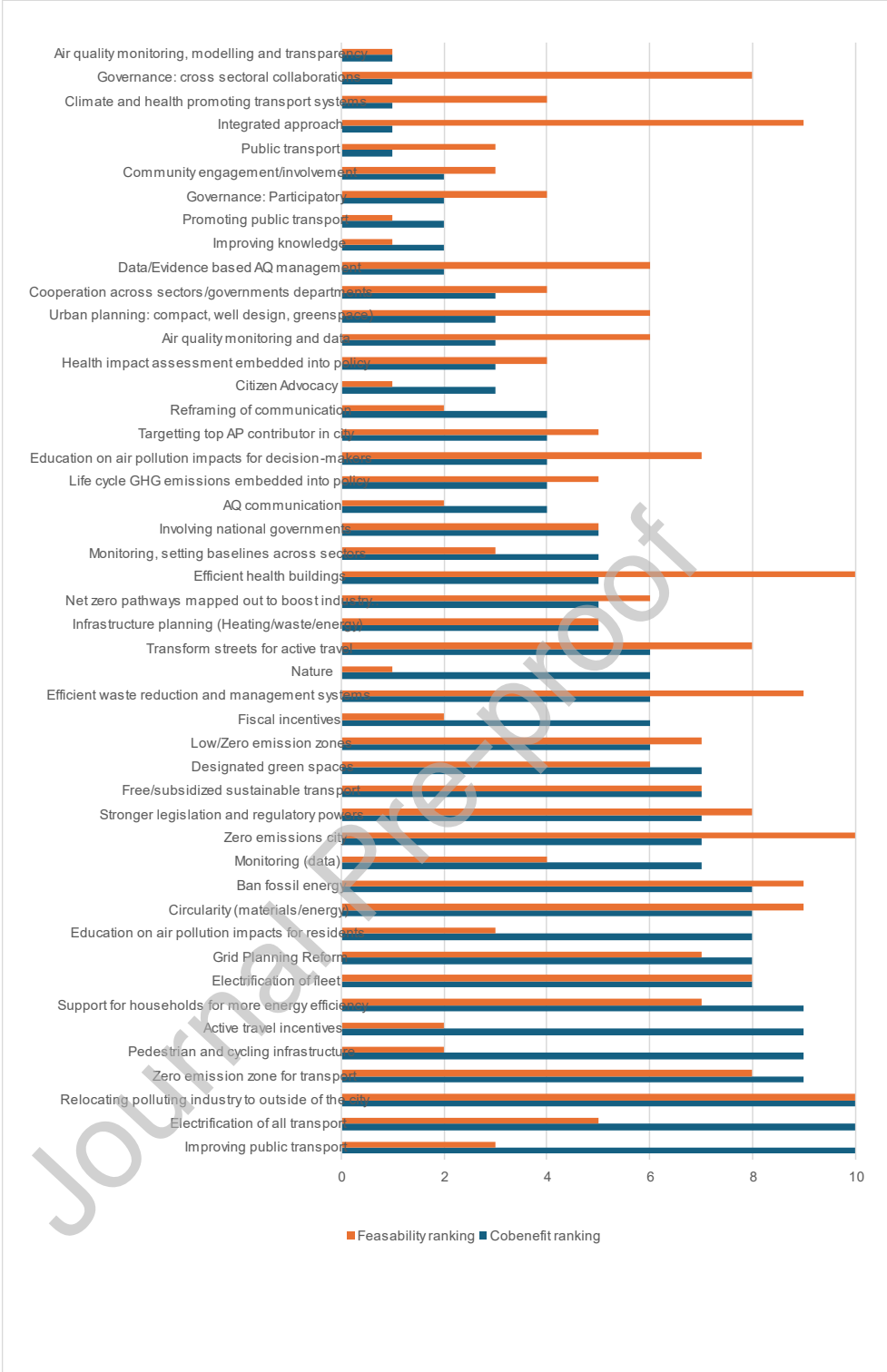


Figure 7- *Top actions ranked most and least feasible and co-beneficial by each breakout group.*

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Figure 8- *Participant's ranking for feasibility (orange) and level of cobenefits (blue) for the top 10 selected actions in each breakout group, presented by descending order of level of cobenefits. A ranking of one equates to most feasible/cobeneficial and feasibility and cobenefits decrease with number.* ***NB. There is multiples of each rank because voting occurred in breakout groups rather than collectively.***

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Collaboration and integrated approaches ranked amongst the highest in terms of co-benefits of actions, but received low ranking for feasibility (although not the lowest).

After reflecting on these rankings, the overall top actions subsequently selected by the breakout groups included:

- Air quality monitoring modelling and transparency
- Evidence base *(developing evidence base for clean air action and management)*
- Public transport
- Citizen advocacy
- Improving knowledge *(referring to public and political awareness and understanding of air pollution)*
- Integrated approach
- Climate- and health-promoting transport

Top actions generally were taken from either the most feasible or co-beneficial actions. Again, transport is prevalent in the top actions. Data/evidence was also suggested by multiple groups as a priority action. Some groups struggled to narrow down to one top action, so suggested multiple "top" actions. One group didn't make a firm decision on their top actions to feedback to the group, so are not listed above, this was partly due to needing more time for discussion. The facilitator and notetaker for that group identified that discussion included trying to balance between feasibility of actions to get the ball rolling, whilst recognizing the need for bigger structural changes but there were too many actions raised to narrow down to a top action. Specific actions in this group discussion included participatory and cross collaborative governance, green space, active travel, nature-based solutions and 7th generation stewardship (7th generation stewardship is a concept encouraging of longer term thinking, considering the benefits and consequences for future generations).

4. Discussion

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This research aimed to adapt structured decision-making as a systems thinking tool, gaining insights into the synergies and conflicts of stakeholders in relation to urban air pollution. It identified the shared fundamental objective of health driving stakeholders' work, alongside climate and equity. Stakeholders co-created and evaluated actions to reach their objectives and aspirational city vision, with key themes of transport, data and integrated approaches being identified by stakeholders as some of the top actions to consider. Whilst there were many synergies between actions identified by stakeholders, there wasn't always consensus in the actions, partly due to different perceptions of feasibility of actions, or different prioritizing of feasibility compared to co-benefits and impact of action.

4.1 Data

Data was a key theme throughout the workshop, identified as an objective, action and barrier to action. The importance of data highlighted by stakeholders (through objectives such as "data-driven clean air action") to an extent aligns with the academic theory that 'what gets measured gets done' (Giles-Corti et al., 2022). The suggestion of "Air quality monitoring modelling and transparency" as a top action is in alignment with recent research, evidencing that air quality data has driven demand for change by highlighting the depth of the problem (Hasenkopf et al., 2023, Goldsmith and Crawford, 2014, Giles-Corti et al., 2022). 39% of countries globally lack basic air pollution data infrastructure (with those countries disproportionally located in the global south) (Hasenkopf et al., 2023).

Therefore, it is unsurprising to see a demand for data from stakeholders, although interesting to hear the call is still being raised by stakeholders working in high income regions which are more likely to have access to some air quality data. In contrast to the above theory of "What gets measured gets done"(Giles-Corti et al., 2022), stakeholders themselves raised that even when data is there, it isn't always used. Data itself comes with a number of inherent challenges; communicating uncertainty, creating hierarchies of knowledge and power, potentially limiting creative understandings of how and why things happen in favor of numerical value and creating a gateway where data becomes a requirement to having a voice (Shapiro et al., 2020). Moreover, data does not always translate into the evidence selected for decision making,

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there is a gap in understanding between scientists and what makes good evidence, and the dynamics of policy practice (Kent et al., 2022).

The challenges relating to embedding data across the air quality system are particularly hard to overcome given the current digital skills gap, something identified both by the participants and by researchers (Chapman et al., 2023, Evans et al., 2024, Topping et al., 2021). Moreover, previous literature has recognized the need for urban data governance, and the challenges in translating data into action (Kaginalkar et al., 2023, Cowell et al., 2024). There are a number of opportunities available to enable integration of data science into decision-making, which is particularly important in a world of growing big data and smart cities. Firstly, the stakeholders' suggestion of "air quality monitoring, modelling and transparency" as a top action, and a feasible action to implement, is reflected within the literature. Air quality monitoring is being revolutionized by the development of low-cost sensing, making this actions to monitor air pollution more affordable and accessible to non-specialists than before (Cowell et al., 2022, Lewis et al., 2016, Snyder et al., 2013). Yet with increased air quality monitoring, there is evidence of conflicting data uses and interpretations by different stakeholders. Scientists and environment justice groups approach concepts such as long-term vs short-term exposures differently. Furthermore, even among scientists and experts, practices for connecting air monitoring data and environmental health vary (Ottinger and Sarantschin, 2017). This creates a particular challenge in the context of low-cost sensor data where there are associated uncertainties and technical limitations that can limit application and may be subject to different interpretations and perspectives on data quality and use cases (Cowell et al., 2025, Lopez de Ipiña et al., 2024).

Participants also promoted partnerships with research and the creation of visualizations that help the understanding of complex data. Research-policy collaborations would offer opportunities to bridge the skills gap; research has demonstrated use cases where collaborations could support the development of business cases for air quality action or to support practicalities in generating air quality data (Baldo et al., 2023, Simpson et al., 2022, Cowell et al., 2023). Embedding data science (and data scientists) into

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policymaking would support the skills gap in the public sector; participants suggested that tracking the number of data scientists embedded in policymaking sectors could help track progress. Communicating data via visualizations is a growing area of development, especially to create agency for change. Pope et al. (2024) for example collaborated with artists to "paint" particulate matter onto images, creating a visualization to make particulate matter concentrations visible for policy makers. Next steps for air pollution data should ensure that data is presented in ways that are dynamic and easy to interpret for different audiences (Riley et al., 2021, Lee et al., 2022, Ramírez et al., 2019).

4.2 Transport

Whilst there were varying suggestions as to the specific transport solutions needed to achieve the workshop objectives, the majority of participants agreed that transport should be addressed. This may be reflective of; i) the representation of the transport sector within the workshop (three participants from the transport sector and others from sectors where we would expect some indirect knowledge of transport such as urban planning or air pollution); and ii) the high proportion of participants from European locations, where low emission zones and other policies aimed at sustainable transport were initially established and are of growing popularity (Ku et al., 2020, Seter et al., 2023). The focus on transport also may be linked to the decision context proposed to the participant, which focused on highlighting benefits of air quality actions.

Transport is well recognized within the literature as having direct and indirect benefits for health and climate (Glazener et al., 2021, Nieuwenhuijsen, 2020, Whitmee et al., 2024, Negev et al., 2022b). The strong evidence from the literature on the large range of co-benefits that could be achieved from modal shifts away from car use d supports the prominent position of active travel-related policies in top rankings by stakeholders (Caputo and Nazelle, 2022, Rojas-Rueda et al., 2012, Negev et al., 2022b) (de Nazelle et al., 2011, Barban et al., 2022). In contrast, for some transport solutions, co-benefits are accompanied with trade-offs for health. For example, electric vehicle uptake has trade-offs (non-exhaust emissions, physical inactivity) that are in conflict with the climate co-benefit of greenhouse gas reduction (Penn et al., 2022).

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Some subgroups recognized co-benefits of improving transport or of improving urban design and planning (which in turn can promote alternative travel modes) Some groups, however, deemed active travel to beamongst the least co-beneficial actions . This could be due to challenges in translating scientific literature to practitioners (Negev et al., 2022a); to walking and cycling continuing to be perceived as insignificant modes in transport decarbonization (SLOCAT, 2018, SLOCAT, 2022) and receiving less investment and attention in transport planning (Allen and Nolmark, 2022); or to the lack of relevance or appropriateness of current evidence to help compare wide ranges of policy options (de Nazelle et al., 2021, Negev et al., 2022b).

Another reason for the prominence of transport within the actions could be because participants raised how transport changes feel more achievable than curbing other types of emissions, such as those from buildings and homes, with a participant stating “transport is relatively easy to implement” in comparison to building changes. This stands in contrast to other studies emphasizing that transport behavior is difficult to achieve due to ingrained individual habits and constraints of the built environment (Linder, 2022, Wang et al., 2020, Bouton, 2014, De Vos et al., 2022, Garrott et al., 2024, Hoffmann et al., 2017, Kosmidis et al., 2023, Whittle et al., 2019). Transport mode shift has also been highlighted by both energy and transport experts as the second largest challenge to reducing transport sector emissions(Murdock and Staffell, 2022). It is also surprising considering that transport has seen the slowest progress in shifting from fossil fuel sources compared with heat and power(REN21, 2022).

4.3 Equity

Equity was identified as a fundamental objective within the workshop and arose as an important co-benefit of actions. This is likely due in part to i) the rapid increase in equity, diversity, and inclusion initiatives and discourse over the past decade(Stears et al., 2024, Tu, 2024), ii) an increasing number of often high-profile legal cases around the world that have brought more attention to the disproportionate impact of air pollution and climate change impacts on disadvantaged communities (Climate Case Chart, 2022, Smith v. Attorney-General, 2022, Department for Environment Food & Rural Affairs and Rt Hon

George Eustice, 2021), and iii) the many studies that have demonstrated the inequitable contribution and exposure to both indoor and outdoor air pollution within cities (Ferguson et al., 2021, Jbaily et al., 2022, Rentschler and Leonova, 2023, Terrell and Julien, 2023, Yu et al., 2022). Inclusion of equity in urban planning documents also has increased slightly over the past two decades, though its inclusion remains relatively low and appears less important to policymakers than health (Kasraian et al., 2024).

Despite the largest cause of pollution typically being wealthier segments of the population, it is often the most socially and economically vulnerable communities that live in areas with unhealthy air, leaving them poorly equipped to act on the problem (Rentschler and Leonova, 2023). For example, in the United Kingdom, wealthier areas emit more pollution emissions from vehicles, but poorer communities have the highest concentrations of traffic-related pollution (Barnes et al., 2019). Similarly, in the United States, most air pollution is caused by consumption of the non-Hispanic white majority, while black and Hispanic minorities are disproportionately exposed to that pollution (Tessum et al., 2019). Furthermore, deprived populations not only experience greater exposure to air pollution but also are more susceptible to its negative health effects (Hooper and Kaufman, 2018). There are also complexities in the distribution of co-benefits from climate and air pollution actions; it is not clear whether the co-benefits of actions will be shared inclusively or whether patterns of inequity such as those listed above will persist through the distribution of co-benefits(Walker et al., 2024).

Stakeholders' ranking equity as a fundamental objective stands somewhat in contrast with their ranking of active travel as among the least co-beneficial actions. Sustainable urban mobility plans aimed at addressing multiple urban transport issues can also address equity (Arsenio et al., 2016), and such plans often emphasize active travel as a central feature (Kasraian et al., 2024). Urban solutions that shift away from the greatest sources of pollution such as private car ownership could support stakeholders' equity and health objectives, protecting vulnerable populations.

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4.4 SDM as Systems Thinking Approach

This SDM study demonstrates the promise and value of SDM to both inform systems thinking and inform policy deliberation.

The systems approach of SDM identified synergies between stakeholders' objectives and identified actions to prioritize for air pollution. Through the SDM process, NGOs, industry, policy and academia were able to collectively express their views and to share expertise with each other. The transdisciplinary nature of the workshops allowed for different perspectives to be integrated and helped to identify the co-benefits of actions as suggested by the systems thinking literature (Negev et al., 2022a, World Health Organization, 2021). Whilst stakeholders identified objectives in breakout groups, it was easy to recognize the synergies in fundamental and means objectives across the wider group. Agreement on broad principles was common, but when it came to specific actions, these were much more personalized due to the context and experiences of individual participants.

Due to the different backgrounds of participants, it was not surprising that they had different perspectives on air pollution and how to mitigate it. There was nonetheless a shared demand for more collaboration-with "integrated approach" and "governance cross sectoral collaborations" being identified as most co-beneficial. Since air pollution is a cross-cutting issue, a "wicked problem" with implications for equity, health, and climate, this demand for collaboration makes sense (Andres et al., 2022, Guadarrama Baena, 2016). Structured decision making itself is conducive to fostering collaboration, thinking in systems terms, and taking a big picture view, because fundamental ends-orientated and means-orientated objectives are formalized in its structure. Participants embodied this in their discussions' content and in their desire to collaborate with attendees afterwards. There is an appetite among the policy, research, and practice communities for such systems thinking tools and methods to help mitigate societal-scale issues, like air pollution. Various organizations have called for systems approaches (OECD and International Institute for

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Applied Systems Analysis, 2020, Climate Change Committee, 2020, Tooley, 2021) , but what this means for everyday practice remains vague (Nguyen et al., 2023).

SDM can perhaps contribute concrete examples of what everyday systems practice could look like. Systems Thinking methods, such as Causal Loop Diagrams, Participatory Systems Mapping and Rich Pictures have already had promising impacts and results (Barbrook-Johnson and Penn, 2022, Penn et al., 2022). A strength of SDM is its formalized transparency: decisions and ultimate objective and means objectives are made clear whereas systems dynamics models, for instance, have been criticized for their complexity and their potential to alienate decision-making stakeholders (Barbrook-Johnson and Penn, 2022). SDM gives an opportunity for more transparency and trust and hence buy-in across people in different domains with different jurisdictions and sometimes divergent priorities (Wilson and McDaniels, 2007, Wilson and Arvai, 2011, Gregory et al., 2012). This is relevant in urban air pollution since individual agencies and departments often make decisions about their part of the system in a siloed way (de Nazelle et al. 2021), rather than the system as a whole, leaving co-benefits and indirect effects as often accidental spillovers from activity (Negev et al. 2022) rather than deliberate policy actions.

4.5 Limitations

The sample of stakeholders engaged in this study was not perfectly distributed globally, with greater success recruiting participants in the European region due to stronger networks in this region. This may have skewed some priority choices such as on transport actions. Moreover, the workshop and recruitment was in English only, limiting participation. Contextual differences occasionally raised conflicts between participants. Occasionally participants from the less represented regions would raise that while in theory they agreed with the consensus of their group, the priorities in their own regions were different. For example, transport is a topic where priorities may differ in different geographic contexts, and where choices such as a push for EVs in the global north may even have negative consequences in some African

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countries due to rare metal mining(Musa Obadia et al., 2024, Kayembe-Kitenge et al., 2023, Banza Lubaba Nkulu et al., 2018). These varying contexts may be influencing the ranking outcomes of the benefits and feasibility of the actions, which varied greatly for similar action types. This could also be influencing the visioning exercise- what is considered a "good" air quality future may vary dependent on a stakeholder's professional and place-based contexts. Future research could reflect on the geographical differences and aim for better representation from non-European stakeholders or plan to repeat workshops in different geographical contexts including low- and middle-income countries where there is a paucity of information around how systems thinking can be implemented (Giles-Corti et al., 2016).

We also recognize that there will be bias in the workshops analysis due to the qualitative nature of the research. Identifying themes, whether that be through facilitators, notetakers or post workshop analysis is subjective and influenced by our context outlined in our positionality statement (see methods section 2.3). To minimize any such bias,this paper was reviewed by all facilitators before publication and any contested themes were discussed.

Much like Tiernan et al. (2022), time was a restrictor in our research. It was not possible to complete a full structured decision making cycle and limited time was given to measuring impact and progress of actions. A compromise had to be made to allow time for detailed discussion, but also to ensure that the workshop was of an appropriate length to ask stakeholders to take out of their working day . We set a 3 hour time limit per session with comfort breaks included, but facilitators were reporting fatigue at the end of a session despite participant enthusiasm (and even with this time limit and advanced diary invites, some participants had to leave sessions earlier due to existing commitments). However, ideally SDM is an iterative process with time for detailed discussions (Tiernan et al., 2022, Gregory et al., 2012, Irwin and Terhune, 2017, Lyons et al., 2008). A recommendation would be for future SDM workshops to use follow up surveys to engage with participants about the outcomes of the workshops and evaluate if they caused any shift in participants' actions or viewpoints. This would help overcome some of overcome some of the limitations in time constraints to monitor and evaluate progress in the implementation of actions.

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5 Conclusions & next steps

In conclusion, structured decision making provided novel insight into the synergies between stakeholders. Our participatory research contributed valuable insights into the priorities of stakeholders in urban air quality and related sectors, and encouraged learnings between stakeholders. Stakeholders recognized many synergies within their objectives for urban air quality. Despite the diverse professional contexts and roles of workshop participants, stakeholders clearly agreed upon three fundamental objectives as the main drivers of air quality action: human health and wellbeing, equity and planetary health and climate. Top priority actions to reach objectives included addressing transport emissions and generating/communicating data. Data is key to inciting change for urban air quality and acts as an objective, barrier and action identified by participants.

Our research identified the need to apply systems thinking in different geographical contexts to understand the global picture of air quality decision making. Future research should consider deploying similar techniques regionally, especially across low and middle income regions where the application of systems thinking is currently understudied. There is a clear call from stakeholders for enhanced cross collaboration, and systems thinking approaches could be a tool to encourage this in decision making processes, however the practicalities of how to do this are limited. Understanding how we integrate systems thinking such as structured decision making into real-world decision-making practice is going to be the next step in ensuring healthy, equitable cities with clean air.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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